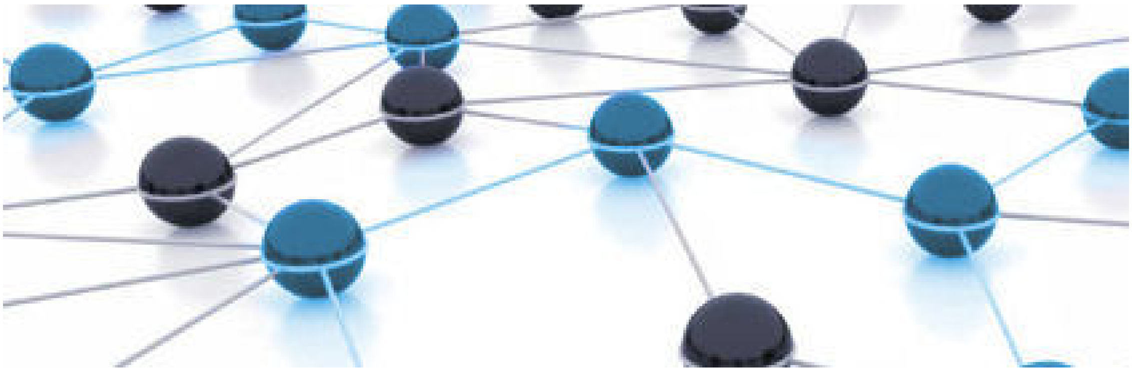

Conceptual Framework for Semantic Interoperability in Sensor-enhanced Health Information Systems (SIOp4Se-HIS)

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Abstract

Transducer integration into different accessories such as eyeglasses, wristbands, vest, wristwatches, among others, has brought myriads of physiological data that could be of help in making patients health monitoring easier. However, this myriad of data are generated from different devices with different formats and uncoordinated data types which ultimately compromises the data integrity and renders it medically less importance. Furthermore, several wearables do operate as data island as they cannot incorporate their captured data into the Health Information Systems (HIS) for easy accessibility by the health-care professionals for further processing, interpretation and actions on the patients' health. Therefore, to enable the flow of data that will be useful to both patient and health-care professional, the existing HIS should be transducer enhanced / enabled, and they should operate at the same semantic interoperability level to allow for exchange of meaningful data from transducers to HIS. In bid to achieve this, several attempts have been made using standards, and archetypes, which goes a long way in providing interoperability at the technical and syntactic level. However, repositories of heterogeneous transducer data as provided by health monitoring systems, requires actionable knowledge of context (environment) from which the data is collected for it to be medically useful and interoperate at the semantic level with the HIS. There are three approaches: the model-driven; standard-based and archetype approach but only the ontology driven guarantees making the applications smarter, or make the data smarter. The study propose the latter option using a dual model approach to leverage semantic technologies in order to provide and apply more meaningful health monitoring data representation between transducers and HIS. We approached this study using the design science research methodology and developed a hybrid methodology by combining two methods to develop our ontologies that are based on standards in the domains, with this unique method we

achieved a novel approach to solve the obstacle of semantic interoperability through our proposed framework for Semantic Interoperability for Sensor-enhanced Health Information Systems (se-HIS) and bridged the gaps in systems' interoperability between monitoring units and HIS. The outcome is a robust, explicit conceptual framework for sensor-enhanced health information systems Interoperability (IOp) at the semantic level. This semantically enabled our HIS, to interoperate with Transducers that are compliant with the Institute of Electrical and Electronics Engineers (IEEE) 21451 family of standards, and it provides the ability to query high-level knowledge of the data context as well as low-level raw data accessibility in a multi-transducer enable HIS.

Author's Declaration

I declare that the work in this dissertation was carried out in accordance with the requirements of the University's Regulations and Code of Practice for Research Degree Programmes and that it has not been submitted for any other academic award. Except where indicated by specific reference in the text, the work is the candidate's own work. Work done in collaboration with, or with the assistance of, others, is indicated as such. Any views expressed in the dissertation are those of the author.

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Acronyms

ADL Archetype Definition Language

AI Artificial Intelligence

ALC Attributive (Concept) Language with Complements

BLE Bluetooth Low Energy

CU control unit

CVD Cardiovascular disease

DFS Data Flow Sequence

DL Description Logic

DM DeLone & McLean

DSR Design Science Research

DSRM Design Science Research Methodology

DV Dependent Variable

ECG Electrocardiogram

EPC Electronic Product Codes

EHR Electronic Health Record

EIF European Interoperability Framework

EPAN	European Public Administration Network
FHIR	Fast Healthcare Interoperability Resources
HIMSS	Healthcare Information and Management Systems Society
HIS	Health Information Systems
HL7	Health Level-7
HTML	Hyper Text Markup Language
IEEE	Institute of Electrical and Electronics Engineers
IOp	Interoperability
IoT	Internet of Things
IS	Information Systems
IT	Information Technology
ICT	information communication technologies
IV	Independent Variable
LAN	Local Area Network
NFC	Near Field Communication
OIOp	Organizational Interoperability
OSI	Open Systems Interconnection
PHD	Personal Health Devices
RFID	Radio Frequency Identification
SAR	Semantic Analysis Representations
se-HIS	Sensor-enhanced Health Information Systems

se-HISIF Sensor enhanced-Health Information Systems Interoperability Framework

SIOp Semantic Interoperability

SIOp4se-HIS Semantic Interoperability for Sensor-enhanced Health Information System

SHIQ transitive roles(S), role hierarchy(H), inverse roles (I), and qualified number restrictions(Q)

SPARQL Simple Protocol and Resource Description Framework Query Language

TAM Technology Acceptance Model

TEDS Transducers Electronic Data Sheets

TRA Theory of Reasoned Action

UML Unified Modeling Language

WLAN Wireless Local Area Network

XML eXtensible Markup Language

Part I: Framework for Semantic Interoperability between wearable devices and health information systems

1

Introduction

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1.1 Background

The recent increase in the spread of health-enabling technologies as facilitated by the change in population demography, has led to the rise of heterogeneous data from diverse sources such as the sensors, Internet of Things (IoT), and smart homes for health monitoring. However, with the change in demography due to people aged above eighty years (80yrs), there is now an attending challenge of multi-morbidity which requires frequent health monitoring and timely interventions by the medical personnel. The increase in the aged population has led to excess care than the healthcare system can cope with and has become a great challenge for the system as a whole, one viable panacea, is the use of health-enabling technologies to reduce the challenges faced in health monitoring and mobile health care.

The integration of health-enabling technologies with the existing health systems is a promising solution to the problem, they will help to provide appropriate (real time) health-related information that can be used to support care processes, by professional and non-professional caregivers, for example, the case of the patient with congestive heart failure that requires constant monitoring can better be achieved through health monitoring devices. At the core of health-enabling technologies is the sensor. Sensors are used to capture various health parameters that are of importance to the patient's health during the monitoring phase of their care process.

Furthermore, these sensors can be used to solve the surging problems in health care and supervision, and eventually reduce the overall cost of healthcare delivery. The ability of the sensor to sense and capture measurements from their surroundings has made its usage in various sectors, such as transports, health care, environment observation, agriculture, among many others possible. Nonetheless, this ability has not been fully integrated into the existing information systems especially in the healthcare domain.

Sensor-enhanced Health Information Systems (se-HIS), consists of two core systems - the remote monitoring system i.e. the monitoring system unit and the Health Information Systems (HIS). The monitoring unit comprises of three main blocks: sensor and data acquisition hardware - to capture physiological and mobile data; the communication hardware and software to send data to a remote centre, and the data analysis techniques which enable relevant information extraction from the physiological and movement data.

Although the health monitoring units capture different physiological data in real time; most of the monitoring devices are standalone or stovepipe systems. They have various proprietary software e.g. Google health, Apple health, rendering the captured data medically unimportant as a result of different standards and data formats that cannot meet the clinical information requirements for the care of the users of such devices. The integration of these data (Table 3.1 contains the lists of physiological parameters) with the patient's data in the existing HIS, will help to close the Interoperability (IOp) gap at the semantic level.

The lack of Interoperability at different levels (syntactic, technical, semantic, organisational detailed explanation in section 3.2) could lead to mishaps; that may cause considerable harm or death to patients. It can also reduce the trust in the data captured from wearable devices. Therefore, to promote interoperability among sensor-enabled devices and the HIS, IOp at various levels must be given serious attention.Since the raw data captured by the wearable devices serves as the main inputs for semantic computation in wearable devices, the data can be transformed to series of meaningful information, for example, the raw data from an accelerometer which primarily provides three-axis components of the carrier can be used to compute the micro- and macro - activities of the patients alongside patients' locomotive states.

Raw data, if captured with its context, and it is well analyzed, provides semantics in addition to the physiological parameters captured by the wearable devices, using the right modeling techniques such as conceptual and ontologies models.With the Increase in heterogeneous data as shown in Fig. 1.1, the proliferation and proposal of wearable for monitoring health due to its numerous advantages have brought about unavoidable exponential growth in the rate of health related generated data.

The physiological data comes in different formats due to manufacturers'innovations and proprietaries rights, while the Health Information Systems (HIS) at the target end is used to accommodating data that has been standardized based on various standards such as Health Level-7 (HL7) [20–22],which are entirely different from the standards that operate within the wearable systems primarily Institute of Electrical and Electronics Engineers (IEEE) 11073 [23] and Institute of Electrical and Electronics Engineers (IEEE) 21451 [24].

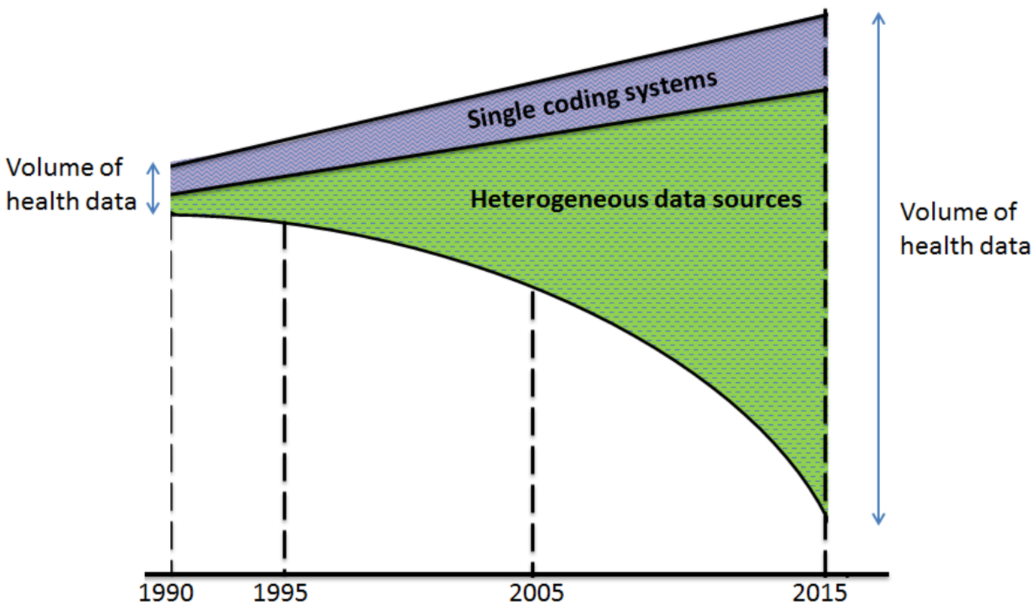

Figure 1.1: Increasing proportion of heterogeneous data sources [1]

The high business competitions among the various wearable devices manufacturers has robbed the devices of the ability to interoperate at all the levels of interoperability particularly at the semantic level, while the regulatory bodies are gearing efforts in creating standards and regulations for equipment manufacturers to adhere to. These failures have been the reasons for different data across various healthcare application platform for patients' health monitoring using sensor enabled devices. The standards are not adequate to enhance interoperability at all levels of interoperability but remain helpful at the technological and syntactic interoperability level which has given rise to needs to facilitate semantic computation from wearable sensor and the information systems in the healthcare domain.

In the studies of [25,26],they concluded that standards are not enough to guarantee end-to-end interoperability, particularly at the semantic level, although, it has been able to cause progress at the technical and syntactic level when it is widely accepted by the industries involved. Therefore, in the health care domain, wearable can only be incorporated into the health care systems, so long different data are adequately coordinated with the right context and accurately sent across networks from aggregators to the health care providers [27, 28], until then wearable data will not be of medical importance.

Furthermore, for the clinical data captured through sensors to be of medical importance, during this study, the requirement analysis showed that contextual data is necessary for the comprehension of many physiological parameters obtained from the sensors. This study, therefore, focused on developing a framework based on semantic technologies for integrating heterogeneous data sources such as sensors with the existing HIS. The reoccuring standards been IEEE 11073 [29], IEEE 21450 [30] , in the wearable systems and HL7 [20],Fast Healthcare Interoperability Resources (FHIR) [20] among others on the side of HIS.

1.2 Motivation

The need to create seamless connection between the existing HIS and the new technologies for health monitoring is of importance, especially at the semantic level. The integration of these systems is facing limitations such as lack of system integration of individual sensors, non-existent support for extensive data collection and knowledge discovery plague with disparate systems generating different data which are not compatible with existing health information systems infrastructure. In the study of the importance of Transducers Electronic Data Sheets (TEDS) by Morello [31] focus was on the issue of TEDS and the opportunities the concepts can provide for sensing and processing of signals and data. The study explored the potentials of TEDS to improve performances of biomedical sensors (transducer enabled devices for health monitoring) and instrumentation. Earlier on the IEEE proposed that all transducers should be "smart".

Transducers being "smart" means, the transducers must be able to describe themselves digitally to any systems in which they are integrated. On the contrary, the IEEE 11073 standards [23] for Personal Health Devices (PHD) has device specification repository that helps to describe each device to the system in which they are operating for proper identification of the devices and its measures. The development by Morello [31] has revealed that TEDS can be of great importance in patients data processing through the adaptation of diagnostics algorithm to the particular patients using information concerning them and their critical history with the diagnostic criteria when stored for data processing optimisation.

The attention from manufacturers on the IEEE 21450 -x standards is increasing,this attention on these aspects if explored, could make it easier for the task of designers and developers in projecting users defined application codes using TEDS, this study extends this to enhance Semantic Interoperability (SIOp) between sensor and HIS. Although, previously the study by Kim et al. [32] provided the integration of the IEEE 1451 standard with the HL7 standard to foster data and information interchange between the monitoring systems and the HIS for patients data. These two studies further strengthen us to extends the IEEE 21450-x standards at the semantic level for information and knowledge exchange between the standards that are in operation in the use of monitoring systems and HIS. The use of the IEEE 21451-x to compute semantics will enhance the knowledge base of the health monitoring systems and foster SIOp with HL7 in HIS.

1.2.1 Problem Statement:

The traditional method of heart health monitoring has been that people go to the hospital where a cardiologist or medical personnel examines the patient for the possibility of any heart diseases. An Electrocardiogram (ECG) machine cost so much and requires a specialist to operate causes an increase in the patient's medical bill. However, the advent of sensor technology has increased the chances of using a low-cost portable heart rhythm sensor-enabled device as the foundation for portable, mobile, and cheap heart rhythm monitoring.

Meanwhile, despite the potential of sensors to help monitors the functions of the heart, the existing health information systems do not have the ability to integrate the data from the sensor into the health information systems for easy accessibility by the health personnel in the hospitals. Also, various manufacturers design their product in a restrictive way that leads to stove-piping of data. For example Samsung Gear S3, Apple Watch series, Xiami Mi Band, Pebble 2 among others wearable device do not interoperate with one another and store their data in their proprietary cloud storage facility.

Moreover, in the bid to automate the diagnosis of heart diseases criteria, the study of Hancock et al. [33] established criteria that would allow the real problem in the heart rhythm to be captured automatically. Most commonly used diagnostic criteria such as systolic (pressure) overload and diastolic (volume) overload have limited accuracy when diagnosing patients with congenital heart diseases and in adults, therefore their use is not recommended. Okin et al. [34] observed that the sensitivity and specificity of different ECG criteria reflect issues related to the types of the heart disease, anatomic patterns of left ventricular hypertrophy (LVH) and degrees of hypertrophy in various patient populations.

Therefore for effective monitoring of the heart electrical activities, factors such as gender, race, site of the electrode placements and body habitus affects the diagnosis of the heart problems. As such, there is need for an automated system that will be able to capture the contextual information and carry accurate analysis for better diagnosis of the heart problem.

1.3 Research Problem / Gaps

The increasing proportion of heterogeneous data sources in recent time and the lack of se-HIS as identified in the studies of [35, 36] calls for a collaborative, synchronization of meaningful data from sensors with the HIS in the health-care domain. The aggregation of the correct and accurate data in real time could help the health-care providers to gather information that could lead to good knowledge about the patient's state of health.

However, wearable are manufactured by different manufacturers with their proprietary data formats which further makes it difficult to harvest data from such devices by non-proprietary systems without bottleneck problem of interoperability, this has led to the introduction of standards. Many standards have been defined over the past decade in both wearable systems domain and the health domain by bodies such as IEEE, and HL7. These standards support machine - to - machine interoperability and fail to address the issue of semantic and organizational IOp levels [25] of IOp outlined in the levels of interoperability framework as shown in Fig. 1.2.

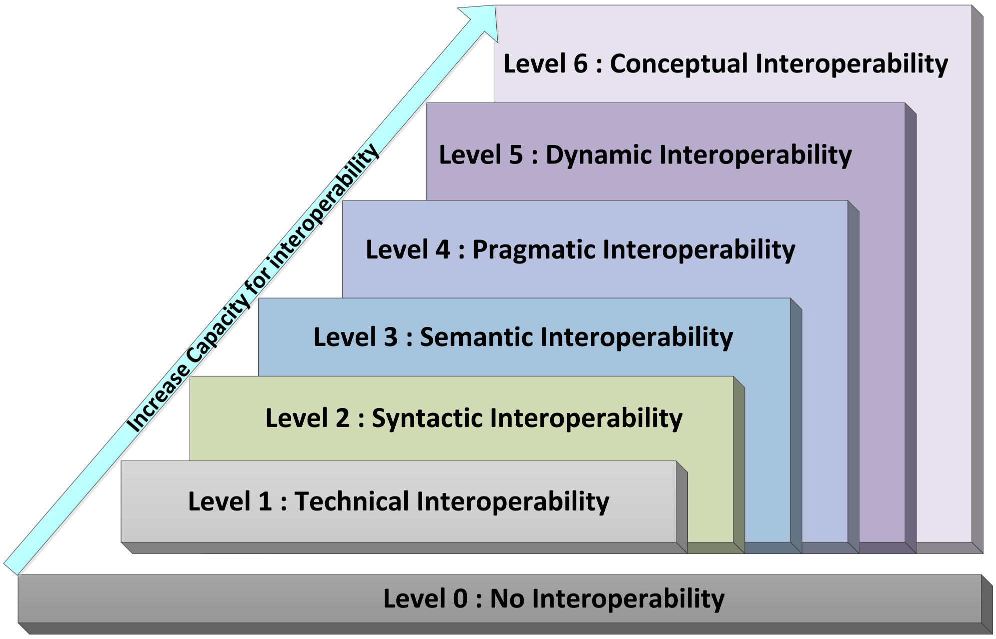

Figure 1.2: Level of Interoperability in Information Systems [2]

In the two major domain of discourse in this research, two major standards are governing the systems - wearable and HIS i.e.the IEEE standards and the HL7 standards for exchanging medical information on the other side of the HIS. HL7 been a messaging standard for exchanging medical information only deals with texts messages, recently as wearable devices are involved in health monitoring a new type of data has appeared such as streaming data which usually comes from sensors from various networks such as Wireless Local Area Network (WLAN), wired Local Area Network (LAN) or cellular networks [32].

The HL7does not include information from wearable devices, mobile patients, mobile devices, and sensors. In the area of sensor systems, a group of standards known as IEEE 21450 was known as IEEE 1451 [37] which deal with the various aspects of sensors such as the definition of sensors, actuators, has a complete set of standards that deals with different types of sensors that are of importance to the health monitoring domain [32, 38–40].

The research explores the possibilities of the semantic between the two standards; IEEE 21450 and HL7 (v2.5 and v3). Since the data structure of TEDS which is the core of IEEE 21450 and the format for the HL7 message are different, we implemented a new ontological framework that supports semantic interoperability between the two systems based on their standards.

Based on the scenario above we identified five (5) problems P1 - P5 which contributes to the difficulties encountered regarding the use of sensors (transducers) to monitor patients health and integrating it with the HIS are itemised as follows;

- **P1:** The inability of the current health information systems to recognise sensors devices by their detailed descriptions such as the name of the device; the manufacturer, the function of the devices etc. which does not allow the hospital to understand the type of equipment and its purpose.

- **P2:** The problem of lack of context in the data observed from the sensor devoid the data the details of the circumstance of the patient as at the time the data such as a vital sign are captured as it is essential to reason what the challenge with the patient is at a particular time.

- **P3:** The lack of interoperability and heterogeneous data formats

- **P4:** Data scalability and expressibility

- **P5:** Extensibility and openness problem is not yet achieved in the HIS and wearable systems, because most wearable are stovepipe devices with their proprietary software and applications data formats. Even though there are standards such as HL7 and IEEE21451 family of standards, they still do not support functionality or API functions to be added in se-HIS.

1.4 The aim and objectives of this study

This study aims to provide a conceptual framework that will support semantic interoperability between sensors (wearable devices) and HIS based on dual modelling approach for ontology-based on standards with the aim of achieving higher quality semantics in se-HIS. The realization of the purpose of this work benefited in the support of effective knowledge sharing procedures between different health monitoring system and HIS. The objectives identified with the intention of meeting the aim of this study are as follows:

- **Objective 1:** To investigate existing literature on the various technologies, concepts, and gaps in semantics interoperability in heterogeneous systems such as the se-HIS and established the need for semantic interoperability. The findings of the review is published in Ajigboye and Danas [41].

- **Objective 2:** To define a formal specification with definition of a se-HIS semantics using a knowledge representation language.The findings of the review is published in Ajigboye and Danas [42].

- **Objective 3:** To investigate the functional requirements for semantic interoperability between Sensors and HIS integrated systems

- **Objective 4:** The proposal and exploration of the conceptual framework which meets the investigated requirements

- **Objective 5:** To evaluate and demonstrate the functional adequacy of the proposed framework via its review and testing.

1.5 Scope of the Thesis

The aim of the research is to develop a more pragmatic framework that allows semantics from sensor data and optimize the use of wearables devices or sensor-enabled devices for health monitoring through a heavyweight ontology across the wearables and HIS dimensions of health care domain. The thesis reviewed the state of the art technologies that supports interoperability between the wearables devices and the HIS. It gives series of context that supports semantics in different obtainable data through wearables. The ontological framework creates a semantically interoperable systems between wearables and HIS.

1.6 Research Methodology

A methodology in line with the precepts of Design Science Research (DSR) i.e. Design Science Research Methodology (DSRM) is used for this research project see figure 1.3. The method is adopted due to its ability for discovering and identifying opportunities and problems relevant to the implementation of semantic interoperability between the sensors and HIS for directly creating new or improved conceptual means to address those problems. We choose DSR as the philosophical approach due to the following reasons:

- DSR is centered towards practical problem solving (including prescriptive or solution-oriented knowledge)
- DSR has its primary focus on developing a realistic solution, which includes prescriptive or solution-oriented knowledge where the solution from scientific justification can be used to design solutions to complex and relevant field problems
- DSR is rather field-problem driven and solution-oriented with a core mission to develop knowledge that can be utilized by professionals in the area in question to design solutions to their problem area by describing and analyzing alternative courses of action in dealing with field problems.
- DSR is focused on how things ought to be to attain goals and to function [43]. Also, the outputs includes something created by humans usually for a practical purpose i.e. artefacts [44]

1.7 Contributions to the body of knowledge

The contributions of the conceptual framework for SIOp4se-HIS in the design of se-HIS health monitoring that supports wearable devices are the set of linked concepts and propositions that are focused on the important phenomenon of interest in building a se-HIS that support semantic IOp. The conceptual artefact helped in organising the related aspect and function as maps that enhance the coherence of wearable systems integration with the existing HIS while improving their interoperability at the semantic level. Thus, in the context of semantic IOp, this conceptual framework is conceived of, as an overarching representation of essential elements, and the interrelationship among the elements, to build and acknowledge in the process of designing and implementing semantic IOp in se-HIS.The following artefacts were identified and built:

- **Semantic Interoperability Framework:** The conceptual framework has helped to provide adequate definitions of components, concepts and taxonomies needed to ensure semantic is correctly transferred from monitoring devices to the Sensor-enhanced Health Information Systems (se-HIS), thereby, providing adequate measurement tools for evaluating semantics in se-HIS. The framework serves as gyrocompass that will help health information systems developers in navigating their way through the semantics interoperability in se-HIS.
- **TEDSOnto Ontological Model**: A heavyweight ontology derived from the IEEE 21450 family of standard for transducers. It is a specification schema; it is comprehensive, specification extract, and a robust ontological conceptual model for Transducer specification and function extract and its normative statements.
- **On-Body Transducer Location Ontology**: This ontology is the resultant combination of our on-body sensor position identification model and the contextual ontology extract for the where context (on-body locality) that helps to determine the location the sensor is positioned on the user's body.
- **Policy Ontology:** the policy ontology contains the detailed policies to guide the privacy of the wearable system user's resources from unauthorised access and intruders.
- **Ontological approach:** This helped us to understand that the clear articulation of concepts, relationships and axioms improves quality of information and semantic interoperability according to utility theory.

Publications:

- O. Ajigboye and D. Konstantinos, Review of Interoperability techniques in data acquisition of wireless ECG devices," IOSR Journal of Mobile Computing f&g Application, vol. 2, no. 2, pp. 1925, 2015. [41]

- O. S. Ajigboye and K. Danas, Towards semantics in wearable sensors: The role of transducers electronic data sheets (teds) ontology in sensor networks," in 2016 IEEE 18th International Conference on e-Health Networking, Applications and Services (Healthcom), Sept 2016, pp. 16. [42]

- Ajigboye S Olamidipupo, Design of Semantic-based Transducer Electronic Data Sheet for Semantic Wearable ECG Monitoring Systems (SemWECG)," in 3rd International Conference on Health Informatics and Technology, New Orleans,USA, 2016. [45] [46]

1.8 Thesis Structure

The comprehensive and systematic structure used to achieve the aim and objectives of this study is structured as follows and shown in figure 1.4 while, Fig. 1.3 represent the visual picture of our thesis structure in summary.

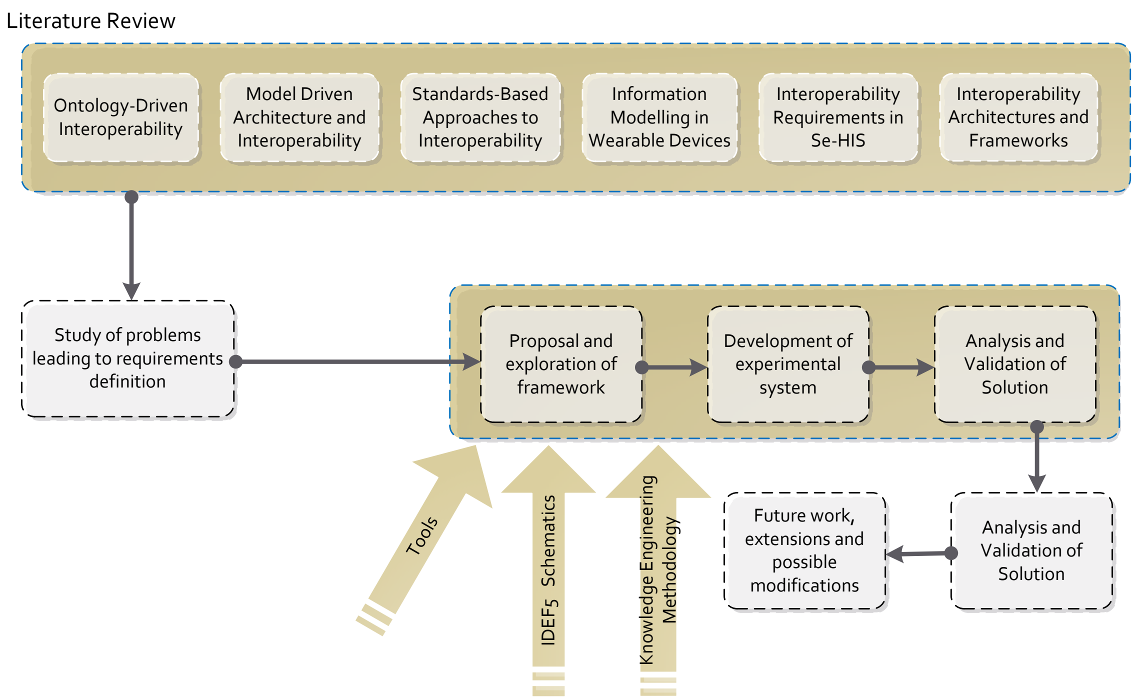

Figure 1.3: Thesis Structure

- **Chapter 2:**

  In this chapter, the thesis focused on the presentation of the methodology used to conduct the whole study that is, the DSR and the other methods used to carry out the additional objectives as set out in the introduction. It details the DSR research perspective, the rationale for choosing DSR and the methods that were used to achieve the objectives one after the other. It discussed the literature review method, the combined method for ontology development and finally, the DeLone and McLean Information Systems (IS) [47] success model evaluation method used for evaluating the output of the study.

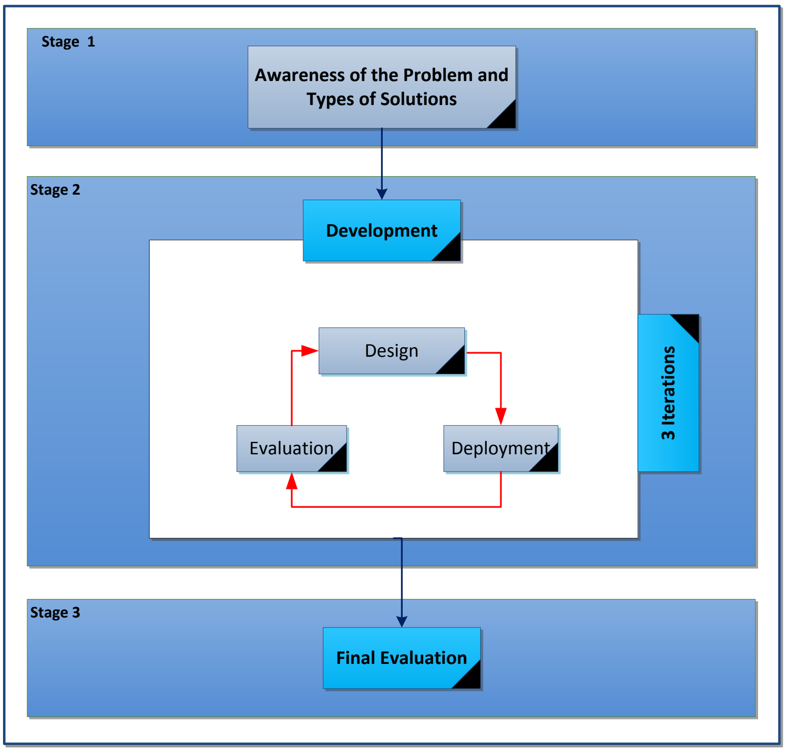

Figure 1.4: DSRM

- **Chapter 3:**

  In this chapter, a comprehensive and systematic review detail was documented, after setting up a thorough literature review protocol using relevant criteria, we established critical research gaps that needed to be addressed in our study. The research gaps gave us our research scope; various concepts in the domain; the different approaches to the deficiencies in past research works; the limitation of previous research works, which finally formed the components of our novel method and framework for semantic interoperability in se-HIS and further reported (such as the requirement analyses for semantic interoperability; semantic interoperability; standards; ontology; contextual meaning and its formal representation, and the Health Information Systems). The limitations of the current state of the art in SIOp summarily and explored the need for a new approach. The user's requirement was also captured through the data flow diagram to determine the semantic requirement for SIOp.

- **Chapter 4:** The Chapter presents the novel framework that supports semantic interoperability between wearable devices for health monitoring and health information systems, this framework resulted in the full system analysis using data flow model, and complete description of the various components / or modules of the structure (TEDS, Domain, Policies ontologies and the semantic reconciliation layer) was discussed.

- **Chapter 5:** It covers the details explanation and discussion of the framework evaluation using the modify DeLone and McLean IS success model for assessment of the structure. The review gave us results that further supports the model for evaluating DSR study approach using the following constructs the intention to use the framework, the framework information quality, the quality of the structure, the individual impact and the user's satisfaction.

- **Chapter 6:** Finally summarised the whole study, discussed the contribution of this study to the body of knowledge. The reflection on the various challenges faced during the study and the limitation the study faced and the future research directions and concluded with the conclusion.

Part II: Methodologies & Literature Review

2

Research Methodology and Design

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2.1 Introduction

In this chapter, this study presents the method used to conduct this study and detailed the work-flow and justification for the steps taken to achieve the outcome set at the outset of the work. This encompasses the complete research process which entails: literature review, the research methodological approach, design, procedures and data collection methods and data analysis used in the study. The research was approach from the developmental perspective which involves formative concepts and framework as categorized in the work of Glass et.al [48], so this research is best classify as a DSR [49] with the following objectives: the formulation and validation of models and theories about the phenomenon of health monitoring with all its facets; as it relates to se-HIS.

2.2 Design Science Research Methodology

Design science research methodology emphasize the importance of investigating the needs of the users and understanding the situation a product is supposed to improve, in particular when the situation is complicated, and the product's failure is expensive or unacceptable, such is the case of this study proposed solution to the problem of SIOp, as any failure in this final system is totally unacceptable [3, 50]. The solutions are in line with the output of DSR. DSR poses as a type of research alongside behavioural, social, and other scientific approaches aiming to understand a phenomenon. It is the strategy of inquiry, which moves from underlying assumptions to study design and data collection [51].

2.3 Design Science Research - The Rationale

DSR consists of the construction and the evaluation of the artefacts that resolve a significantly recognized problem. It also provides a suitable and comprehensive framework for the design and the analysis of artificial phenomena such as organizations or information systems. It defines the research subjects and the methods applied to the matter to systematically enhance the body of knowledge [3], a parallelism is drawn between the design and nature science as presented in March & Smith's [3] framework for research in information technology see Fig. 2.1.

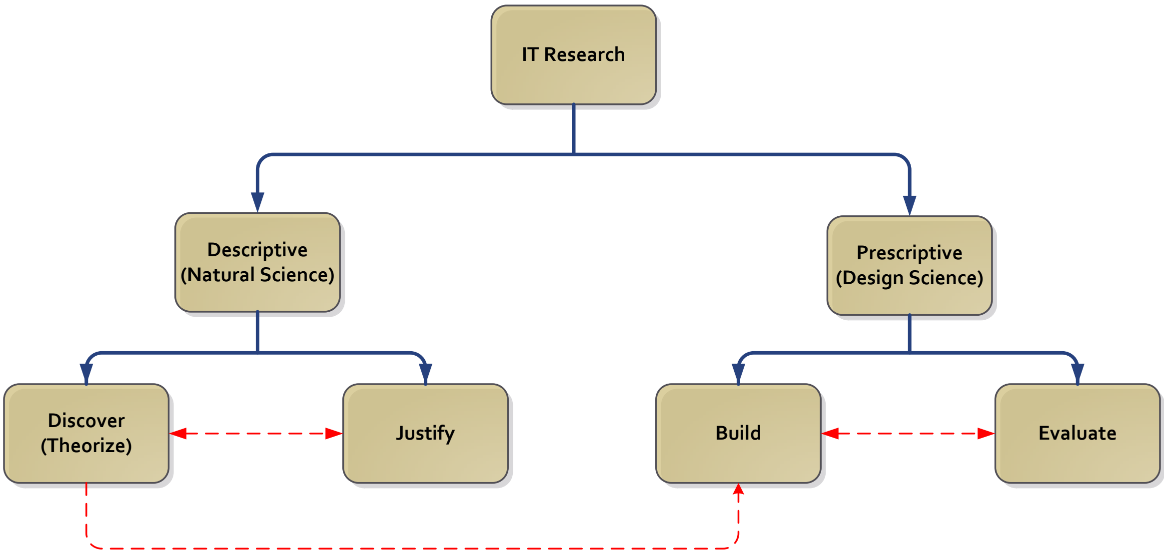

Figure 2.1: Branches of Information Technology Research [3]

According to Simon [43] the paradigm of design research came from engineering and sciences of artificial which is fundamentally for problem-solving. It seeks to create innovations that define ideas, practices, technical capabilities, and products through which the analysis, design, and implementation and use of information systems are optimally accomplished. DS research in information systems addresses what are considered to be "wicked problems" [52,53] as cited in [49]. Simon in his book "Sciences of the Artificial" in 1969, inspired the embracing goals to design and invent innovative artefacts such as constructs, frameworks, models, methods, processes, and systems. However, research in information technology studies artificial phenomena as opposed to the study of natural phenomena. It deals with the creations of systems such as organisations and information systems [54], in the work of Simon [43], natural science is concerned with the explanation of how and why things are, while the design science is the concern with devising artefacts to attain set goals, that is, furthering our understanding of how things come about [43]. “An artefact progresses from an idea to things in the world ” [55].

As shown in Fig.2.1 Information Technology (IT), has two types of scientific interest - descriptive and prescriptive. “Descriptive research aim at understanding the nature of IT ... while prescriptive research is intended to improve IT performance, this duo correspond to natural science and design science respectively” . March and Smith [3] concluded their work with the position “that both design and natural science activities are needed to ensure that IT research is both relevant and effective”. This position was the motivation for the creation of design and natural science framework for IT researchers which gave birth to the unified approach Design Research that combines both design science and natural science perspectives that bring a greater relevance to IS research.

2.4 Design Science Research in Information Systems

DSR has shown its importance and why IS discipline needs it and has become an interesting way to approach research in IS [4, 56], which has increased in recent times [57]. The design aspect is one of the primary purposes of IS; many scholars believe that IS is design in nature, it is a complex discipline and combines many phenomena. For this reason, researchers use different methods for different purposes. It is noticed that some IS researchers focus only on some aspect of IS. This observation led to more focus on the design aspect of IS phenomena since design is a primary goal in IS research. Although, there are many ongoing debates on what constitute the core of IS core artefacts, the investigation of IS literature reveals that there are three main views of what constitutes IS core artefacts. These views are:

- IS is concerned only with software development
- IS also includes methods and models and
- a broader perspective that includes how people use IS, organizations implement IS and impact of IS on the people and organization [58–61]

However, Wand and Weber defined the core of IS based on a strong, grounded theoretical foundation and believe that IS is “being used to represent or to mirror or to stimulate phenomena in the real world which provides a representation of some real-world systems as perceived by someone or some group of people " [62]. Moreover, since representation is the key aspect of IS, this study bring in and work with their view and theory about IS to integrate it with the DSR paradigm. Based on Wands and Webers's view we look at two main points to justify the injection of DSR into the IS core:

- How DSR addresses the core IS
- The representational aspects in IS and DSR

2.4.1 DSR Addresses the Core of Information Systems

Wand and Weber studied IS and concluded that the core of IS is "the deep structure " as shown in Fig.2.2. The deep structure describes the characteristics of the real world phenomena that the IS is intended to represent, such as; Entity Relationship Diagram (ERD) or various actions that customers can take (for example when placing an order for items). The physical structure describes the choices that designers have made regarding how surface and deep structure will be map onto underlying technology that will be used to operate the IS, for instance, the use of encryption procedures when data is to be transferred. The surface structure describes the facilities, what is available in the IS; for example, the format of a display screen, buttons, that users can click to run functions or reports, this phenomenon is mainly the concern of psychology and sociology - not IS.

All these are shown in Fig. 2.2 surface structure phenomena; deep structure phenomena, and physical structure phenomena, as the main components of the internal view of IS. The outer part of IS is the IS External view which focuses on the individuals and organisation that use, implement, and deploy IS, for example, the impact of IS on users effectiveness in undertaking their tasks. Wand and Weber believe this view is important but is not the core of IS as supported in the works of Wand and Weber [4], Weber [62] and Weber and Wand [63]. This belief indicates that both DSR and deep structure in IS share the intention of constructing things for users needs or problems; therefore, DSR focuses on the core of IS.

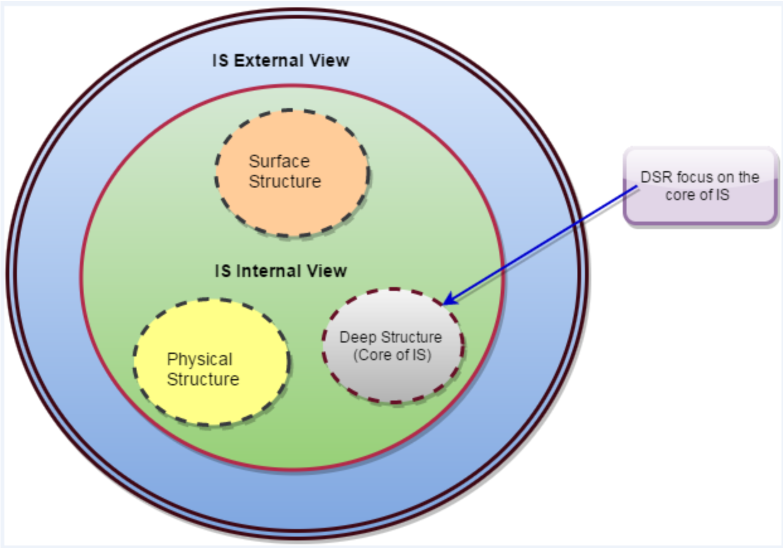

Figure 2.2: IS Deep Structure Structure Overview [4]

2.4.2 Representation aspect in IS and Design Science Research

Wand and Weber believe that representation is the key issue of IS, it represents things in the real world. Accordingly, IS contains historical representations of things in the reality in the ways IS designers choose to envisage these things. The rationale of using representation in IS is to know the histories of things, their behaviours and their states in the real world in an efficient manner, and there are two ways to capture histories: observe them directly or observe the representation of things which are cheaper and effective. Representation in DSR could be seen in its outputs, for the former, IS researchers may have the interest in Design Science or Design Research. However, their work at its core level is a construction of many related things which interact with each other to produce artefacts to solve real or foreseen problems or build innovations.

Design Research artefacts are grouped into four categories and produced in one of the four suggested activities. The research outputs are solution concepts, and this solution is for addressing the research problem. March and Smith [3] identified four main types of artefacts that are crucial for design research framework and are recognized as valid research outputs of design research process. These four outputs are constructs, models, methods, and instantiations are the elements of the first dimension of the framework while build, evaluate, theorise and justify refers to the second part of the dimension

- `Constructs:` These are concepts, assertions, or syntax that has been constructed from a set of statement, assertions or other concepts. They are vocabulary and conceptualization of a domain used to describe the problems and specify their solutions within the domain [64].

- `Models:` These are set of statements that express the relationship among constructs [3]. Models are used to represent the problem and solution situations. The key criteria are that the model is useful in representing and communicating information system requirements and for developing artefacts to serve human purposes [3]. In the notion of design science, the model‘s function is utility, not truth, in contrast to the model definitions in natural science, in which the model‘s function is to describe.

- `Methods:` define processes that search the solution space to solve a problem. These methods can be formal, mathematical algorithms or informal descriptions that act as a guideline. Based on a set of underlying constructs and models of a solution space a method is a set of steps used to perform a task [3]. Models are often inputs to methods, which can be used to translate from one model to another in the course of solving a problem. For example, system development methods facilitate the construction of models of user needs and then translate that model into other models such as system requirements, system specifications and finally into an implementation [3]. Also, methods are inputs to models, which can be used to produce models from the methods. For example, the DSR methodology (defined in this thesis) provides models that help to resolve a problem.The desire to use a particular method can influence the constructs and models that are developed.

- `Instantiations:` are the realization of the artefacts in their environment. It shows that the constructs, models, and methods can be implemented in the real world as a working system. Instantiations in IS research can be specific information systems or tools that address various aspects of designing information systems.

- `Build:` refers to the construction of constructs, models, methods and artefacts demonstrating that they can be constructed.

- `Evaluate:` refers to the development of criteria and the assessment of the output‘s performance against those criteria. Parallel to these two research activities in design science, March & Smith [3] add the natural and social science couple, which are theorized and justify:

  - `Theorize:` refers to the construction of theories that explain how or why something happens. Theory building includes the development of new ideas and concepts, and new methods, construction of frameworks, or models (e.g., simulation models, mathematical models, and data models). In the case of IT and IS research, this is often an explanation of how or why an artefact works within its environment.
  - `Justify:` refers to theory proving and requires the gathering of scientific evidence that supports or refutes the theory.

In summary constructs, models, methods, and instantiations are built to perform a specific task. According to Hevner et al. [50] the information systems discipline is characterized by two paradigms namely behavioural science and design science paradigm. The behavioural science paradigm is more focused on the “development and verification of theories that explain human or organization behaviour ”on the other hand,“the design science paradigm seeks to extend human and organizational capabilities boundaries by creating new and innovative artefacts [50].”

2.5 Methodology for Objectives 1 and 2

The methodology this study adopts within the DSR methodology was to get the understanding of the current situation in the domain of se-HIS, the state of the art technologies or method of overcoming issues or gaps that are available in the systems. To enable a thorough investigation of the problem or opportunities, in the se-HIS domain study used meta-analysis techniques and systematic literature review to establish the gaps in literature to understand the current situation and propose a solution to the problems.

2.5.1 Method 2: Systematic Literature Review

Kitchenham [65], emphasised the importance of an evidence-based approach to software engineering (EBSE) to research. In the study, EBSE brought to the limelight, the need to find and sum up evidence on a specific topic through the application of some studies as the methodological framework for locating and aggregating evidence especially in studies like systematic literature reviews and mapping studies [66]. In this study, the primary reason for the systematic review is to identify, evaluate and interpret the available and accessible research in the domain considering the research questions in Table 2.1 and to enable us become aware of the existing gaps and opportunities for further study. The review was carried out based on the procedure proposed by Kitchenham [67]: planning, conducting and reporting study.

2.5.2 Review and Mapping Planning:

The study aimed at identifying, describing, and categorising the gaps and opportunities in se-HIS and propose a solution to the main interoperability problem.

- **Planning**: during the planning stage we identified the objectives of the literature review and defined protocol. The protocol defines the method that is used in the systematic review and mapping to reduce bias on the part of the researcher [67]. The protocol set or defined to allow for study reproducibility.

The research questions: The systematic mapping aimed to answer the questions listed below:

The systematic review aimed to answer the questions below:
RQ1: What solutions have been use to enhance semantic interoperability problem at different levels of interoperability?

Table 2.1: Research Questions

MQ1:	What is se-HIS ?
MQ2:	What are the components of se-HIS ?
MQ3:	What are the main issues of se-HIS?
MQ4:	What is the framework for se-HIS ?
MQ5:	How many of the issues have been solved and how?
MQ6:	Which method(s),was / were used to solve the issues in se-HIS?

Therefore, base on the research questions the study employs the population (P), intervention (I), comparison (C), outcomes(O),and context (C) known as PICOC method proposed by Petticrew and Roberts [68] to define our literature search scope:

- **Population *(P)*:** All the solutions that implement interoperability at all levels in se-HIS
- **Intervention *(I)*:** The various interventions proposed for semantic and pragmatic interoperability
- **Comparison *(C)*:** There is no comparison intervention
- **Outcomes *(O)*:** Solutions proffered to the problem(s)
- **Context *(C)*:** the applied computational solution proffered.

2.5.2.A Inclusion and Exclusion Criteria:

To extract information from research articles regarding each of the research questions. The papers were organised in five inclusion criteria (IC) and five exclusion criteria (EC) as shown below:

- IC 1: The research papers that proposes semantic interoperability in se-HIS (framework, model, tool, technique, method) AND
- IC 2: The proposed solution are applied on software OR system OR application OR service OR infrastructure AND

- IC 3: The paper is written in English language
- IC 4: The proposed solution supports machine to machine interoperability at semantic and pragmatic levels
- IC 5: The research papers are reported in peer-reviewed workshop or conferences or Journal or Technical Reports

The following criteria were established as exclusion criteria(EC):

- EC 1: The papers that do propose solution to semantic interoperability OR
- EC 2: The proposed solution are not applied on software, OR system OR application OR service OR Infrastructure
- EC 3: The proposed solution does not support machine to machine semantic interoperability OR
- EC 4: Paper that is not written in English
- EC 5: Papers not published in peer-reviewed journal, conference.

The source of the papers: The study adopts the requirements listed below:

- Availability and accessibility of research papers to researcher/reviewer
- The research paper coverage, they should cover the research in the domain in the mapping i.e. Semantics in se-HIS.

Therefore, five electronic databases were used as shown in Table 2.2 and the search terms used are listed in Table 2.3

2.5.3 The Rationale for the Systematic Review:

The investigation, exploration, evaluation and synthesis of systematic review applied to the domain of discourse facilitates the scientific method of separating all the insignificant, unsound or redundant deadwood [67] in the field of sensor-enhanced health information systems from salient and previous studies. The suitability of this approach is its strength in establishing the generalisability of scientific findings which

Table 2.2: The Database

Database	URL
Springerlink	www.link.springer.com
IEEExplore	www.ieeexplore.org
ScienceDirect	www.sciencedirect.com
Web of Science	www.apps.webofknowledge.com
ACM DL	www.dl.acm.org

Table 2.3: Search Terms

$$\left\{ \begin{array}{rc} ((\text{"}hospital\ information\ systems & \text{OR} \\ \text{"}medical\ information\ systems\text{"} & \text{OR} \\ \text{"}health\ information\ systems\text{"} & \text{OR} \\ \text{"}health\ information\ exchange\text{"} & \text{OR} \\ \text{"}hospital\ information\ systems\text{"} &) \\ \text{AND} & \\ (\text{"}mHealth\text{"} & \text{OR} \\ \text{"}mobileHealth\text{"} & \text{OR} \\ \text{"}eHealth\text{"} & \text{OR} \\ \text{"}TeleHealth\text{"} & \text{OR} \\ \text{"}Wearable\text{"} & \text{OR} \\ \text{"}sensors\text{"} & \text{OR} \\ \text{"}sensor\text{"} &) \\ \text{AND} & \\ (\text{"}interoperability\text{"}\text{OR} & \\ \text{"}semantics\text{"}\text{OR} &)) \end{array} \right\}.$$

are capable of revealing the consistency of relationships in the se-HIS framework, models, techniques and tools as well as determining the accuracy or at least an improved reflection of reality [69].

2.6 Methodology for Objectives 3 and 4

There are many different ways to design an ontology because there is no single consensus ontology design methodology, found in the literature. During this study, we examined all the available methodologies listed in Table 2.4 and finally came to the conclusion of combining two major methodologies to enable us to develop an ontology that will be rich in fulfilling the semantic interoperability between sensors and health information systems. Two methodologies - Knowledge Engineering Methodology and Methontology Methodologies were combined to develop the proposed solution to the interoperability gaps,to enable us to capture data at granular level.

Table 2.4: Methodology Approaches for Ontology Development

Methodology	Author(s)
Knowledge Engineering Methodology	Uschold and Gruninger [70]
DOGMA Methodology	De Bo et al. [71]
Methontology	Fernaandez et al. [72]
SENSUS Methodology	Swartout et al. [73]
DILIGENT Methodology	Pinto et al. [74]
TOVE Methodology	Gruinnger and Fox [75]

2.6.1 The Ontology Design Methodology:

In the works of Kabilan and Mojtahed in 2006 [76] they concluded that an information system application should have standard functional design requirements and summarized the requirements as follows: flexibility; re-usability; easy maintenance; rapid development cycle; extensibility; traceability and shared understanding. In this section, we present that the methodology which we adopt for the ontology conceptualization, design, and development as shown in Fig.2.3, complies with Kabian and Mojtahed views [76].

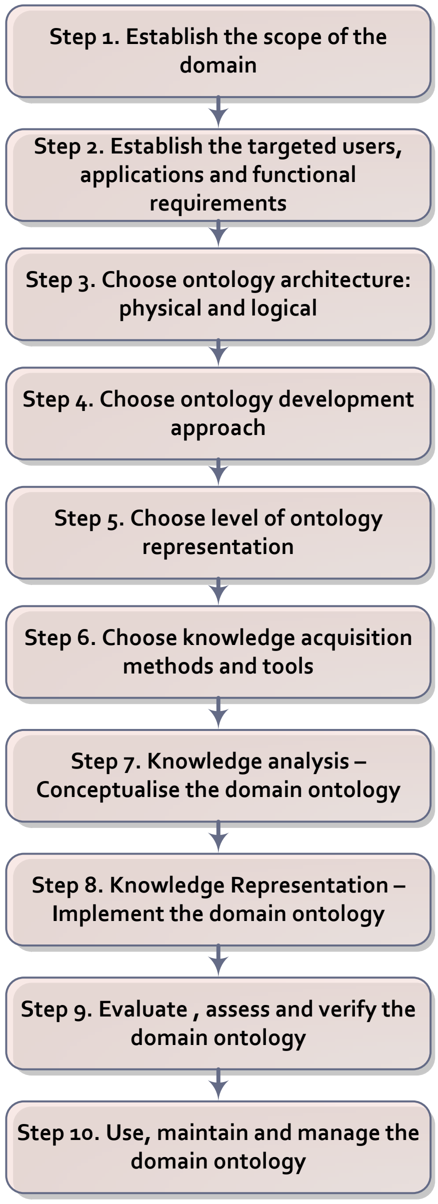

Figure 2.3: Ontology for Information Systems Design Methodology

2.6.1.A Step 1: Establish the scope of the domain

In this phase the domain of interest, the purpose or problem to be solved through the use of the developed ontology is formulated and documented. The domain is the universe of discourse in which the focus of the study is that is: the interoperability between sensors and health information systems. The different boundaries of the domain under investigation is identify following the procedure of identifying the domain which the proposed ontology is to be used in, that is the context of the application(s). The identification of the required functionalities of the applications is carried out and immediately followed by the identification of the main features of the domain to understand how it relates to other domains.

2.6.1.B Step 2: Establish the targeted users, applications, and functional requirements

In this step, a list is created for all the projected end uses, their requirements and targeted users. The scope of the ontology and its application context, the people who are the targeted users, contacts with domain experts from the health care sector was arranged. At this stage, the targeted user groups, the targeted user's group profiles and their usual expertise with the domain is identified. Also, the typical usage scenarios were also identified.

2.6.1.C Step 3: Choose ontology architecture: - physical and logical

This stage is the stage where the appropriate architecture for the proposed ontology was decided. The system requirement for the application environment, current ontology design architectures, we preferred a multi-tiered architecture for logical architecture. The process was carried out by choosing a physical architecture from single ontology for a central application; multiple local ontologies for distributed applications and a hybrid ontology for distributed application that supports interoperability. Furthermore, for the logical architecture design for domain ontology, we choose the multi-tiered ontology structure consisting of upper generic ontology, specific domain ontology, and the application or template ontology.

2.6.1.D Step 4: Choose ontology development approach.

This phase comprises the decision-making phase where the decisions on how the analysis and design work of the domain ontology begins. The current approaches for the design and development of ontology are limited to three choices; top-down approach,bottom-up approach and the middle-out approach. Therefore, based on convenience, the newness of Transducer Electronic Data Sheets, the scope of the proposed ontology and scale of the ontology we choose the top-down approach because the domain is very understood and well documented in the IEEE 21450 family of standards. However, due to our need to support interoperability with other health information systems, the study also combined it with the middle out approach, where the study begin by identifying the users (patients) but after that, we also map existing ontologies like the HL7 to identify 'users' as an 'actor.'

2.6.1.E Step 5: Choose the level of ontology representation.

In this phase, the purpose of the ontology determines the degree of representation in the ontology. For example, if the purpose is only for human understanding and communication, then an elaborate formal knowledge representation is not needed or warranted. According to Uschold and Gruninger [77] ontologies are classified based on the complexities of knowledge representation formalism belonging to the following broad categories: Highly informal; semi-informal; semi-formal, or Rigorously Formal. We proposed to model our domain of interest in two phases as illustrated in Fig. 2.4, we first capture the domain knowledge as a series of Unified Modeling language (UML) conceptual models to conform to semi-formal ontology type. The UML class diagram is essential for human understanding, and it does promote rapid reuse amongst users and can be transformed to formal ontologies.In the second stage, the UML conceptual models are converted into machine-readable formal ontology representation using Web Ontology Language (OWL) [78]. The Dual Conceptual Representation (DCR) of the domain, is a novel method as compared to other contemporary ontology design methodologies.

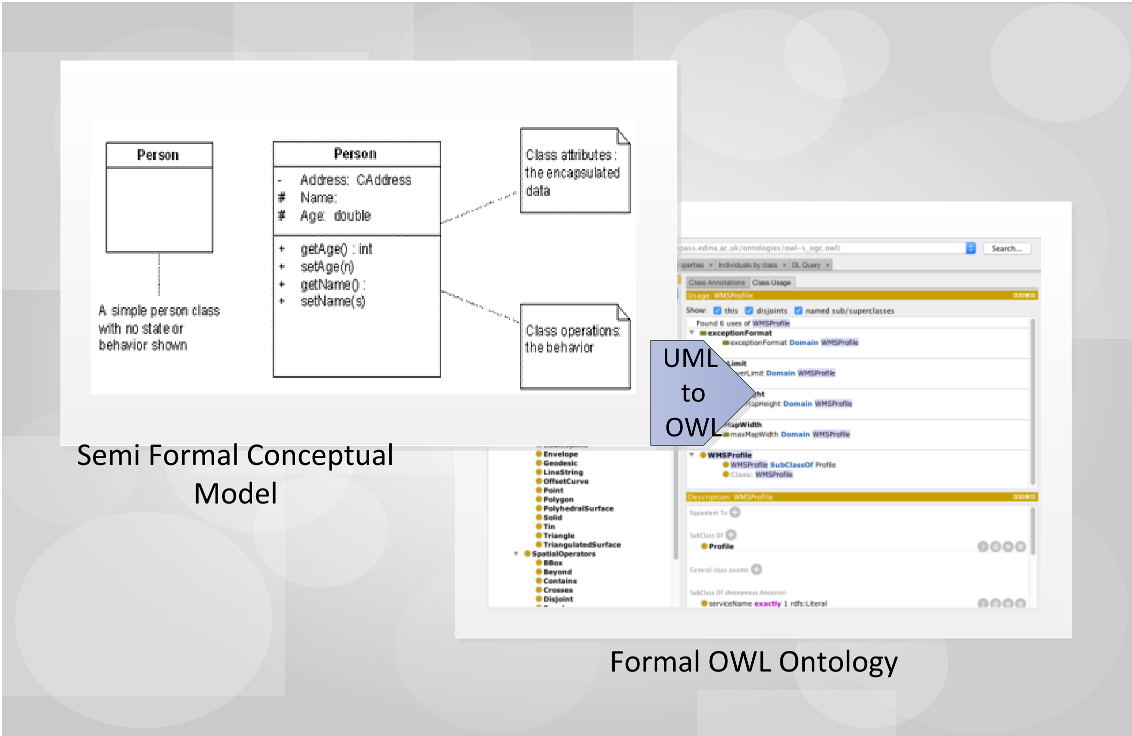

Figure 2.4: Modeling Illustration

2.6.1.F Step 6: Choose knowledge acquisition methods and tools

The knowledge acquisition method and tool is used for the extraction of and information from natural language text, and web pages, etc. either manually, semi-automatically or automatically. Uschold and Gruinner [79] suggested guidelines capture Informal Knowledge from natural language; we adopted investigating and obtaining the domain first in natural language. The other method we could choose from is the method put forward in Unified Process for Ontology Building (UPON) by De Nicola and Missikoff [80]. We choose the Protege Ontology Editor as our ontology design and development tool, and for the conceptual modeling, we prefer the Microsoft Visio.

2.6.1.G Step 7: Knowledge Analysis: conceptualize the domain ontology

The knowledge analysis phase is carried out after the knowledge has been captured, a choice was made for the mechanism for analyzing and thereafter modeling the implicit and explicit knowledge retrieved. We used our proposed integrated method which builds on the fundamental steps introduced by Noy and Gruninger and Fox. In other, for us to be able to analyse and model the semantics (concepts), and the dynamics (procedures) and the pragmatics (using deontic analysis models) alongside the 5Ws approach - who, why, where, when, and what analysis tool. We conceptualized the domain knowledge from different perspectives - the semantics, the procedural; and the pragmatic. The phase output a set of conceptual models following our integrated methodology.

2.6.1.H Step 8:Knowledge representation: implement the domain ontology

The knowledge representation phase is the stage at which we finally apply the conceptual models as the formal ontology. The set of conceptual models designed at the end of the previous step - step seven, the ontology development environment - Protege to translate UML to OWL. The stepwise provision made by Noy and McGuinness [81] although, it is carefully adapted to the Protege ontology editor, it is generic enough to be adapted for other ontology development as well. It is important in capturing the descriptive concepts and their relationship in the domain.

2.6.1.I Step 9: Evaluate, assess and verify the domain ontology

The evaluation, assessment, and verification of the domain ontology is the penultimate step we carried out. The designed ontology, competency question setup at the outset, and the functional requirements that were to be met were all verified by the domain experts. The competency questions as suggested by Gruninger and Fox [75], are used to assess the minimum level of required information to be captured and modelled to support the standard of inferencing and targeted application usage. Davis et al. knowledge representation roles as evaluation criteria to assess if our conceptualized ontology fulfils its purpose.

2.6.1.J Step 10: Use, maintain and manage the domain ontology

This is the final stage where the designed ontology has to be put to use, maintained and required modifications be made from time to time. The methontology methodology is followed in part in this phase due to the ontology evolving life cycle. The Semantic Analysis Representations (SAR)s help the IS designers in their ontology creation role as well as the end users to populate the designed ontology with relevant information. Maintenance of the designed ontology requires periodic housekeeping activities on the part of the designer. New concepts may have to be added, redundant ones removed, and existing ones modified. As stated, an ontology is a consensus model, and it has to support flexible evolution. It should also support the integration of other existing sources, migration of data and information from older legacy systems and data models and so forth.

2.7 Methodology for Evaluation - DeLone & McLean Information System Evaluation Method

In this section, we reviewed various approaches that contribute to the validation of our research. The aim is to identify the existing evaluation methods and models which are appropriate to our purpose and can reliably demonstrate the soundness of our solution in the field of ontology and conceptual modelling. A combination of methods or single method, can be used in computer science and these methods are acknowledged to give reliable results in design sciences [50], as design science are concerned with the study of 'artificial objects or phenomena designed to meet certain goals' [3, 50, 82]. The selection of an appropriate evaluation method or the combination of methods,therefore, depend on the type of research and its expected outcomes. Venable, Pries-Heje and Baskerville [17] suggested in their study that DSR researchers should consider combining the identified relevant, higher priority criteria in the white and blue cells in Table 2.5 is a better option as it will help in reducing conflicting goals.

Table 2.5: DSR Evaluation Strategy Selection Framework [17]

DSR Evaluation Strategy Selection Framework		**Ex Ante**	**Ex Post**
		•Formative •Lower build cost •Faster •Evaluate design, partial prototype, or full prototype •Less risk to participants (during evaluation) •Higher risk of false positive	•Summative •Higher build cost •Slower •Evaluate instantiation •Higher risk to participants (during evaluation) •Lower risk of false positive
Naturalistic	•Many diverse stakeholders •Substantial conflict •Socio-technical artifacts •Higher cost •Longer time - slower •Organizational access needed •Artifact effectiveness evaluation •Desired Rigor: "Proof of the Pudding" •Higher risk to participants •Lower risk of false positive – safety critical systems	•Real users, real problem, and somewhat unreal system •Low-medium cost •Medium speed •Low risk to participants •Higher risk of false positive	•Real users, real problem, and real system •Highest Cost •Highest risk to participants •Best evaluation of effectiveness •Identification of side effects •Lowest risk of false positive – safety critical systems
Artificial	•Few similar stakeholders •Little or no conflict •Purely technical artifacts •Lower cost •Less time - faster •Desired Rigor: Control of Variables •Artifact efficacy evaluation •Less risk during evaluation •Higher risk of false positive	•Unreal Users, Problem, and/or System •Lowest Cost •Fastest •Lowest risk to participants •Highest risk of false positive re. effectiveness	•Real system, unreal problem and possibly unreal users •Medium-high cost •Medium speed •Low-medium risk to participants

In this study, after a thorough review of the various methods, we rely on the framework for design science research as proposed by Hevner and March [50]. They specified four types of research outcomes: constructs, models, methods and instantiation. Hevner and March [50] in their study, summarized the recommended content and structure as well as proved and tested evaluation methods and quality criteria for each of the four types of outcomes. The structure of each research artifacts includes the information sources which are required to give full particulars on the actual solutions, and thus enable a feasible evaluation procedure. The details of the main components of each artifact and the suitable evaluation methods and criteria are listed in Table 2.6.

Table 2.6: DSR Evaluation Method Selection Framework II [17]

DSR Evaluation Method Selection Framework	Ex Ante	Ex Post
Naturalistic	•Action Research •Focus Group	•Action Research •Case Study •Focus Group •Participant Observation •Ethnography •Phenomenology •Survey (qualitative or quantitative)
Artificial	•Mathematical or Logical Proof •Criteria-Based Evaluation •Lab Experiment •Computer Simulation	•Mathematical or Logical Proof •Lab Experiment •Role Playing Simulation •Computer Simulation •Field Experiment

Information Systems (IS) success definition research started a few decades ago, however, it lacks appropriate definition and consensus on factors affecting IS success in the studies of [83, 84], as cited in [7]. Although the introduction of some IS success theories, has been deemed inconsistent by empirical studies results [7], most citations, replications, validations and modifications on IS success assessments are on the DeLone & McLean [47] model shown in Fig. 2.5.

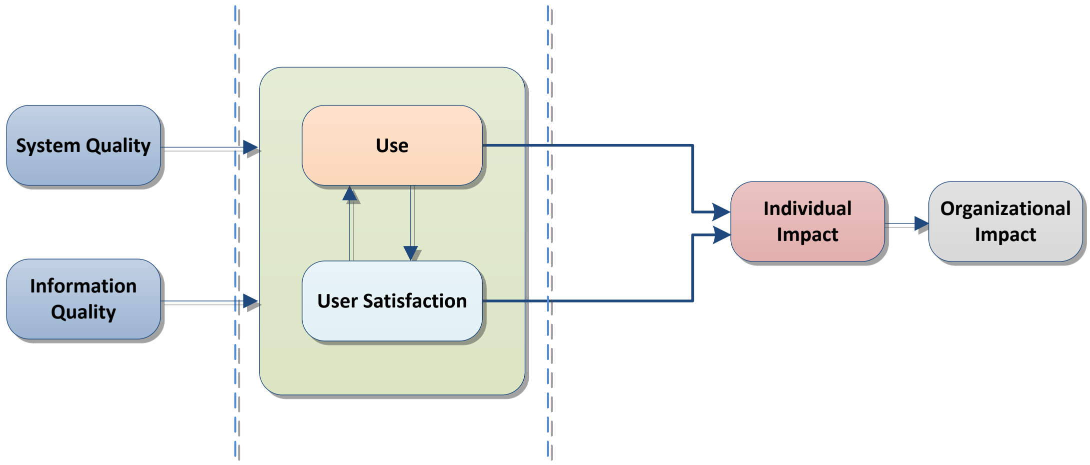

Figure 2.5: Delone and McLean IS Success Model [5]

Information Systems (IS) success model. Seddon [85] later criticised the model, then DeLone & McLean updated the model by adding two variables into the previous model: service quality and intention to use as shown in Fig.2.6 .

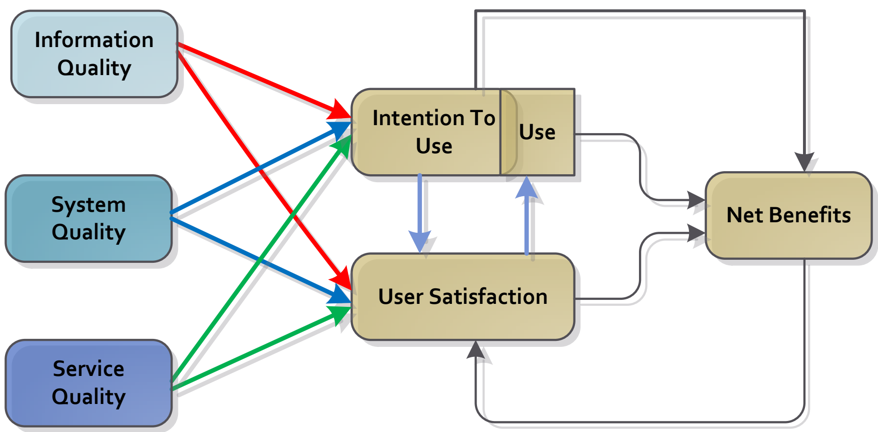

Figure 2.6: Updated DM IS Success Model [5]

The following factors: information quality, systems quality, service quality, and user satisfaction determine the intention to use variable added to the D & M IS success model details in Fig.2.7. Mardiana [7] proposed the connection between information systems success model and Technology Acceptance Model (TAM) in his bids to establish the proper variables to determine the intention to use. The Intention to use theoretically came from psychology discipline while information quality and system quality came from the technical aspect of communication theory [86] which raises the internal consistency from the theoretical perspective.

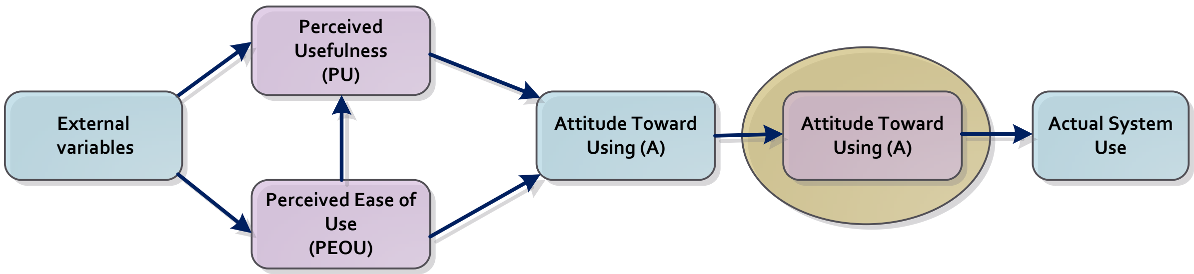

Figure 2.7: Behavioural intention to use in TAM [6]

2.7.1 Intention to Use Information System in Organisation

Intention to use originated from behavioural intention concept introduced by Fishbein and Ajzen [86], they asserted that certain behaviour can be predicted by the intention of doing the behaviour in question from their Theory of Reasoned Action (TRA). The behaviour in question in the theory of IS success model by D & M is the system's use (as presented by the variable "use "as seen in Fig.2.6). This intention to use translates to the willingness of the user to use the system, according to view postulating that behavioural intention to use is the antecedent of actual system use, which researchers in TAM support. In the TAM meta-analysis study [87], behavioural intention is a good predictor for actual system utilisation in both subjective and objective measurement; the subjective measurement is taken from self-reporting questionnaire, while the objective measurement is conducted by looking at the system log. Comparing the TAM and IS success model based on the "intention to use "the fundamental difference between the prediction of intention to use in TAM and D & M IS Success Model is determined by the attitude and perceived usefulness Fig.2.8. The D & M IS success model predicts “intention to use ”using system quality, information quality and service quality as shown in Fig.2.8. However, the analytical review study between 2003 and 2010, indicates that perceived usefulness is the best predictor for behavioural intention [87–92] as cited in [7]. This finding is similar to the studies of [93, 94] which show that perceived usefulness is a strong predictor for intention to use.

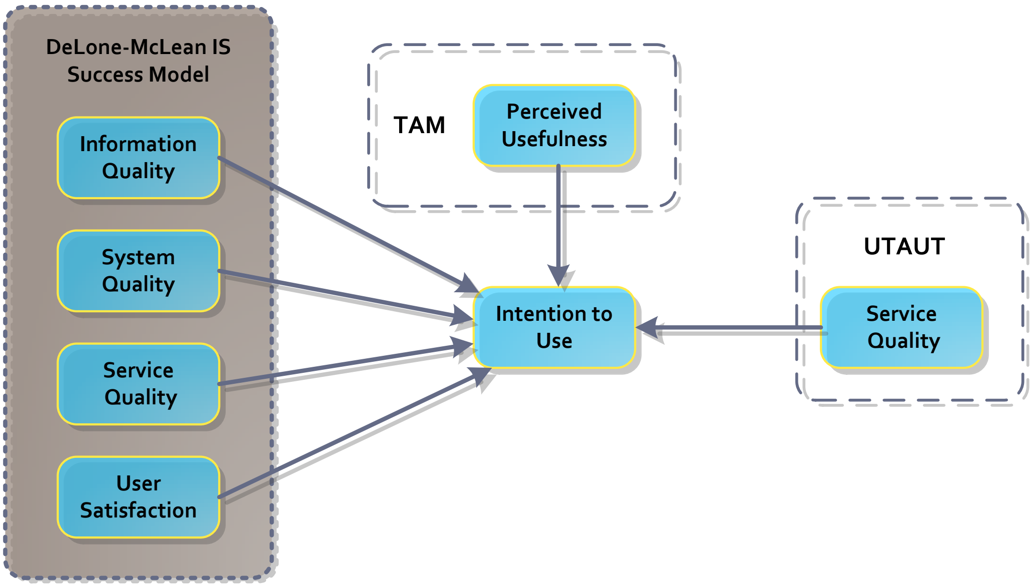

Figure 2.8: The Conceptual Model for Predicting intention to use [7]

2.8 Chapter Summary

In this chapter, the study addressed the issue of how the study was conducted, the approach used and how it the choice of approach was made. The discussion on methods used to evaluate the output of the study was detailed, and the rationale was also stated. The DSR approach was used, the rationale was discussed and more discussion followed on the method used in designing the ontologies and finally, the study established an evaluation method to determine the success of the framework and discussed the reason for using the model for the evaluation.

3

Literature Review / State-of-the-Art

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3.1 Introduction

This chapter has a strong focus on the semantic interoperabilIty in se-HIS frameworks. It gives details on the: state-of-the-art in semantic interoperability between wearable devices and HIS, approaches to semantic interoperability, the information requirements for semantic interoperability, as well as the role standards play in semantic interoperability in se-HIS. The historical role of standards in the interoperability of HIS and wearable devices (that is, wearable devices for health monitoring) is also explored ranging from the standards in wearable devices to standards in HIS. Furthermore,investigation carried out on the various semantic solutions available in the literature to establish measures taken to overcome challenges faced at the semantic level of interoperability is reported. The later sections give a summary of some of the important standards in operations to enable seamless integration between wearable devices and HIS.

3.2 Semantic Interoperability

Rector et al. [95], concluded that there are differences between the "information models" and "models of meaning" in their study, and it was in agreement with the position of Ceuters and Smith [96]. They were of the opinion that information model facilitates the specification of information and tests the validity of data structures for ease of exchange and re-use in different information systems. While the "model of meaning" is to facilitate the understanding of the real world to enhance the reasoning about the world (patients) either in general or individual.

Therefore, lack of homogeneity between information model and model of meaning has led to lack of focus on patient and associated focus of "concepts" and "contexts " thereby, causing incompatibility in terminologies exhibiting non-resolvable overlap, the above challenge is known as Semantic Interoperability (SIOp). According to Ceuters and Smith [96] SIOp is defined as:

> *"the ability of two or more computer systems to exchange information and have the meaning of that information automatically interpreted by the receiving system accurately enough to produce useful results to the end users of both systems."*

It relates to sharing the conceptualization that leads to correct or accurate interpretation through the communication of its representation as strings of bytes, with minimal mutual dependency [97]. SIOp enables systems to combine received information with other information resources and process it in a meaningful manner as stated in the European Interoperability Framework (EIF). Also, it has been part of many scientific disciplines for example information extraction (IE), information retrieval (IR), knowledge representation (KR), artificial intelligence (AI) among many others, although these disciplines have their views of semantics which is all built on some meta-theoretical and epistemological assumptions. According to Hjorland [98] the different perspectives implies different cognitive view, concepts and meaning, SIOp is attained when the contents of the information exchanged are interpreted in the same way on all the systems.

Although, there is no single definition of interoperability in some domains, as meaning is based on the context [99]. The primary focus of IOp is the ability of different devices to interconnect efficiently, exchange data, and function with each other, by transmitting data accurately in real time and in some cases carry out actions based on the data and interpret that shared data, as defined by Healthcare Information and Management Systems Society (HIMSS):

> "the ability of health information systems to work together within and across organizational boundaries to advance the efficient delivery of healthcare for individuals and communities." [100]

while, IEEE standards glossary define it as the ability of a system or a product to work with other systems or products without special effort on the part of the customer [101]. However, the term "Interoperability" does not have a clearly agreed upon definition within the overall community. The IEEE [102] glossary defined it as:

> "the ability of two or more systems or components to exchange information and to use the information exchanged".

Also, other definitions and characterization have suggested a different perspective, such as syntactic versus semantic in Wegner [103], Heiler [104], and Park and Ram [105], interoperability is defined from different perspectives and it takes several forms in information systems [8, 106] as shown in Fig.3.1

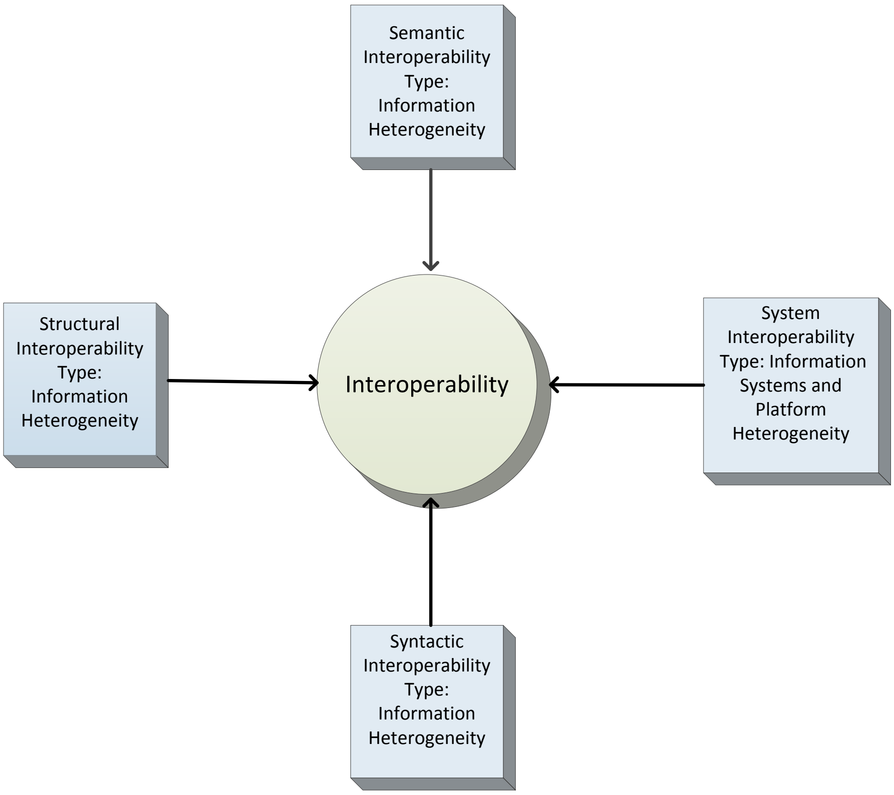

Figure 3.1: Heterogeneity in Information Systems [8]

Furthermore, Asuncion and van Sinderen [107] discussed it from a pragmatic perspective i.e. "pragmatic interoperability", which is the interoperability that deals with the mutual understanding between collaborating systems when they use data. Thus in 2004 the European Commission and Candela, Castelli and Thanos proposed more comprehensive frameworks to capture the many facets of interoperability: these facets of interoperability are often overlooked, whereas, they help to demystify the myth that interoperability is a mere technical issue.

Therefore, most interoperability frameworks (IFs) adopt a three layer structure categorized into technical, semantic, and organizational [108]. The European Telecommunication Standards Institute (ETSI) introduces the layer of syntactic interoperability above technical interoperability while the likes of Sheth [8] categorized it as system, syntax, structure, and semantic. Kiourtis [109] cited [99] as adding the fifth one named organizational interoperability, the various levels of IOp conceptually are shown in Fig. 3.2.

Interoperability is a problem affecting the interaction of entities at various levels, the IOp problem affects the use of wearables in monitoring the health of its users, as the exchange of information from the sensor/ digital resources must be accurately reported alongside its context for medical professionals to be able to make sense of the health data logged into the HIS.

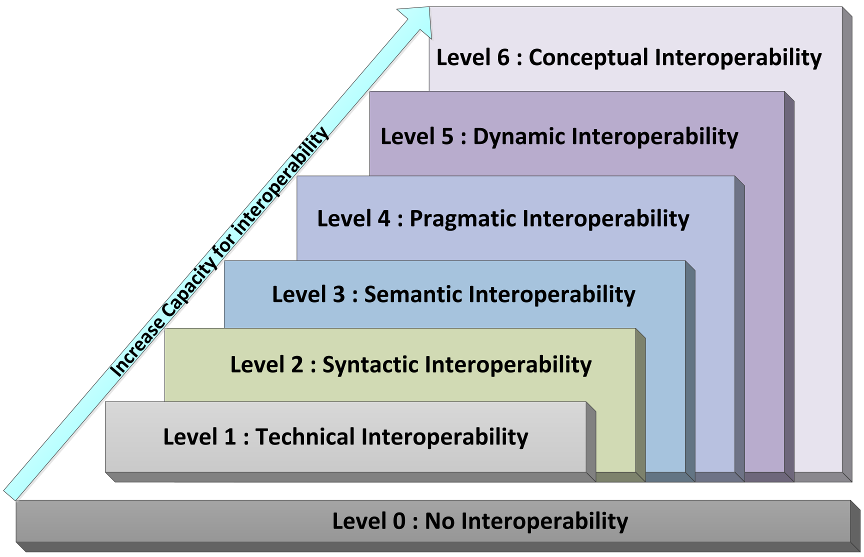

Figure 3.2: Levels of Conceptual Interoperability [2]

3.2.1 Syntactic Interoperability

Syntactic Interoperability is the aspect of interoperability which focuses on data formats; it defines common data structures. Organized syntax and encoding are needed to transfer messages through communication protocols, with many protocols carrying data or content, which are represented using high-level transfer syntaxes such as XML-Schemata, Hyper Text Markup Language (HTML), eXtensible Markup Language (XML) or ASN.12 [99] are important and needful for systems to interoperate.

3.2.2 Organizational Interoperability (OIOp)

Interoperability is an essential factor for effective data capture, transfer, and processing from wearable devices (sensors) to the HIS. Organizational interoperability has several definitions based on different framework concepts as defined by various IOp frameworks such as the EIF for Pan-European E-Government Services , European Public Administration Network (EPAN) [110]. However, Archmann [111], defined OIOp in a broader way and called it "Services / Process - related interoperability aspects"but Tambouris [112] distinguish it from the narrower definition in EIF. According to EIF, OIOp is

> "...defining business processes and bringing about the collaboration of administrations that wish to exchange information and may have different internal structures and processes, as well as aspects related to requirements of the user community " [110] as cited in [113].

3.3 Complexity of the se-HIS DOMAIN

This study cuts across two main domains namely the wearable system and the HIS: the wearable system is the recent advancement in health monitoring, diagnostics, and telemedicine technologies which have led to the development of cost-efficient healthcare system [9] as shown in Fig. 3.3 with its core component being the transducers as defined by the IEEE 21451 [24] family of standards.

The wearable system is essential in ubiquitous health-care and is characterized by the positioning of biomedical sensors around the human body to collect physiological data and transmit through wireless means to a base node for processing [114]. These physiological signs vary as shown in Table 3.1. It always ends up as a stovepipe system as they operate on different standards, proprietary data formats and technologies that are not interoperable with the existing HIS previously designed for static data collection through human interactions. Transducers are the core components of wearable devices and it works better as a group, due to the multiplicity of devices / sensory abilities, the current HIS has been developed with different proprietary platforms and standards, thus making it difficult to share data across the newly emerging information system in the healthcare domain known as se-HIS. Although, the HIS already has complications in the area of data fusion across different incompatible HIS and this complication is on the increase by the addition of the sensor system or IoT, and this has resulted in difficulty to obtain complete clinical data in real time by the clinicians from the patients. Therefore, the multiplicity of standards such as HL7 [21] for exchanging messages; openEHR [115] and SNOMED-CT [116] for expressing the semantic value within the healthcare domain, has caused more problems classified into two broad categories by Suphachoke et al. in their study [117]: lack of semantic interoperability in health-care message exchanges and Electronic Health Record (EHR) systems integration and the occurrence of different types of conflict through ontology mapping.

Figure 3.3: Typical mHealth Architecture [9]

For example in a single wearable device more than one sensor can be present such as; the blood oxygen sensor, heart rate sensor, an activity sensor and temperature sensor as presented in the Angel device in Fig. 3.4 [10]. There are several wearable systems for ubiquitous healthcare monitoring [118–121] with their general architecture detailed in Fig.3.3. The device measures the user's pulse, temperature, activity and blood oxygen level simultaneously, the aggregation of these sensors in devices has made possible IoT healthcare technologies such as ambience intelligence, networks, wearable, big data among many others that form the mechanics of the IoT as shown in Fig. 3.5. However, this autonomy has led to increasing standalone wearable systems having different standards; standards such as IEEE 11073 [23], IEEE 21451 [24] family of standards among others in wearable domains.

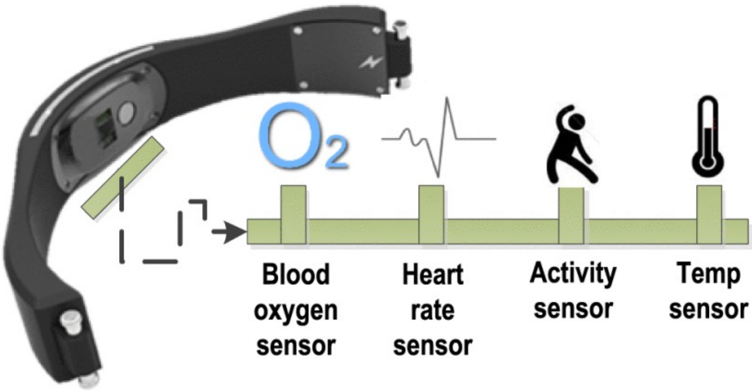

Figure 3.4: Different Sensors in a device called Angel [10]

Figure 3.5: The IoT Elements [11]

3.3.1 Internet of Things (IoT)

IoT is the interconnection of physical objects with sensors, actuators, Radio Frequency Identification (RFID), software embedded into object(s) to enable it to interact with humans and other connected devices to enable it to achieve a set, of common goals [122, 123]. The devices are used for sensing, actuating and monitoring purposes with connection technologies such as Wi-Fi, Bluetooth Low Energy (BLE), ZigBee, Near Field Communication (NFC).

Table 3.1: Disease processes,parameters and Sensor types [18]

Disease Process	Physiological Parameter (Body Sensor type)	Biochemical Parameter (Body Sensor type)
Hypertension	Blood pressure (implantable/wearable mechanoreceptor)	Adrenocorticosteroids(implantable biosensor)
Ischaemic Heart Disease	Electrocardiogram (ECG), cardiac output (implantable/ wearable ECG sensor)	Troponin, creatine kinase(implantable biosensor)
Cardiac Arrhythmias/ Heart Failure	Heart rate, blood pressure, ECG,cardiac output (implantable/wearable mechanoreceptorand ECG sensor)	Troponin, creatine kinase(implantable biosensor)
Cancer (Breast, Prostate, Lung, Colon)	Weight loss (body fat sensor)(implantable/ wearable mechanoreceptor)	Tumour markers, blood detection(urine, faces, sputum),nutritional albumin(implantable biosensors)
Asthma / COPD	Respiration, peak expiratory flow,oxygen saturation (implantable/wearable mechanoreceptor)	Oxygen partial pressure(implantable/wearable optical sensor, implantable biosensor)
Parkinson's Disease	Gait, tremor, muscle tone, activity(wearable EEG, accelerometer,gyroscope)	Brain dopamine level(implantable biosensor)
Stroke	Gait, muscle tone, activity, impaired speech, memory (wearable EEG,accelerometer, gyroscope)	
Diabetes	Visual impairment, sensory disturbance (wearable accelerometer, gyroscope)	Blood glucose, glycated haemoglobin (HbA1c)(implantable biosensor)
Rheumatoid Arthritis	Joint stiffness, reduced function,temperature (wearable accelerometer, gyroscope, thermistor)	Rheumatoid factor, inflammatory and autoimmune markers(implantable biosensor)
Renal Failure	Urine output (implantable bladder pressure/volume sensor)	Urea, creatinine, potassium(implantable biosensor)
Vascular disease(peripheral vascular and aneurisms)	Peripheral perfusion, blood pressure,aneurism sac pressure (wearable/implantable sensor)	Haemoglobin level (implantable biosensor)
Infectious diseases	Body temperature (wearable thermistor)	Inflammatory markers, white cellcount, pathogen metabolites(implantable biosensor)
Post-operative monitoring	Heart rate, blood pressure, ECG,oxygen saturation, temperature(implantable /wearable and ECG sensor)	Haemoglobin, blood glucose,monitoring the operative site(implantable biosensor)
Alzheimer's disease	Activity, memory, orientation,cognition (wearable accelerometer, gyroscope)	Amyloid deposits (brain)(implantable biosensor/EEG)

The cloud plays a major role in enabling the IoT applications to work autonomously any time and from anywhere, while it adapts to and reacts intelligently to different situations and support for easy integration [11]. However, due to considerable heterogeneity and the resource constraint nature of participating devices, the expectations remain as a challenge and accommodating a vast number of different resources constraint devices in IoT, draws the attention of the research community.

The IoT is an emerging technology, and based on the prediction by Garner [124], it will grow up to twenty-six billion units by 2020, which will give an economic value-add of about 1.9 trillion US dollars globally. The IoT is a complex technology that comprises of seamless intercommunication and coordination of objects, data, processes and services that rely solely on sensors. The complexity covers all of the Open Systems Interconnection (OSI) model through its adaptation of different protocols, created to meet the needed requirements for the technology to evolve.Therefore it is hard to have a single solution for every application domain, coupled with the fact that not all IoT systems need the same protocol stack and or same architecture. The richness of IoT lies in the paradigm: proper coordination of sensed data, its processing (cloud services, for instance) and overall coordination of the corresponding action triggers which might occur at different IoT systems. For example a seamless interconnection of a simple, wearable device monitoring a patient's heart rate(current silos and proprietary applications) with another IoT system in a clinical facility.

IoT enables physical objects to see, hear, think and perform tasks by having inter- and intra-communication information sharing and decision coordination [11]. The development of sensors, actuators, smart phones, RFID tags makes it possible to materialise IoT which interact and co-operate with one another to make the service better and accessible at any time from anywhere in the network. Wireless sensor technology allows objects to provide real-time environmental information and context, which allows objects to become more intelligent, able to think and communicate among themselves effectively.

3.3.2 The IoT Elements

IoT are made up of different integrated blocks and technologies for efficient service delivery as shown in Table 3.2 and elements as shown in Fig. 3.5.

- **Identification:** it is important for IoT to name and match services with their demands. Identification methods such as Electronic Product Codes (EPC) and ubiquitous codes [125], helps to differentiate the objects through its objects ID and its address. For example, “S1”–for a particular accelerometer sensor and object address refers to its address within the communication network.

- **Sensing:** the IoT consists of sensors that can be smart sensors, actuators or wearable sensing devices. The sensors are responsible for gathering data from their environments within the network and transferring the data to a data warehouse, database or cloud. The data is analysed for specific actions as services required.

- **Communication:** the communication technologies enable the IoT objects to connect to other objects to deliver specific smart services. Examples of protocols used for the IoT communication are 802.15.4, Z-wave, LTE-Advanced, WiFi, Bluetooth, IEEE, 802.15.4, and LTE-Advanced. Other special communication technologies are also used like RFID, Near Feild Communication (NFC), and ultra-wide bandwidth (UWB.)

- **Computation:** the IoTs have processing units (e.g., microcontrollers, microprocessors, SOCs, FPGAs), and software applications use for computations. Hardware such as Gadgeteer, Arduino, Mulle, FriendlyARM, Raspberry PI, and UDOO, among others is used to develop IoT applications. Also, software platforms are utilised to provide IoT functionalities such as Contiki Real Time Operating Systems, TinyOS , Riot OS , LiteOS which are Real Time Operating Systems offers lightweight OS designed for IoT environments. The hardware and software platforms provides the facilities for smart objects to transfer data to the cloud and allows it to be processed in real-time, for end users to benefit from the extracted knowledge from the big data collection.

- **Services:** there are four main classifications of IoT services namely: identity-related services, information aggregation services, Collaborative-Aware Services and Ubiquitous Services [11]. The identity-related which is vital service, which is the foundation of other services, the application that are bringing real-world objects to the virtual world must have a way to identify the objects. The information aggregation services are responsible for the collection and summarization of raw sensor measurements which must be processed and sent to the IoT application. Collaborative -aware services use data as the basis for decision-making

Table 3.2: Building Blocks and Technologies of the IoT [11]

IoT		Samples
Identification	**Naming**	EPC, uCode
	Addressing	IPv4, IPv6
Sensing		Smart Sensors, Wearable sensing devices, Embedded sensors, Actuators, RFID tag
Communication		RFID, NFC, UWB, Bluetooth, BLE, IEEE 802.15.4, Z-Wave, WiFi, WiFiDirect, LTE-A
Computation	**Hardware**	SmartThings, Arduino, Phidgets, Intel Galileo, Raspberry PI, Gadgetter, Cubieboard, SmartPhones.
	Software	OS (Contiki, TinyOS, LiteOS, RiotOS, Androidd); Cloud(Numbits, Hadoop).
Service		Identity-related (shipping), Information Aggregation (smart grid), Collaborative-Aware (smart home), Ubiquitous (smart city)
Semantic		RDF, OWL, EXI

and react accordingly, and it acts on information aggregation services. Finally, the collaborative-aware services help to make available collaborative-aware services any-time anyone needs them anywhere.

- **Semantics:** this refers to the ability of different machines to extract knowledge for the required services; the extraction includes the discovery and use of resources, modelling information, recognizing and analyzing data to make sense of the correct decision for provision of a specific service [12]. Thus the requirement for IoT to send request to the right resource is supported by semantic web technologies such as Web Ontology Language (OWL) and Resource Description Framework (RDF) Fig.3.6 illustrates details of semantics in IoT.

3.3.3 Wearable Sensor

The steep increase in the need to take care and monitor the changes going on the health an individual has led to increasing importance of health monitoring. Health monitoring, defined as, observing changes occurring from one time to another giving

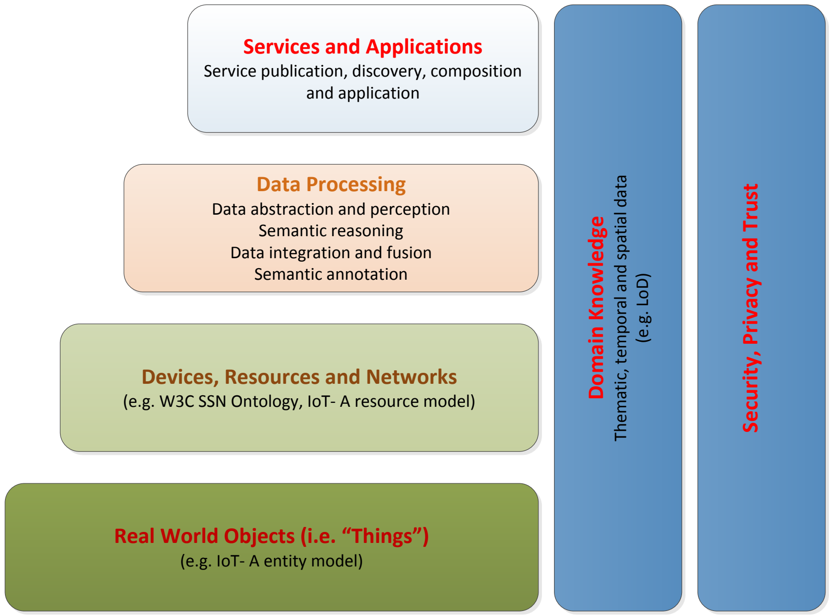

Figure 3.6: Semantics at different levels in IoT [12]

the well-being information about an individual [126]. The monitoring may involve the identification of some irregular fluctuating health measures parameters as stated in Table 3.1. The health parameters are referred to as vital signs (i.e., physiological parameters) and should be monitored in the way that it does not impair or interferes with the patient's mobility and quality of life. In the bid to achieve this goal in the patient's health care unobtrusively, on-body sensors can be advantageous [127] and several types of research [127–135] have reported the use of sensors to monitor different health parameters to help patients maintain a healthy life see Table 3.1 for list of sensors and the parameters. The sensors are built into devices that can stand-alone, or embedded in mobile devices such as the smart-phones e.g. accelerometer, gyroscope among others in smart-phones or embedded in different devices around the the patients home or environment such as home,cars etc.

Advancement in technologies and the reduction in potential support ratio (PSR) - i.e. the number of persons within the age range of fifteen (15) to sixty-four (64) years old divided by the number of persons aged sixty-four (65) as cited in [136] and above has caused a paradigm shift in both health care and health monitoring,the paradigm shift exploits the role of sensors in the health sector for health monitoring, maintenance among many others. It proposed that the ideal sensor system for health-related parameter capture would be deployed at a point in time to continuously measure and transmit health-related information to the health care providers. The sensor system would not be obtrusive in any way and may support a home-based or mobile assessment of a person's health and the information glean from the data generated are useful in detecting the detrimental constellation or emergency situations.

Therefore, a timely intervention and prevention measures may be taken to avoid further damages [15], this kind of care scenario is known as person-centred universal, and it care requires new forms of living and attention [15] and also a new type of information system architecture respect to health information. The new form of health information architecture must include both the personal or home environment as a source of relevant health data and caregivers and other healthcare professionals in contrast to the current institution-centric architectures; such type of system when fully functional needs to be integrated with the existing HIS to form an hybrid health information system like se-HIS.

The transducers embedded in different devices such as smartphones, smart watches etc., form core elements that help to capture the various vital signs in the mobile health systems. A current survey by Research2Guidance [137] over 60,000 health-related apps available on Apple apps store and Google play store [138] has most of the apps developed for health fitness and self-health monitoring [139]. These health apps have been used to give treatments, making a diagnosis, illness monitoring, self-management, or promoting healthy lifestyle behaviours, as an isolated system from the existing health information systems. In the study of Ventola [140] noted that 24% of health apps are used as medical information, 22% is dedicated to the monitoring of the physical parameters, 18% to track diseases, 16% for education and management and 8% for diagnosis. The current capabilities of the health solutions lack semantic IOp and medical data ownership as stated in Table 3.3 for different application purpose in mHealth as categorised in Fig. 3.7. mHealth applications are classified into two main groups - clinical and non-clinical systems. Label a and b in Fig. 3.7, the area labeled c in Fig. 3.7 was added by the Committee on Evaluating Clinical Applications of Telemedicine (CECAT) in 1996 [141], Tulu and Samir [142] added the first three and

Olla [143] adds the remaining 2 in section d on the clinical axis, and the non-clinical axis has eight items.

Table 3.3: mHealth Solutions Capabilities

mHealth Challenges	Current Supports
Security Requirements	✓
QoS (e.g. guarantee of delivery)	✓
Semantic Interoperability	✗
Anywhere Availability	✓
Data Management	✓
Medical Data Ownership	✗
Affordability	✓

Marschollek et al. [144] investigated the progress in se-HIS and concluded that the focus was more on specific diseases and only a few studies identified explicit design of se-HIS or the integration of health enabling technologies into HIS despite the importance of the use of health-enabling technologies to improve care and health monitoring. The inclusion of the health-enabling technologies into HIS faces a real and specific problem of coordinated resources sharing and interoperable information in dynamic, multi-institutional, local, global healthcare organisations.

The sharing and interoperability that is of primary concern is the direct access to sensors, software, data, computers and other resources as required by a range of collaborative healthcare problem-solving and resource brokering strategies emerging in the healthcare domain. This primary concern was further classified by Robkin et al. [19] as shown in Table 3.4 and their conceptual framework was applied to medical devices.

The convergence of information communication technologies (ICT) and sensor technology has given rise to better opportunities to capture health-related parameters that could be used as a base for medical decisions. Health-related data will not only be coming from sensor system produced by same manufacturers and prescribed by physicians [145] but also from other sensor devices used by individual in their everyday lives such as (smart homes, smart phones, smart cars) [36] as the Internet of Things (IoT). The continuous monitoring and capturing of the vitals signs or parameters produce a new and valuable understanding of diseases's onset and subsequently,

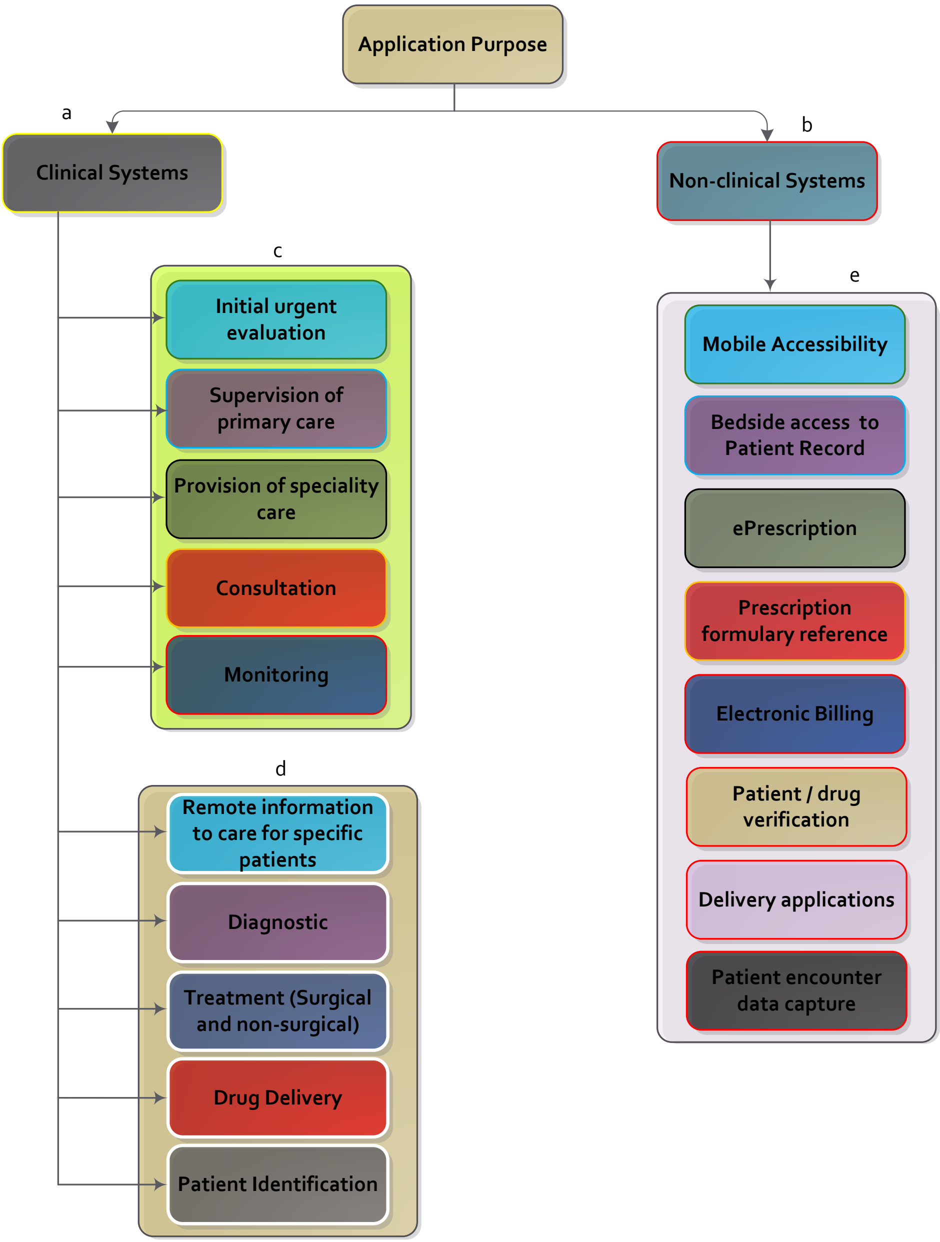

Figure 3.7: Categories of Application purposes in M-Health

therapeutic effectiveness on the individual. However, the analysis, transmission, and decoding of the huge amounts of heterogeneous data must be carried out automati-

Table 3.4: Levels of Conceptual Interoperability in Healthcare [19]

LCIM Level	Organizational Goal	Scope of Exchanged Data	Design Concerns	Result or Product of interoperability	Technical Implementation with Examples	Results from interoperability	Healthcare Implementation
6: Conceptual	One system of interoperable components	Purpose, Goal, or Desired State; Business, Quality, and Engineering Processes	Processes, assumptions, constraints, metrics, feedback, controls	Shared Conceptual Model between participant(s)	Development of a single fully integrated system e.g. ISO 13485	Development of components that can be assembled into a single system	A product possibly made up of components from different manufacturers
5: Dynamic	Using distinct systems with deterministic interactions based on each other's state	State Model: State + Context + Information + Meaning Data	Effect of exchanged data on sender and receiver	Shared States Transition Models	Workflow: e.g. Clinical Care Model standard of care	Safe, predictable Systems of Systems interactions for all states	Fully Deterministic, Reliable, Plug-and-Play Safe Interoperability
4: Pragmatic	The using, distinct systems for the same purpose	Context + Information + Meaning Data	Context = Use of information	Common Context and Workflow	Integration of two systems for a closely defined purpose e.g. Vital Signs Monitoring	Using the same Workflow and Process more than one system	Enterprise or Department HIT systems
3: Semantic	Use data the same way	Information + Meaning + Data	Meaning of data	Technical or Interface Standard	Definitions, Ontology, plus format e.g. SNOMED	Longitudinal / Historic Records	Data in EMR patient records
2: Syntactic	Use the same data records	Information + Data	Structure of Data	Data Format	Data Structure NFS hard drives	Data Records	Dedicated devices and applications
1: Technical	Using the same data media on different computing devices	Data (Bits and Bytes)	Transmission of Bits and bytes	Communication Protocol	Binary Field Description e.g. ASCII	Technical Infrastructure	Shared storage or communication protocols
0: None	No technical interoperability	None	Non-technical processes and knowledge	None	e.g. purely manual processes	None	Manual data input

cally. Therefore, interoperability between the wearable system and HIS will not only be the use of data in the same way but will also include the use of distinct systems for the same purpose thus establishing the context, the information and meaning of data. However, the notion of context has been studied in the area of Artificial Intelligence (AI) and it may be traced back to Waybrauch work [146]. The wearable sensors should be physically and technologically flexible to capture the subjects in their natural environment and provide a rich stream of information that will be capable of transforming the practice of medicine. Therefore, the rich information captured should involve the context of the physiological data obtained from the subjects. For example, chronic illness such as CVD can now be diagnosed and monitored at the patients'place of comfort or environment with the use of various body sensors. The sensors monitor vital signs in humans, such as physiological data e.g. blood pressure, body temperature, and pulse which are sensed through medical sensing sensors that automatically transmit the signal to a computer or a physician for further investigation or medical exploration. Sensors placed in the blood stream can continuously monitor, analyse and prevent coagulation and thrombosis of the blood [147]. Monitoring such as described above is usually carried out within the hospital, away from the home of the patient which impact the patient's physiological state. The effect is known as the "white coat syndrome"in which a patient's blood pressure increases when visiting a physician in the hospital, thereby given a false representation of the patient's blood pressure measure [148]. This monitoring enhances diagnosis and treatment. Therefore, for proper representation of the physiological parameters, there must be a contextual representation of the acquired data. For example, the frequency of the heart rhythm (irregular, too fast (tachycardia), too slow (bradycardia), too early (premature contraction) or too irregularly), can affect the interpretation of the heartbeat. Therefore, to better diagnose the causes of cardiac dysrhythmia, patients are asked to keep a diary log of their activities and symptoms [149]. As a result, the ECG signal is tagged by patient's activities context, and both of these data are transmitted to clinic physicians for diagnosis.

3.4 Contexts in SIOp

Many works in the area of context-aware computing field have attempted to define context in their studies. Previously, enumeration of examples was used to define context or by just choosing synonyms for context. Schilit and Theimer's work was the first to introduce the term context-aware, they referred to context as location, identities of nearby people and objects and changes to those objects [150, 151]. Brown et al. [152] define context as location, identities of identities of the people around the user, the time of day, season, temperature, among others, however, other studies gave examples of contexts rather than its definition such studies are:

- Schilit & Theimer‘s work - the first to introduce the term context-aware, they referred to context as location, identities of nearby people and objects and changes to those objects [150, 151].
- Brown et al. [152] define context as location, identities of identities of the people around the user, the time of day, season, temperature, etc.

- Ryan, Pascoe, & Morse [153, 154] define context as the user's location, environment, identity, and time.

- Dey [155] listed context as the user's emotional state, focus on attention, location and orientation, date and time, objects and people in the user's environment.

However, these definitions based on examples are difficult to apply. It makes it unclear to classify a new type of information as context or not, as these definitions do not help to decide whether a user's preferences or interests are context information. The other sets of definitions provide synonyms for context by referring to contexts as the environment or situation. Some considered context to be the user's environment, while others considered it to be the application's environment. For example:

- Brown defines context to be the elements of the user's environment that the computer knows about [156].

- Franklin & Flaschbart see it as the situation of the user [157].

- Ward, Jones, & Hopper view context as the state of the application's surroundings [158].

- Rodden et al. define it to be the application's setting [159].

- Hull, Neaves, & Bedford-Roberts include the entire environment by defining context to be aspects of the current situation [160].

These definitions based on synonyms are general than enumerations and limited in its generality, because it provides little guidance to analyze the constituent elements of context, much less, to identify them. Therefore in other to establish a contextual requirement in the se-HIS information for the sake of systems interoperability a more operational definition to be drawn. The definitions by Schilit, Adams,and Want [150], Dey, Abowd, Wood & Pascoe are the only ones closest to the operational definition we seek for in our work.

Schilit, Adams & Want [150] claim that the important aspects of context are: where the user is, who the user is with, and what resources are nearby. They define context to be the always changing execution environment, the environment is of threefold:

- **Computing environment:** available processors, devices accessible for user input and display, network capacity, connectivity, and costs of computing
- **User environment:** location, collection of nearby people, and social situation
- **Physical environment:** lighting and noise level

Although, in a se-HIS the context acquisition does not only entail what the user is trying to accomplish but also what the physician is trying to achieve (i.e. monitors the health of the patients correctly, and diagnose accurately). However, in the real world, most context may not be sensed automatically. Therefore, applications or the entire systems must rely on the patients to manually provide it. The relevance of how the patient's vital signs or physiological parameters are acquired should not impact it been seen as context or not. The primary goal of providing this definition of context is to offer guidance in identifying broad categories of context.

3.4.1 Categories of Context

One important feature of using the sensor (wearable computing)in monitoring patients health is the ability of the sensor to track the changes in its environment with a new class of applications that are aware of the context in which they are run [150]. More often than not, the original direction of research in wearable computing has been inward; that is to use sensors to make observations about the carrier, rather than to sense a phenomenon of interest (e.g. the context).

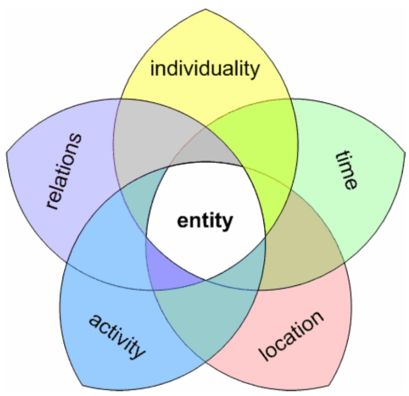

Figure 3.8: Five fundamentals Categories of Context Information [13]

In the work of Zimmermann, Lorenz, and Oppermann [13] context information is categorized into five main groups as shown in Fig. 3.8 namely: individuality, location, time, activity, and relations. Although, the works of Dey, Abowd & Wood [161] who represented individuality as personal context identified four essential categories as identity, location, status (or activity) and time.

3.4.2 Context Awareness in Semantic Interoperability:

The framework for interoperability at the semantic level supports the monitoring of any physiological parameters which is studied in Body Sensor Networks have identified to be crucial; context i.e. environment of the person being monitored is in when interpreting these parameters. The five W's of context are identified as; who, what, where, when, and why as shown in Table 3.5.

Table 3.5: The Five W's of Context

No	The Five W's of Context	Descriptions
1	Who	The identity of the user or other people environment
2	What	Human activity and interaction in current systems
3	Where	The environment within which the activity is taking place
4	When	Timestamp of the capture records
5	Why	Affective states and intention

Table 3.5 Considering context in context-aware applications Pascoe in [162] concentrated on the following:

- Contextual Sensing: the ability to detect contextual information and present it top the user to augment the user's sensory system;
- Contextual Adaptation: the ability to execute or modify a service automatically based on the current context;
- Contextual resource discovery: allows context-aware applications to locate and exploit relevant resources and services; and
- Contextual augmentation: the ability to associate digital data with the user's context in such a way that a user can view the data when he is in the associated context.

Pascoe [162] considerations are evident in some of the taxonomy proposed by Schilit et al. [150]. In the work of Dey & Abowd [163] context is defined as:

> *"Any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves".*

In addition to location and identity, activity and time were added to their context categorization, and context-awareness was defined as:

> *"A system is context-aware if it uses context to provide relevant information and or services to the user, where relevancy depends on the user's task".*

Therefore, the general definition of a context-aware system is related to the issue of whether the system can extract, interpret and use contextual information and adapt its functionality to the current context of use, as illustrated in table 3.6 showing the main consideration for designing a context aware systems. For the purpose of wearable, the main emphasis of a context-aware design is concerned with the interpretation of physical and biochemical signals acquired and their association with the ambient environment. The contextual information is therefore mainly focused on the user's activity, physiological states, and the physical environment around the user. In the case of the healthcare domain, the environmental context includes location, proximity, time, social interaction, and connectivity information of the healthcare environment. The user–centred context, on the other hand, includes physical action, cognitive or mental activities, and affective states.

3.4.3 Individuality

Individuality is the category of contextual information that gives the entity the context which is bound to. An entity can be an individual, or groups, that share common aspects of the context. Entities can behave differently within a context-aware system or obtain different roles, for example, the vital signs of the patients collected from the arm may be distinct from the vital signs collected from the upper body (chest). Individuality Context information is further divided into four entity types according to Zimmermann, Lorenz, and Oppermann [13] : natural, human, artificial and group entities.

- **Natural Entity Context:** This kind of context includes all living and non-living things that occur naturally, and are independent of human activity or intervention for example plants, stones and other things relating to nature without any artificial add-on. Also, the product of the interaction between nature and humans is part of this category as well.

- **Human Entity Context:** The characteristics of humans beings are covered in this category. Heckmann provides a detailed view of the features that are taken into account in this category in the General User Model Ontology (GUMO) [164]. The primary user's properties such as preferences in language, color schemes, modality of interaction, menu options or security features and numberless other personal favorites.

- **Artificial Entity Context:** Every entity that are products or phenomena which are a result of human, technical processes arr included in the category of artificial entity context. The artificial entity context covers descriptions for human-built things like buildings, computers, vehicles, books, and much more. It also includes computing hardware descriptions for devices such as laptops, personal assistants (PDAs) or smart-phones, features like a screen or display size, the bandwidth or reliability of the available network connection. All sensors that measure physical or chemical properties (like temperature, humidity, pressure, sound, lightness, magnetism, acceleration, force, and much more) are also artificial entities.

- **Group Entity Context:** this is the category that contains a collection of entities, with same characteristics, and they interact with one another or have established certain relations between each other. The main focus of using groups is to structure sets of entities and to capture characteristics that only emerge, if entities are grouped together.

3.4.4 Time Context

In capturing the patient's vital signs via the wearable units time is critical to the physician understanding and classification of the context, because most statements (data–sets) are related over the temporal dimension [165]. This category includes time information as the time zone of the patient, the current time or any virtual time. Using the more straightforward representation such as Central European Time (CET) format facilitates mathematical calculations and comparisons, also the context model enhances the ability to represent intervals which constitutes an important role.

In patients health monitoring consistencies in capturing and storing context or situations creates data pool of the history of obtained contextual information. This history forms the basis for accessing the past context information, analysing the interaction history, inferring usage habits of the users and predicting the future contexts.

3.4.5 Location Context

The advent of wearable computing devices has brought location as a parameter in context-aware systems. It is more than the two-dimensional space; it expands to include elevation and orientation of the entity. The physical objects and devices are spatially arranged, and humans move in mobile and ubiquitous computing environments: this task includes mobility. This category describes location models that classify the physical or virtual residence of an entity, as well as, other related information like speed and orientation [166].

Furthermore, a location may be described as an absolute location (meaning the exact location of something) or as a relative meaning the location of something else. Models for physical location are classified into two categories: quantitative (geometric) location model and qualitative (symbolic) location models [167].

- **Quantitative Location Models:** This refers to coordinates with two, two and a half or three dimensions. For example, the two-dimensional geographic coordinate systems express every location on the earth in the format of degrees, minutes and seconds for longitudes and latitudes. The Global Positioning Systems (GPS) supply the location information through measuring distances or angle to known reference points and translating these relative positions to absolute coordinates.

- **Qualitative Location Models:** this category includes spatial information such as buildings, rooms, streets, countries, etc. that depicts a mutually nested relationship. Stahl & Heckmann investigated spatial concepts and models and propose hybrid location modelling approach [167].

3.4.6 Activity Context

According to Dey & Abowd [161] this category identifies intrinsic characteristics of the entity that can be sensed. In the works of Zimmermann, Lorenz & Oppermann [13], they described activity by means of explicit goals, tasks, and actions. An entity usually engaged in a task that determines the goals of the performed activities [168]. For a place, this can be the current temperature, or the ambient light or noise level. For a person, it can refer to physiological factors such as vital signs or tiredness or the activity the person is involved in such as reading or talking.

3.4.7 Relations Context

This category of context information captures the relationship between entities; it is the relationship between an entity and surrounding entities which can be persons, things, devices, services, or information (for example text, images, movies, sounds). The set of all the relations of the entity builds a structure that is of the entity's context. The features of an entity's environment (i.e. presence and the arrangement of other entities) are majorly determined by the spatial and temporal context of this entity. The relation category is subdivided into social, functional and compositional relations:

- **Social Relations:** This subcategory describes the social aspects of the current entity context. It is the interpersonal relations which are social associations, connections or affiliations between two or more people. For example, social relations can contain information about co-workers, relatives friends, neutrals, and neighbors.

- **Functional Relations:** This indicates that an entity makes use of another entity for a certain purpose and with a certain effect, for example, the transformation of input into a particular output.

- **Compositional Relation:** This is the whole-parts relationship, in the case where the object is destroyed, the parts seize to exists.

3.4.8 Context Formalism

Human knowledge is presented informally, predominantly in natural language whereas to represent knowledge in computing, people use formal languages; which have a well-defined syntax and an unambiguous semantics, and support formal methods, specifically reasoning. In the investigation of Ratnesh et al. [169] established four states of the art approaches to semantic interoperability in the health care and life sciences systems which are:

- **Logic for context:** The notion of context is mainly concerned with the representation and use of information, and this concept has been used to account for the context of validity of information by Kleer and the efficiency of reasoning in a more narrow context by Guha. In John McCarthy's work, he investigated the idea of marking the dependency of propositions on context and track the dependency through changes of context and stages of reasoning. The step involves moving from a (simple) proposition to the (meta) proposition that the proposition in question is true in a context. Context is made the first class object in the domain that can be quantified, be the range of function and so on. However, Akman & Surav demonstrated that it is quite difficult to provide an adequate model theory and tough to compute with it as shown in Table 3.6.

  According to John McCarthy:

Table 3.6: Logic for contexts

ist	(c, p)		—	1
ist	(c, p)		—	2
ist	(p, c)	$\Rightarrow ist($ d, p)	—	3

1 = for proposition p and context c
2 = the context obtained from c by assuming p
3 = expression of the consequences of context change

- **Contextual Reasoning Local Model Semantics:** this is a new semantics, called Local Models Semantics. It is mainly concern with reasoning with context. LMS was proposed by Fausto Giunchigilia [170] following their argument that people do not exhaust their knowledge in the attempt to solve a problem rather they construct a "local theory" where each independent theory is related to some particular domain knowledge. Therefore, in LMS context is a theory of the world that encodes an agent's perspective of it and that subset is used during a reasoning process. Reasoning will then be carried out locally on a single context and is shared only via explicitly specified connections, following the principles of locality and compatibility. However, Serafini et al. proposed refinements of LMS to realize distributed reasoning framework.

- **Standard Approach - OWL:** The Web Ontology Language (OWL) [171] is an expressive language based on description logic (DL), through which semantic interoperability between systems in the health care and life sciences has been improved. Ontology-driven systems are systems that make use of explicit and formally defined ontologies; these ontologies could either be local or global or both.They are useful for integrating multiple data sources and for zooming on data cube dimensions [172].

  However, when reasoning is performed across different ontologies (local or global), these ontologies share a single and universal interpretation domain, thus indicating that representing and reasoning contextual knowledge is outside the scope of OWL semantics [173, 174]. OWL solution to interoperability provides an import feature through its property owl:imports, that helps to modularly integrate several domain ontologies. For example if Hospital A has a local ontology that imports RIM and LOINC (Global Ontologies), the axioms of these ontologies are automatically made part of Hospital A's ontology. In a case where Hospital A wants to Inter-operate with Hospital B with a different local ontology, then the concepts and properties of teh two hospitals are modeled differently, although, correspondences can be identified and expressed in OWL.

Table 3.7: Extract of OWL supported mapping

Class:	(foaf:Person)	**SubClassOf**:	(rim:entity)
Class:	(HospA:OrderAct)	**SubClassOf**:	(rim:Act)
Class:	(rim:playedRoleIn	**some** rim:RolePatient)	**EquivalentTo**:(HospA:Patient)
Class:	(HospB:LabTestOrder)	**EquivalentTo**:	(HospA :OrderLabObservation)
Class:	(HospB:HemoglobinTest	**and**	(rim:measures **some** Ionic:_4548-4))
EquivalentTo:	(HospA:BloodSugarTest	**and** (HospB:hasCode	**some** snomed:_43396009))
EquivalentProperties:	(HospB:first_name)	(foaf:	firstName)
EquivalentProperties:	(HospB:hasMedication)	(HospB:	hasTreatment)
Instance:	(HospB:Sean)	**sameAs**:	(HospB:3456781E)

Table 3.7 shows the axioms that should be added to make the two systems interoperate. Note that these mappings relating terms in two different contexts cannot be distinguished from mappings between terms of imported ontologies within one context. Rector et al [95] have argued the method above (Table 3.7) to be the only possible way to deal with heterogeneity which fully complies with the established semantic web standards when compared to previous standards such as HL7. Therefore, OWL is limited in addressing the issues of global ontologies versus local ontology as it can not differentiate between the two ontologies after mapping them together especially the sub-parts. Also it can not handle context of an axiom or term of individual ontologies in the newly mapped ontology.

- **Distributed Description Logic (DDL):** In other to formalize contextual reasoning with description logic ontologies, Borgida & Serafini [175],propose the distributed description logic (DDL) formalization method. In their proposition indices $i \in I$ are used to determining the context of an ontology or an axiom from the source. For instance according to their proposition, an axiom i $C \sqsubseteq D$ from source ontology O_i, the DDL uses the prefixed notation $i:\ C \sqsubseteq D$.Also cross-context formulas are been defined to relate different terminologies using the bridge rules. The bridge rule is written either as $i : C \xrightarrow{\sqsubseteq} j : D$ or $i : C \xrightarrow{\sqsupseteq} j : D$ where i and j are two different contexts, and C and D are terms from the contextual ontologies O_i and O_j respectively. Therefore, in bridge rule such as $i : C \xrightarrow{\sqsubseteq} j : D$ (resp. $i : C \xrightarrow{\sqsupseteq} j : D$) will be understood to mean: from the point of view of O_j (i.e.in the context of $_j$, C is a subclass (resp. super-class) of D. The strength of this approach is its ability to identify context, a better robustness on heterogeneity, improved modularity. However, it still does not address the issue of different policy at various sites or hospitals.

- Other Contextual Reasoning formalism
  - Package-based Description Logic:
  - Integrated Distributed Description Logic
  - $\mathcal{E}$-connections:
- Context in Semantic Web technologies
  - Models provenance
  - Contextual RDF(s)
- Other formal handling of heterogeneity
  - Database-Style Integrity Constraints for OWL
  - Modular Web Rule Bases
  - Query-based Data Translation
  - Reasoning with Inconsistencies

Scenario 1 : Class: **(foaf : Person)** SubClassOf: **(rim : entity)** Class: **(hospitalA : OrderAct)** SubClassOf:**(rim : Act)** Class: (**rim : playedRoleIn** some **rim: RolePatient**) EquivalentTo : **(hospitalA : Patient)** Class: **(hospitalB : LabTestOrder)** EquivalentTo: **(hospitalA :OrderLabObservation)** Class: **(hospitalB : HemoglobinTest)** and (**rim:measures some Ionic: _4548-4**) EquivalentTo : (**hospitalA: BloodSugarTest**) and (**(HospitalB: hasCode some snomed: _43396009)**) EquivalentProperties : (**hospitalB : firstname**) (**foaf : firstName**) EquivalentProperties : (**hospitalB : hasMedication**) (**hospitalB : hasTreatment**) Instance : (**hospitalB:sean**) sameAs : (**hospitalB:3456781E**)

The system designed to capture or acquire health-related parameters from its users without interfering in their day-to-day life for further transmission of data to a healthcare provider for further action(s) and does not need maintenance is known as se-HIS [176]. The system describes still sound like fiction, but at the rate technology is advancing in the last decade it is very close to realisation. Marschollek et al. [15] proposed an improvement scheme to organise sensors for health-related parameters using a scheme consisting of four axes - mobility, connection, measured property and measurement process [15] as shown in Fig. 3.9

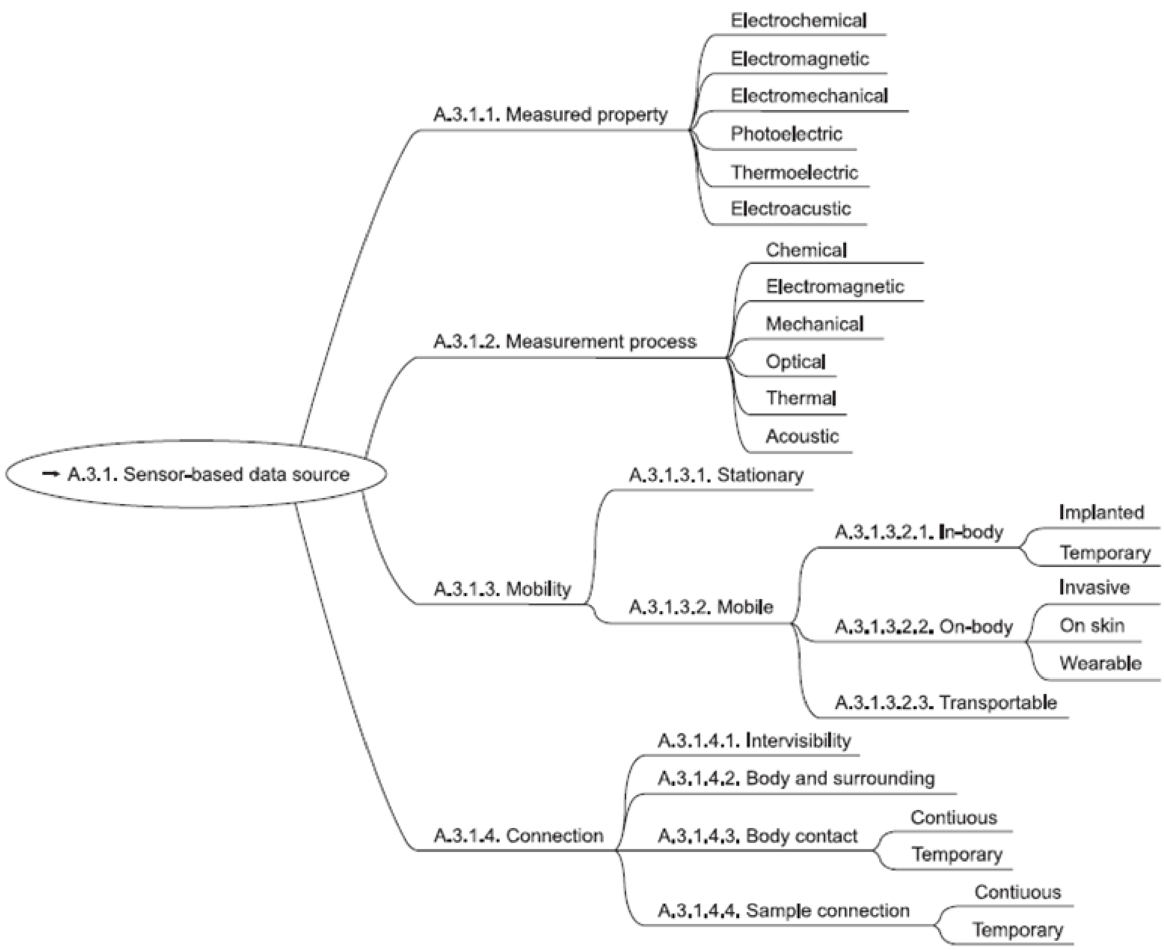

Figure 3.9: The context axis (A) of the nomenclature proposed in [14] and as modified by [15]

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In a se-HIS the data sources will be heterogeneous not only at the manufacturers base or the physicians prescribing them; but also at the patient's base,while data sources will include devices in daily use, worn or carried around on individual basis such as cars, smart homes, smart-phones among many others. The proliferation of sensors in collecting and computing health-related parameters that can facilitate right and faster medical decisions at a cheaper cost in larger cohorts, the management of data is an issue.

3.5 State-of-the-art Approaches to SIOp in seHIS

This study used the methods discussed in section 2.5 to examine the various methods, technologies and architectures that are utilised to solve SIOp problems existing in the Sensor-enhanced Health Information Systems (se-HIS). Attempts have been made to bridge the semantic gap using different techniques and services. A literature review over a period of five years between 2012 and 2017 was done to establish the various methods, services and technologies which have been used to solve the SIOp gap in the data from sensor systems to HIS, our finding is recorded in Table 3.9. The inherent plurality of data sources poses a challenge to existing classical approaches developed for the management of information systems, thereby, making the existing HIS insufficient for emerging se-HIS [15]. Several attempts to attain semantic interoperability and knowledge representation in natural language, information models, clinical repositories (databases), depends on agreements about the understanding of the so-called "concepts" stored in terminology systems such as nomenclatures, vocabularies, thesauri, or ontologies.

State of the art in this area of interoperability is approached from different perspectives. The existing formal approaches focused primarily on McCarthy's [177] and Guha's [178] approach on the one hand and Giunchiglia et al. [170] on the other hand. However, the involvement of stakeholders, such as hospitals, healthcare standards, pharmacy, patients, multiplies the integration complexity of this domain. Therefore, there is need for logical aggregation of information, intelligent processing, synthesis and analysis, and development of knowledge systems that can serve such purposeful end, whereas in the past, researchers have tried to formalize and integrate knowledge bases in health care and life sciences systems with record success that are centralized and limited to the sub-domain or particular application of healthcare domain.

The issue is also applicable to the technical aspect of the information systems as many data captured might not be for health-related uses and medical exploitation may often be a by-product. The current approaches to se-HIS, reveal that se-HIS address specific medical conditions or problems, therefore, the implementation of the information systems includes only the necessary parts, while the remaining were left out, however, Marschollek in his study identified three crucial parts for a complete se-HIS [36]:

- **Person-centeredness:** the Se-HIS were not expected to be institution centered rather it should be person-centered care architectures that can accommodate multi-data sources [35, 179]. Although, the shift towards person-centered records will compromise data security rules and measures, for example, Gomez et al. [180] presented the use of authentication methods to overcome the security challenge.
- **Standardization:** this is crucial in se-HIS, devices interfaces [181], data representation, information [182, 183] and decision logic [184] should be standardized.
- **Multi-modal mass data analysis:** in the works of Bardram [179] he admitted the importance of data fusion and reduction with efficient analytical techniques to extract relevant information from the multiple heterogeneous data from different sources and probably different quality.

Generally, across literature, there are three main approaches proposed to resolve the issue of interoperability in HIS. The methods are; standards-based approach, archetype, and ontologies.

3.6 Standards–Based Approach to IOp

The primary focus of works by standard organizations such as the Institute of Electrical and Electronics Engineers (IEEE), the International Electrotechnical Commission (IEC), the International Organization for Standardization (ISO), the European Committee for Standardization (CEN), the American National Standards Institute (ANSI) among many others around the world is both for commercial and private needs [96, 185, 186]. Standards are sets of consistent specifications expected to be shared by all parties manufacturing the same products or providing the same services which are supposed to be rooted in the consolidated results of science, technology, experiences and aimed at promoting optimum community benefits [187]. They may be derived from different processes, but in most cases, they are results of the voluntary process initiated by principal actors in a domain to bring order, clarity and to establish a common base for development.

In time past standards have been dominated by the suppliers until recently that the development of standards is under pressure from end users (the consumers) or is even initiated by them as the case is nowadays for Health Information Technology (HIT). A caveat is raised for the use of standards as an inhibitor to novelty and new products in the markets. In se-HIS many standards have been established by the various organizations and from the combined efforts of others. The standards that are of importance and consequences in se-HIS and are related to our universe of discourse are the followings:HL7, Digital Imaging Communications in Medicine (DICOM), IEEE11703, IEEE P1157,and ISO/IEC/IEEE 21451.

3.6.1 Health Level Seven (HL7)

HL7 [20] was founded in 1987 by several vendors of software for the healthcare industry, with the assistance of academics and major Health Maintenance Organizations. Their goal was to develop consensual message formats to facilitate better interoperability within and between Hospital Information Systems (HIS). In 1994, HL7 was accredited by ANSI as an SDO, meaning that HL7 approved specifications automatically channeled into the formal, global standardization process as formal American National Standards. Version 1.0 of the "HL7 Standard" message specifications was approved in 1987 and was followed by version 2.0 in 1998, summary of literature that proposed HL7 for interoperability is in Table 3.8.

Subsequently, version 2 has itself evolved through a succession of modified releases. It still forms the basis for the many HIS systems implemented in the US and many European countries. Version 3 message specifications use a formal Message Development Framework methodology, employing what is called the Reference Information Model (RIM), which developed to help make messages more consistently implemented than they are for Version 2 [21]. The RIM is now a major focus of current interest in HL7. The large task of forming an object model of core building blocks for all health

Table 3.8: HL7 Standards in SIOp

Authors(Year)	Standard	Platform	Disease and specific care
Brugues et al. [188]	HL7	Mobile (Android) and Web	Diabetes
Peng [189]	HL7	Desktop	Diabetes
Gencturk, [190]	HL7	Web	Rheumatism
Franz et al. [191]	HL7	Mobile (Android)	Cardiac and vital signs
Song et al. [192]	HL7	Mobile (Android)	A limited data group
Moraes et al. [193]	HL7	Not Specified	Only read sensors
Zhang et al. [194]	Not Specified	Cloud	Not Specified

information is now considered by HL7 to be complete and mature enough to be recommended for productive use, even though the RIM, and specifically its documentation, have been found to contain several fundamental flaws [195, 196]. Nevertheless, the RIM (Fig.3.10) is accepted as an ISO Standard, without any successful implementations of the Version 3, HL7 standard built on its basis, in operational systems. The limitation of HL7 are majorly in its inability to provide or supports the followings:

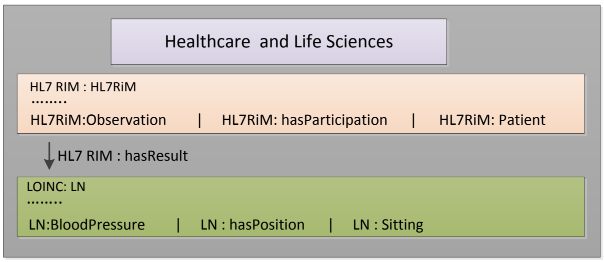

Figure 3.10: Technical communication overview [16]

- **Security or Access control:** The HL7 does not provide any means to enforce security or access control for user's security policies and does not support specific encryption method, which is an essential feature in the sensor domain from the perspective of the patients.

- **Privacy of Confidentiality:** In HL7 the patient's privacy and confidentiality are not protected, also the usage of the data at the source, or the destination of the message is not addressed.

- **Accountability / Audit Trails:** The transaction processing features needed in the users environment is not defined

3.6.2 Limitations of HL7 Standard

The HL7 alone has two versions: version 2 and version 3, which has interoperability gap, within each version also there are interoperability issues between applications deployed on the same version. However, interoperability within version 3 applications is less critical compared to those based on version 2. The HL7 approach does not support sensor technologies as its components cannot accommodate the elements of the sensor for health monitoring, i.e. the streaming data from the sensor network. The HL7 version 2.5 is more suitable for streaming data. The streaming data from mobile patients, mobile devices and mobile sensors should be compatible with the HL7 for interoperability of systems, therefore,the HL7 standard cannot interoperate with the IEEE 21450 family of standards, due to the differences in their message formats.

In the study of Bicer et al. [197] standards-based interoperability has issues peculiar to the EHR standards including openEHR [115, 198, 199], HL7 CDA [20]:

- The reference information model of the EHR's does not contain specialized clinical concept, but has generic classes and it fails to address the issue of context.

- The information mapping reference models are not compatible between the target domain and the source domain of different ontologies due to differences in their reference information models structures.

Table 3.9: Different Approaches to IOp

Author(s)	Focus	Solution Proposed	Device(s) Focused on	HIS	Sensor	Year
Robkin	Interoperability	Conceptual Framework	Medical Devices	NO	No	2015
Tayur	Application Layer Inter-operabiltiy	Data Model framework ontology	IoT	No	Yes	2017
Andersen	Semantic Interoper-ability	Mapping ICE Archi-tecture to FHIR using standardised terminolo-gies such as IEEE 11073 Nomenclature Sensors and LOINC (Logical Observation / Identifiers Names and Codes)	Medical devices /HIS	Yes	Yes	2016
Andersen	Semantic Interoper-ability	DOR IEEE 11073 / HL7v2	CIS / HIS Medical Services	Yes	Yes	2015
Lex	Generic In-teroprability	Maturity model Standard-ization	eHealth	Yes	Yes	2015
Milosevic	Reference Ontology	HL7 SOA Healthcare On-tology (UFOS)				2016

3.6.3 The Institute of Electrical and Electronics Engineers (IEEE)

The American Institute of Electrical Engineers (AIEE) and the Institute of Radio Engineers (IRE) merged in 1963 to form the Institute of Electrical and Electronics Engineers (IEEE) [30]. AIEE primary focus was wire communications, light, and power systems while the IRE addressed wireless communication. These later constituted different committees to develop standards relevant in the context of semantic interoperability in healthcare such as:

- **ISO / IEEE 11703 (x73) standards:** This is referred to as x73; it enables communication between medical, and wellness devices and with external computer systems. They provide electronic and detailed electronic data captured that are client- related, vital signs information, physiological data and device's operational data [200].

It is fundamentally concerned with the interface between the medical devices (agent) and concentrator device, the latest version x73-Personal Health Devices [201,202], is based on the Optimized Exchange Protocol (ISO/IEEE 11703-20601) which defines the framework for making an abstract model of available personal health data in the transport-independent transfers syntax required to establish logical connections between systems and to provide the presentation capabilities and services needed to perform communication tasks. It defines device specializations for different medical devices (MD) (such as pulse oximeter, blood pressure, thermometer or weighing scale). However, it excludes the ECG device specialization, which specified a normative definition of the communication between basic personal electrocardiography (ECG) devices and managers [203, 204]. For example the standard consists of term codes, formats, and behaviours in telehealth environments restricting optionality in base frameworks in favour of interoperability with the definition of the common core of communication functionality for personal telehealth basic ECG using 1 to 3 -lead ECG devices. The ECG devices were further distinguished from diagnostic ECG equipment on support for wearable ECG devices, limiting the number of points supported by the equipment to three, which does not require the ability to annotate or analysing the detected electrical activity to determine known cardiac phenomena.

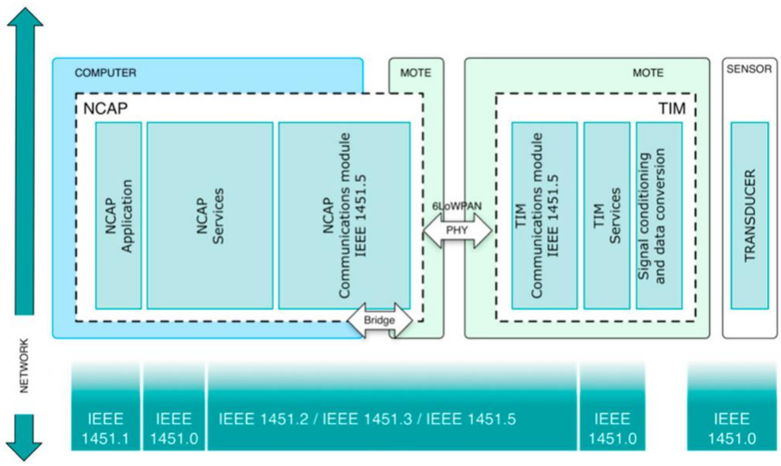

Figure 3.11: General structure of the IEEE 21451 prototype [16]

ISO/IEEE 11073-10406:2012 is consistent with the base framework and allows multifunction implementations by following multiple device specializations (e.g. ECG and respiration rate) while an amendment ISO/IEEE 11073-10406a is underway [205–207]

-

- **IEEE P1157, Standard for Health Data Interchange:** The Medical Data Interchange (MEDIX) Standards Project attempted to bridge the gaps between different islands of healthcare information through the agreed international standards for healthcare data interchange [208]. This specification initiated in 1987, at the time of initiation it comprised of active regional working groups in Europe and North America. The standards' scope encompassed all types of healthcare data interchange, inbounding the scope the fundamental spatial and temporal aspects of healthcare data interchange, as well as the kinds of information which are communicated, were put into consideration. As shown in figure **??**, Information from individual patients is gathered at the point of care and flows both horizontally and vertically [209] [210].

  Horizontally between various members of the team responsible for the patient's healthcare and vertically to organizational departments or units saddled with the responsibility for the increased population of the patient at large. In defining the scope of MEDIX, interoperability is the primary focus of users, which standards for healthcare data interchange must support different networking technologies, communication protocols, and data types. The MEDIX group, therefore, adopted an evolutionary approach to a common framework that is not unique to MEDIX but is an adaptation of current and emerging paradigms to the needs of the current changing and emerging healthcare environment.

-

- **IEEE 1451 family of Standards:** This standard is currently known as ISO/IEC/IEEE 21450 [24, 211] The 21451-x: 2010 focuses on a network-neutral interface for connecting processors to communication networks, sensors and actuators, it allows smart transducers and sensors designers to have reference to protocols, extensible messaging and presence protocol (XMPP), transducer electronic data sheets (TEDS), signal treatment, networks, web services, radio frequency identification among others. The object model contains blocks, services, and components; it specifies interactions with sensors and actuators and forms the basis for implementing application code executing in the processor. TEDS identifies everything about the transducer including the following: manufacturer, model number, revision code, serial number, device type and date code for transducers; timestamp on the unit calibration, the variable, type, and limits of use; calibration constants; signal conversion data model, model length, and number of significant bits; channel timing read / write setup time, sampling period, warm-up time,and update time; power supply requirements (voltage and current) and overhead: TEDS length and number of channels.

3.6.4 Ontology-Driven Interoperability

Ontology originates from philosophy and is traced back to, Aristotle who define it as a description of the world as exists. Several traces since the Aristotle description indicates works from Husserl, Kant, Frege and Carnap amongst others have described ontology, and it has since been associated with logic.Chira in [212] put succinctly in his review, the history and background of ontology, he clarified that when researchers are developing ontologies they use ontology-based meanings to represent their own understanding of the concepts in their particular field and for their particular needs. As defined in Chira ‘s review, he upholds the Artificial Intelligent (AI) perspective of an ontology stating that “Ontology is a specification of a conceptualization ”. Based on Chira review some of the definition are listed to give an overview of the depth and variety of definitions of ontology in philosophy, AI, knowledge and Information Systems.

- **In Philosophy :** Ontology is defined as “A branch of metaphysics concerned with identifying, in the most general terms, the kinds of things that actually exist. Thus, the ontological commitments of a philosophical position include both its explicit assertions and its implicit presuppositions about the existence of entities, substances or beings of particular kinds”.

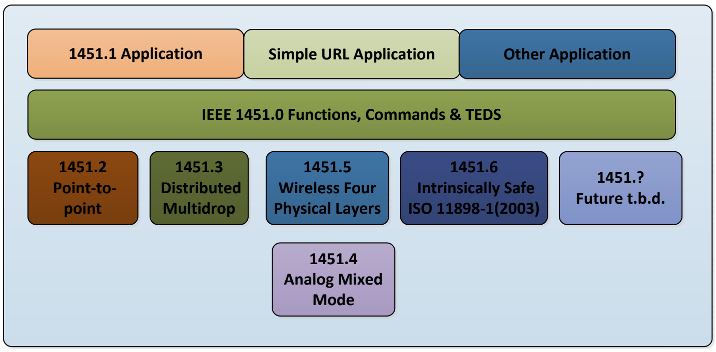

Figure 3.12: ISO/IEC/IEEE 1451.x family of standards

- **In Information Systems :** " An ontology is a software (or formal language) artifact designed with specific set of uses and computational environments in mind. An ontology is often something that is ordered by specific client in a specific context and in relation to specific practical needs and resources" , this definition is based on Smith work [213].

  Smith traced the the first time the word ontology was used in computer and information science to as early as 1967, which was recorded in the work of Mealy in [214]. In his work Meally proposed that the data model represents the real world and its ideas of how it exist in the minds of men, and how they were represented as 'symbols on paper or some other storage medium.

  Furthermore Smith observed that Proceduaralist believed the way to create intelligent systems was by instilling in to a system as much knowledge *how* as possible, whereas, Declarativist believed that the approach was to instill as much knowledge *what* as possible - in the form of knowledge representation. In the realm of database modeling, procedural knowledge is being captured via software programs and code (operational logistics, triggers and so on) while the data structures are representations of the objects and concepts. But to reuse and generalize the knowledge, one needs to build declarative representations of procedural knowledge as well.

Gruber in [215] defined an ontology as "an explicit specification of conceptualization.", though, a vocabulary is nevertheless needed to describe the universe of discourse, the advantage of Gruber's definition is that it makes the need for ontology to be explicit - publicly available and not embedded as part of any knowledge base systems. The advent of semantic web, gave more acceptance to Gruber's definition and it was further elaborated by Borst & Top in [216] as: "Ontologies are defined as formal specification of a shared conceptualization ". while Studer, Benjamin & Fensel [217] has combined both Gruber and Borst's definition as: "Ontologies are explicit formal specification of a shared conceptualization."Studer [217] has explained the term as follows:

- **Explicit:** The type of concepts used and the constraints on their use are explicitly defined.
- **Formal:** The ontology should be machine readable which includes natural lan- guage.
- **Shared:** Reflects the notion that an ontology captures consensual knowledge,that is, it is not private to some individual but accepted by a group.
- **Conceptualization:** "abstract model of some phenomenon in the world by having identified the relevant concepts of that phenomenon".

Noy & McGuiness [81] definition has given us an insight that is pragmatic in approach , their definition is based on their practical experience of developing both formal AI ontologies using different representation formalisms and tools as well. They defined Ontology as

> "A formal explicit description of concepts in a domain of discourse - classes (sometimes called concepts); properties of each concept describing features

and attributes of the concept - slots(sometimes called as roles and properties as well); and restrictions on slots - facets (sometimes also called as role restrictions) ".

Such agreement facilitates accurate and effective communication of meaning, which in turn leads to other benefits such as interoperability, reuse and sharing. Back to Guarino we see that he defines an ontology as: "An ontology is an explicit, partial account of a conceptualization". –Guarino & Giaretta [218]. Guarino [219] further explains his definition as: "An ontology is a logical theory that constraints the intended models of a logical language". He subscribes to the formal machine readable intensional description of the domain of discourse models as ontology.The terminological differentiation between the philosophical branch Ontology in with a capital 'O 'and "ontology knowledge engineering and AI perspective with a small 'o ', is now widely accepted. As seen, there is no clear consensus on the definition of an ontology in the context of Information Systems. It can range from being a formal logical theory to abstract conceptual models. For this research we uphold the definition of ontology to be as: "An ontology is an explicit formal conceptualization of a shared understanding of the domain of interest including the vocabulary of terms, semantics as well as their pragmatics".

3.6.5 Limitations of Archetype

The Archetypes are expressed using the Archetype Definition Language (ADL) which has four primary elements: the header, description, definition and ontology (terminologies). The header and the description are responsible for the general information about the archetype, such as the name language, author, or purpose. The definition segment contains the structure and constraints associated with clinical recording scenario defined by the archetype, while the ontology (otherwise referred to in ADL as terminologies) provides the textual descriptions for each element from the definition elements and binding to other terminologies. However, the current tools in the ADL communities have the weakness and are limited in achieving semantic interoperability. The resultant archetypes, therefore, lack the potential to attain semantic interoperability [220] as cited in [221] this is because the data, archetypes and the terminologies representation and exploitation cannot be performed in the same formalism thus limiting its effectiveness. The ADL technologies are further limited in detecting similar archetypes as it lacks support for automated reasoning on ADL-base contents, more ADL is not a clinical domain language.

3.6.6 LIMITATIONS of OBIS (Ontology-Based Information systems)

- Limitations in dealing with the requirements imposed by heterogeneous information systems
- Inability to distinguish between various types of knowledge used or exchanged between information systems.
- Knowledge expressed within any typical information system is commonly tied to a context (place, events, time) and their appropriate interpretation is scoped or limited to the background.

3.7 Requirements for an Ontology-Based Interoperability Framework

According to the literature review, the fundamental issues at the interoperability level are technical, syntactic, semantic and organizational. However, the one that has posed more challenges is the semantic interoperability, that is, the lack of transfer of meaningful data between the wearable and HIS with emphasis on context. However, in respect to the improvement and convergence of technologies with the emergence of sensors in health monitoring, the existing infrastructure does not support sensor enhanced HIS, thereby data acquired remotely from the patient are not easily integrated into HIS due to their peculiarities and inadequacy of context for the data captured.

Due to different Hospital policies on patient managements and drugs administration, there is also need for interoperability at the organization level especially in the area of policy. Therefore since the cases monitored by wearable devices may monitor different phenomenon. Therefore, it is necessary that the model that will support robustness in portability from one device to another should be developed as the solution to the sensor enhanced HIS integration, to facilitate similar semantics among the heterogeneous systems.

These criteria are emphasized and set as requirements for the development of the ontology base Se-HIS for interoperability framework. The roles of the ontologies are not only limited to improvement of the semantic definition of the captured data and integrated to improve or provides solution to the problems mentioned in the case study section,it also helps to preserve the integrity of the the captured data. The requirements for an efficient ontology-based application framework can, therefore, summed to the following:

1. The semantic description of data acquired from wearable devices should contain descriptive information about data captured, such as the user's identification, spatial information, that is, the framework must support contextual data.

2. The complexities of the semantics and its compatibility with HIS standards and or ontologies must be addressed.

3. The framework should be tolerant to the internal changes at the organization level, i.e., the framework must be effective on Hospital (local) policies regarding the treatments of the captured phenomenon.

4. The framework needs to be adaptable to the structure and the environment of the sensor/devices or the phenomenon been captured and transmitted to the HIS.

5. The framework needs to facilitate portability of interoperability of the semantic level during the integration of components to applications that have similar semantics in the case that the phenomenon is substituted.

3.8 Using Transducer Electronic Data Sheets for Ontology in Wearable Devices

The fundamental issue for this research is the creation of a model that will support semantic interoperability between sensors and health information systems. An attempt to use the existing ontologies revealed their inabilities to address all the issues that will facilitate seamless interoperability between the wearable and health information systems. Therefore, in other to create the abstract conceptualization of the domain that contains all relevant concepts that will support greater semantics, requirements, analytical requirement and policy differences between local health care providers.

Based on the requirements established during the requirement analysis stage, sensor ontology based on Transducer Electronic Data Sheet (TEDSOnto) framework was developed. The TEDSOnto provides the following

- Specific formalization based on OWL ontology to define the concepts that define an upper ontology for all sensors that are compliant with IEEE 21451 standard with TEDS.
- The association of wearable data to their contexts in user's applications
- A contextual process that enables the computation of activities as indicated in section
- The association of activity with the sensor location on the body of the patients/ users to capture the on-body location of the sensor for data captured.

This ontology contains all the concepts (OWL Classes) and their relation (OWL Data-types) as well as their relation (OWL Object Properties). The conceptualization is not based on one specific sensor application of wearable system, however, it relies on different sensors that are compliant with the IEEE 21451 standards, and they can be grouped together in one or more wearable, such as the heart monitoring wearable that can also monitor the activities of the users through accelerometer sensor.

3.9 Chapter Summary

This chapter discussed in details all the concepts, terminologies and approaches that are related to the focus of this study. The relationships between terminologies, domains and concepts were established as well as their importance. The factors that facilitates semantics when monitoring health through the wearable devices were addressed. This was quickly followed by the state of the arts technologies which has been proposed to solve the challenge of semantic interoperability between the wearable devices and HIS such as the use of standards and the use of archetypes. Ontologies as part of the elements of Archetypes, was thoroughly discussed and finally how to formalise an ontology that will facilitate knowledge representation that for efficient health monitoring was also discussed alongside it demerits.

4

Design and Development: Novel Framework to Support Semantic Interoperability in se-HIS

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4.1 Introduction

In this chapter, the study build on the various approaches that has been proposed to solve the issues of SIOp in se-HIS and proposed an ontology rich framework that is based on dual model approach having IEEE 21450-x and HL7 standards at its base. The stakeholder analyses was carried out to establish their various information needs using the Unified Modeling Language (UML) sequence diagram method, the ontology - standard based framework is finally presented and described.

4.2 Analysis of Stakeholders

The requirement analysis began by analyzing the stakeholders in the systems - the monitoring systems and the HIS, as illustrated in Fig. 4.1. The study focused on the on-body medical devices in its various forms (such as wristwatches, vest, smartphones) used for monitoring the health status of the users. The on-body devices as indicated in the diagram, for medical application was considered through its use in health-care which is further classified into outdoor and indoor environments to enable us to capture the contexts of the health parameters (Chapter 3 Fig. 3.7).

In Fig. 4.1 the leaves terminates at the stakeholder's axis for the on-body wearable devices. The axis of stakeholder enabled us to create the ontology for access levels and security levels in the policy ontology in the se-HIS framework, while the healthcare application axis: indoor environment contains entities that established the contextual ontology concerning the user's environment which could either be the user's home or hospital. The outdoor environment elaborates on the contextual entities relating to contexts such as an emergency situation and open area, for example, recreational centers.

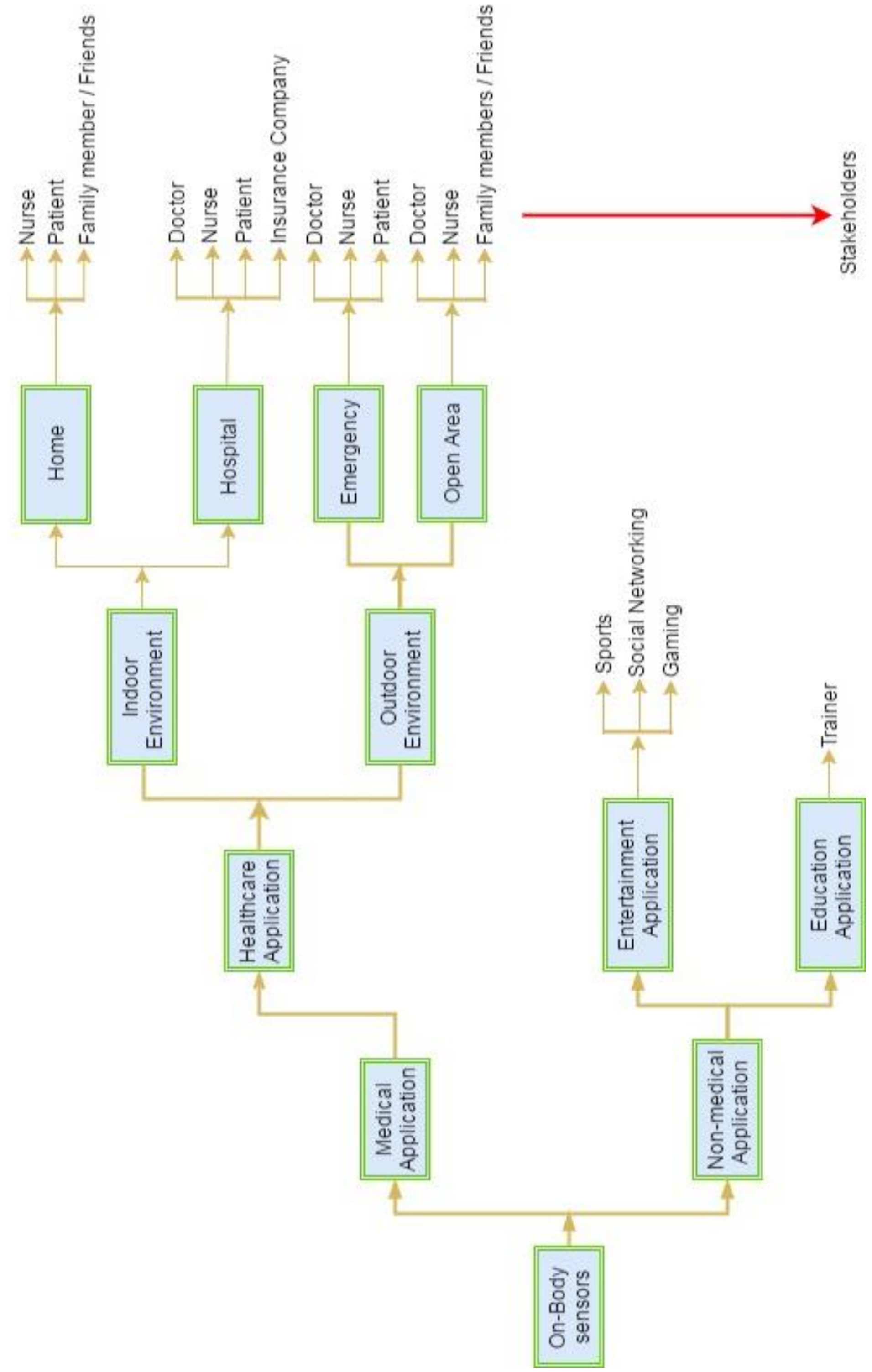

Figure 4.1: Stakeholders in Wearable Applications

4.3 Data Flow Model for se-HIS

This section described the development in details of the data flow model and how it supports the computation of semantics at the interoperability level in se-HIS. The model contains detailed data flows between the stakeholders and the body area network where the wearable devices are collecting data for semantic computation and for further transfer to the health information systems. According to Fig. 4.1,the health care application is categorised into open areas (shopping mall, offices, among others), emergency (emergency vehicles and emergency situations), homes and hospitals, the data flow between the wearable devices in an open area axis described the data flow between the stakeholders such as the patients, doctors, and medical servers while in the indoor environment it shows the data flow from patients to nurses as illustrated in architecture as shown in Fig. 4.2. Four scenarios was proposed in the system as described below:

- **Scenario 1:** The patient vital signs are continuously monitored and stored in the control unit (CU) database and may be published on request to the healthcare provider where the doctor can attend to patient's health information.

- **Scenario 2:** The doctor can issue a request to the medical server or connect remotely to the sensor on the patient via the Internet to get the patient's health information in real time.

- **Scenario 3:**The patient at-wills can publish his /her health information to the doctor for medical attention or advice.

- **Scenario 4:** The sensor system can alert the doctor in the case of an emergency after the patient's health status has reached a preprogrammed threshold.

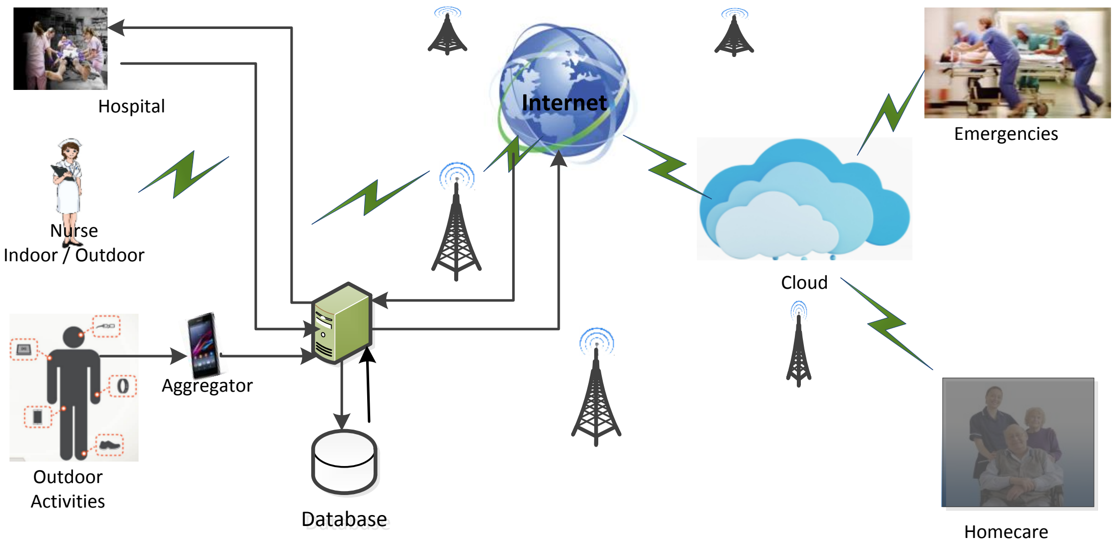

Figure 4.2: Health Monitoring Architecture

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4.3.1 Health Monitoring Data Flow Model

The Star Unified Modelling Language is used to design the data sequence in figure 4.3 to show the data sequence for proprietary wearable systems. The sensors collect the data at the prompting of the patient through the aggregator (smartphones). The aggregator can either send the data to its internal database and or push the data to the cloud account of the user, from where the data can be access for further utilisation at any time, however, in the existing systems the data are proprietary, and not detailed enough for an effective medical decision due to lack of context, but are saved in the patients cloud account.

The Data Flow Sequence (DFS) for Fig.4.6 is detailed in Fig. 4.4. It shows the stakeholders at each stage and the directions of data from the wearable system to the HIS at the healthcare provider's end. The patient push a request to monitor the vital signs, which is received by the sensor through the control unit (CU). The CU then transfers the captured data and its context to the aggregator, in this case, the smartphone. The smartphone is used to store the data locally, or it can be transferred to the patient's computer where is it stored for subsequent use. Also, the data can be sent through the base station to the Internet (using the Internet gateway server), the data packet is then transferred to the nearest base station to the medical server. The patient's vital data which complies with TEDS will then be mapped to the HL7 or Fast Healthcare Interoperability Resources (FHIR) for data compatibility and interoperability. The mapped data is sent to the HIS from where the nurse and the doctor can access it for further investigation. The doctor can access the data using the various available access levels, and he can also query the sensor for real-time data for further investigation as shown in the data flow model presented in the DFS in Fig.4.4.

4.3.2 Hospital data flow model

This model showed the detailed analysis of data flow between different parties in the hospital scenario where many patients with wearable devices or sensors being used to monitor their health status. Fig. 4.5 shows the complete processes, the data flow, the stored data involved and the external entities participating in the model. The model includes different users, such as patients, doctors, nurses, and other external parties (such as insurance company, pharmacist) they can communicate with one another within the same location using different technologies, access levels, responsibilities and privileges levels. Each patient has set of sensors attached to the CU to capture various physiological parameters and their contexts for sending and receiving person data to the hospital shared network. Based on the different roles and policies that are introduced or may be introduced, the doctors, nurses, next of kin, and the insurance company have different privilege levels and instructions about who has access to a particular medical data. For example, the doctor can publish a new event from inside / outside the hospital, but the nurse can only access medical data only at the hospital environment. The CU sends a request to the body sensors to obtain new physiological data from the patient. It also collects personal data from the patients, vital signs from the sensors, the description of the sensor, the functionality of the sensors and all these are stored in the database and forward the requested data to the medical server.

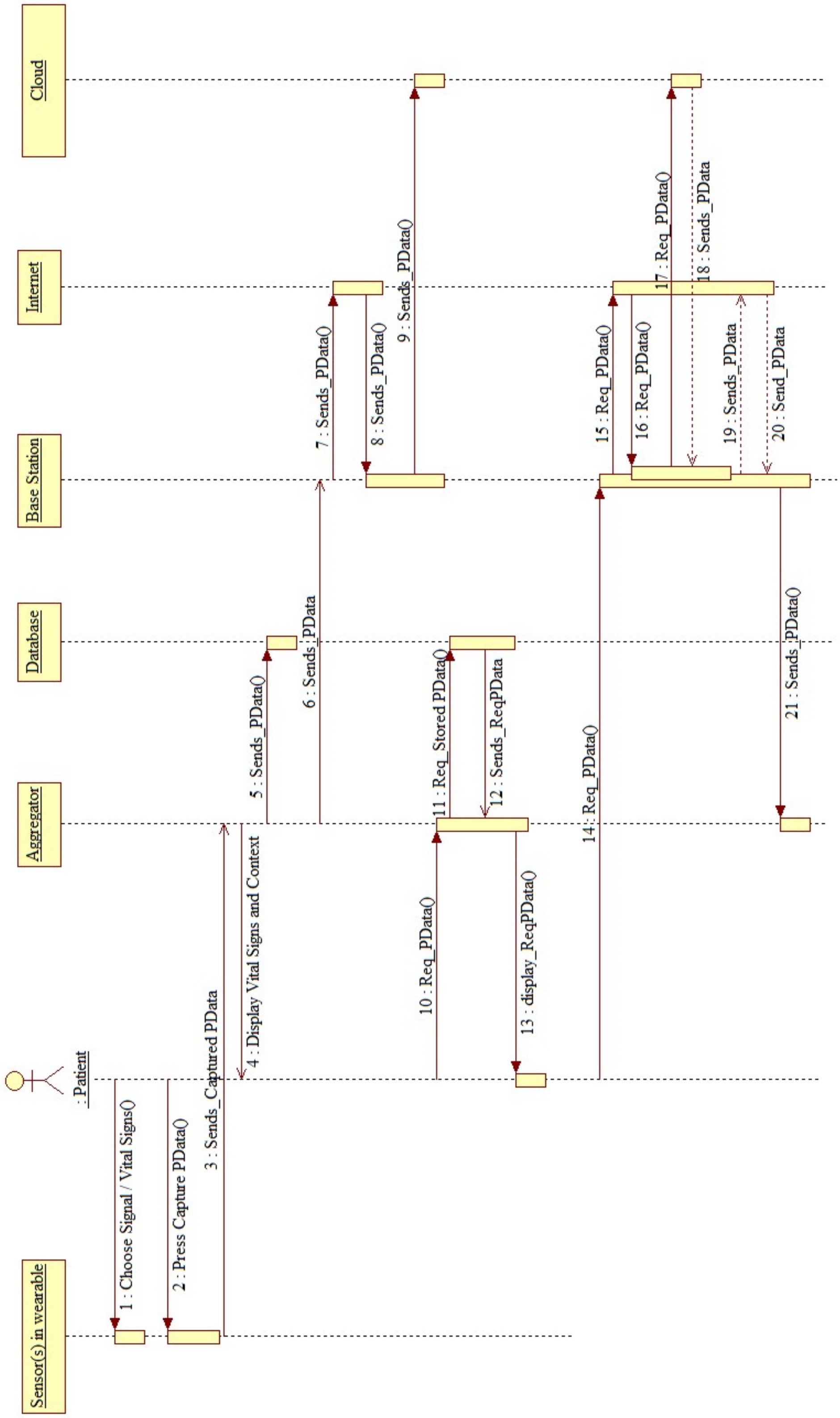

Figure 4.3: Data Sequence for Existing Monitoring Devices

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4.4 Case Study: Cardiovascular disease (CVD) monitoring using wearable devices

Cardiovascular disease (CVD) are the major cause of death globally and more people die annually from it than any other disease [222]. CVD such as severe myocardial ischemia (acute myocardial infarction), heart failure [223], and malignant arrhythmia have a direct relationship with Electrocardiogram (ECG) signals [224], although other measures could help diagnose CVD such as serial blood pressure measurements. The monitoring of such measures are usually carried out within the hospital, away from the home of the patient, and it impacts the patients'physiological state. The impact is known as the “white coat syndrome”in which a patient’s blood pressure increases when visiting a physician in hospital for blood pressure measurements. This syndrome results in a false representation of the patient’s blood pressure measure [148], however, the blood pressure monitoring enhances better diagnosis and treatment for CVD conditions.

The early diagnosis and treatment can not be over-emphasized in the case of CVD, aside the early detection using ECG for prompt treatment: there is the need for continuous monitoring using the 24-Hour ECG Holter. The ECG measuring device is used to keep track of patients’ heart rhythm, while they go through their daily activities by capturing information about their heart functions during every activity for twenty-four hours away from the hospital to overcome the "white coat syndrome." The captured measures guide the therapy to avoid complication leading to atrial fibrillation [18], once patients are diagnosed with hypertension, their pressure monitoring is carried out on a regular basis, and they may have several alterations on their pharmacotherapy. All these and other information on the care and treatment of the patients led to the implementation of Wearable System for Health Monitoring or what is referred to in the commercial domain as Wearable System . Wearable System is the information systems that is responsible for obtaining, processing, storing, retrieving and the transfer of information that are needed by the healthcare professional for accurate diagnosis and treatment of their patients. The physician takes several notes varying from notes such as: history, physical examination, electrocardiograms signals, and reports from investigations and procedures.

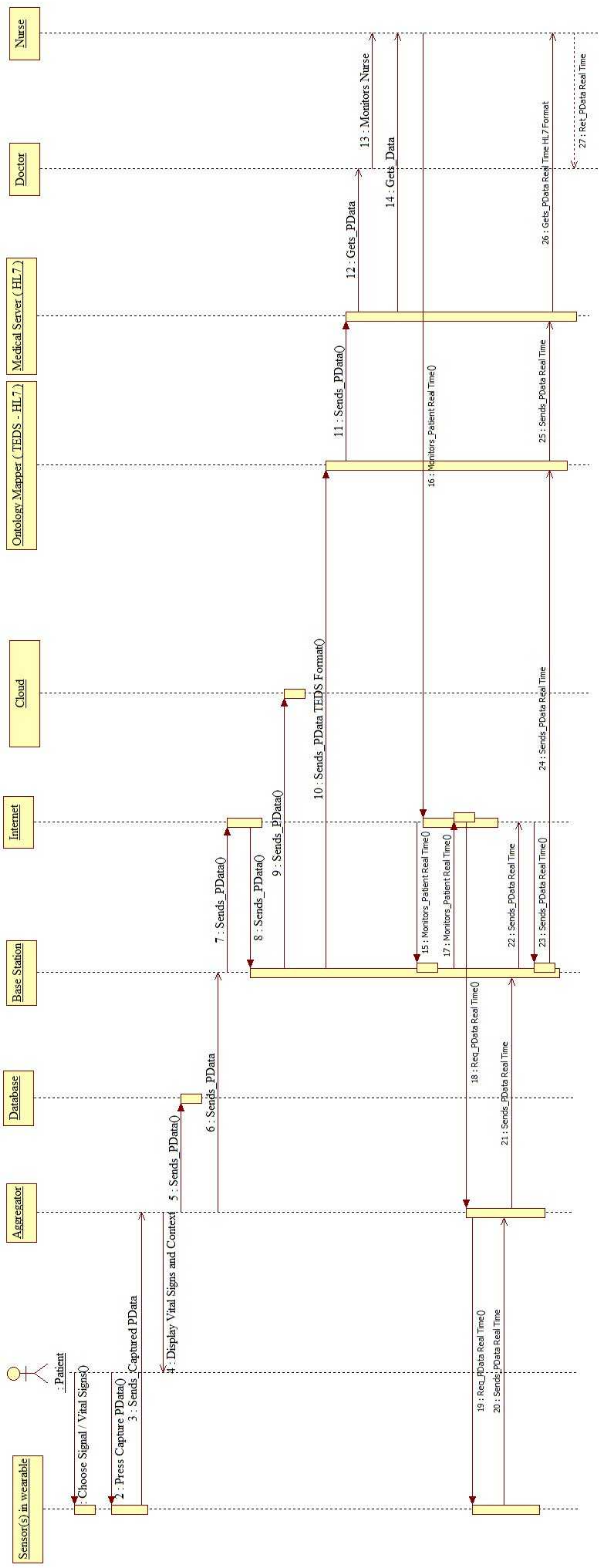

Figure 4.4: UML Sequence Diagram for Proposed SIOp-Se-HIS

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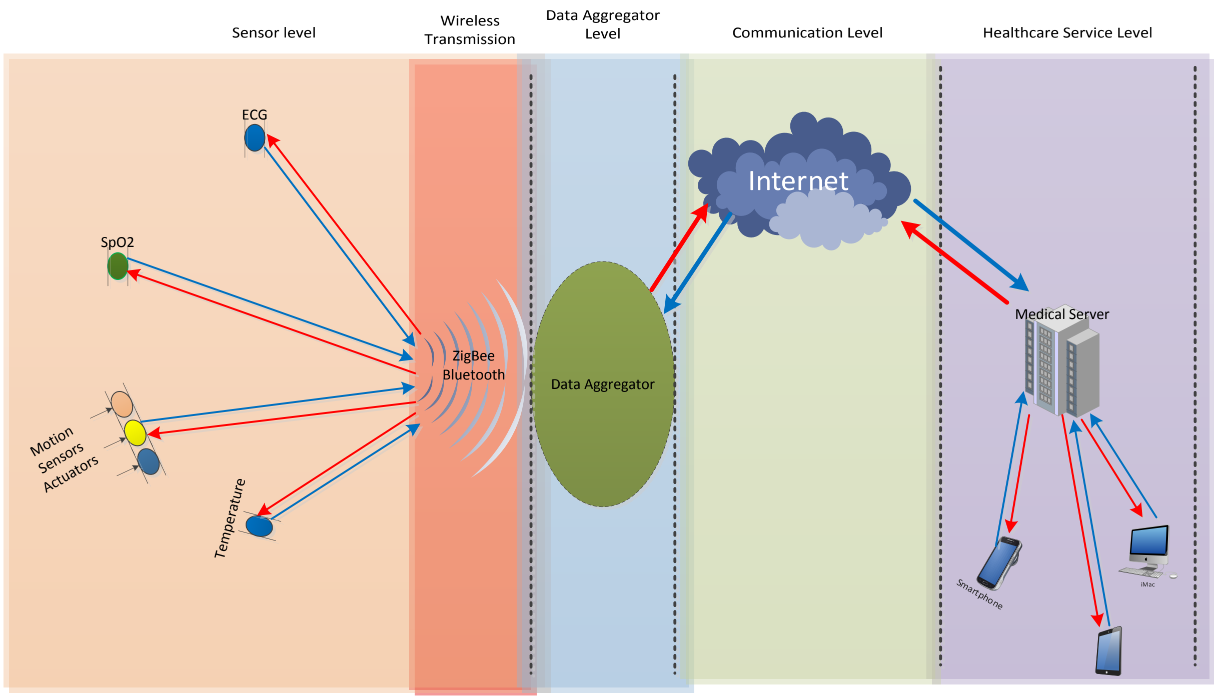

Figure 4.5: Data Flow Diagram for Sensors in within Hospitals

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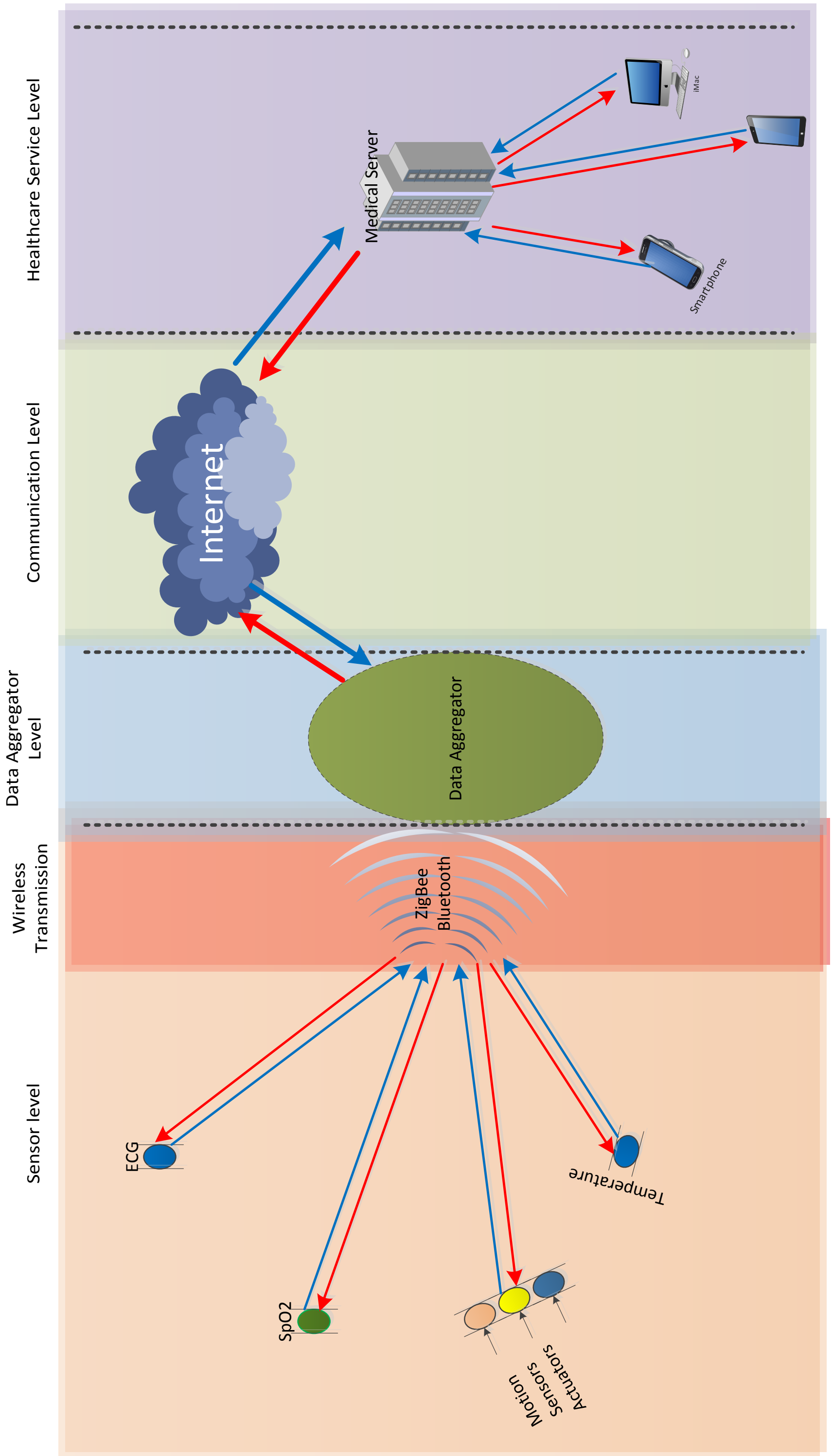

Figure 4.6: Proposed Se-HIS Architecture

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4.5 Semantic Interoperability Framework in Se-HIS

The framework (Fig. 4.7) draws its strength from the combined application and extension of two different methods (Knowledge engineering and methontology) including the ontological background from Gruninger and Kopena [225] on interoperability as discussed in section 2.6.The framework (Fig. 4.7) derived its novelty from the following main areas:

- The semantic interoperability framework for se-HIS is developed to support the transmission of meaningful information (semantics & pragmatics) from the sensors (wearable) in health monitoring system and integrate it with the patient's information in the health information systems.
- The development of a heavyweight transducer ontological foundation containing core feature-based entity information, process and context semantics, which fosters the semantically-sound specialisation of domain models and contextual models.
- The development of a heavyweight transducer ontological foundation containing core feature-based entity information, process and context semantics, which fosters the semantically-sound specialisation of the domain policy and reconciliation models.
- In addition to the knowledge and the understanding of the verifiable method creates an ontology that expresses the combination of semantic, and pragmatic aspects of health monitoring using wearable devices, an algorithm was also developed to determine the position of the sensor on the user's body.
- The contribution to the understanding of verifiable logic-based semantic reconciliation methods as part of ontology mapping processes between pairs of domain models from different format TEDS and another from a different foundation i.e. the HL7 & FHIR being reconciled into one single ontology.

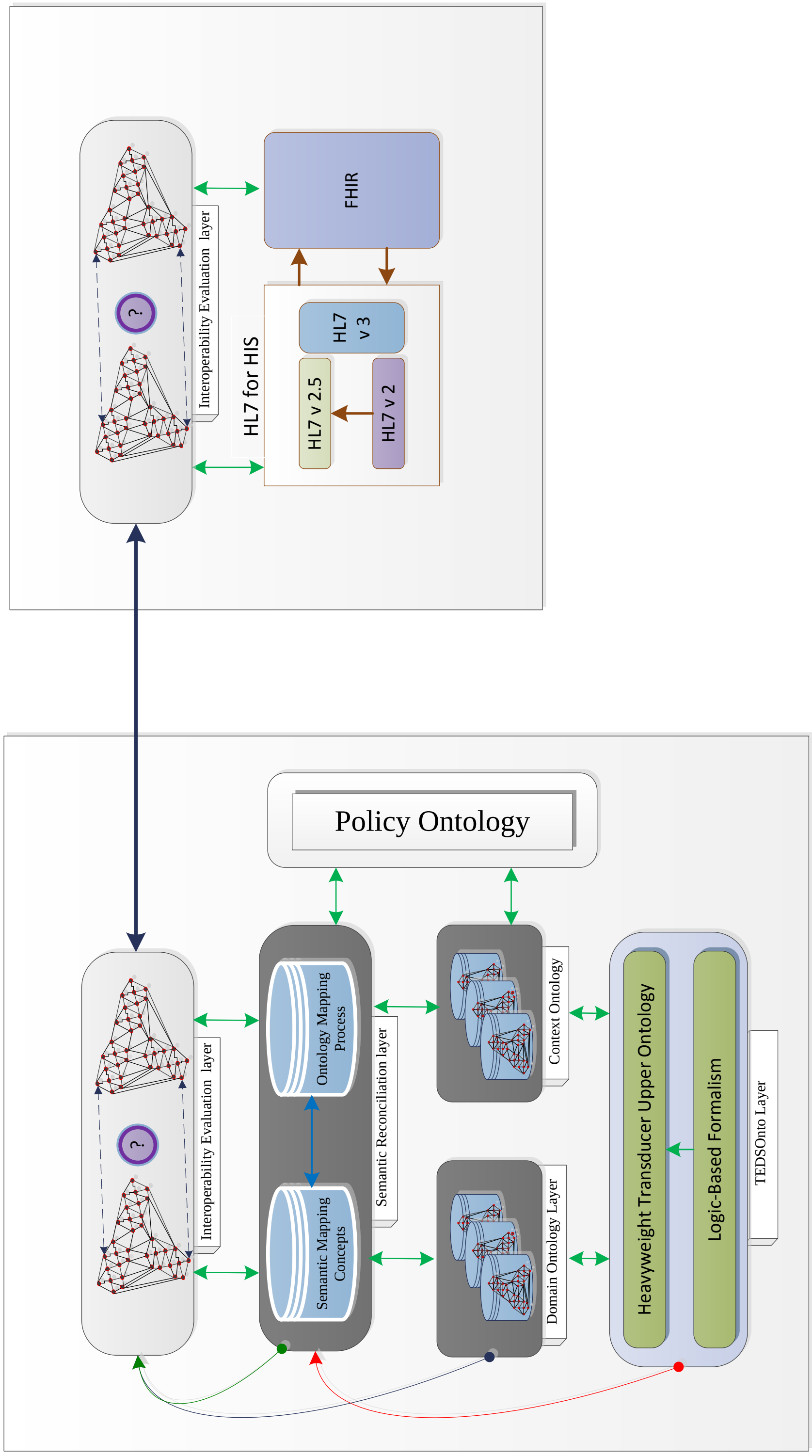

Figure 4.7: se-HIS Interoperability framework

The proposed se-HISIF enables us to bridge the gaps summarized in Chapter 3 about the following: the formalism for contexts, the contextual representation, the pragmatic semantics, heterogeneous data and different standards:

1. The framework uses an ontology based on standards (the IEEE 21450 family of standards) as the foundation layer to support both the generic and specific transducers that are compliant with IEEE 21450 family of standards and fosters the ability to evaluate interoperable knowledge. The framework targets transducers that contain TEDS in wearable devices, used in monitoring health and the HIS.

2. The foundation layer contains the description logic-based formalism over which the heavyweight transducer electronic data sheets ontology is stacked. The foundation layer supports the understanding of effective exploitation of foundation ontology approaches.

3. The description logic-based system capability backed by the foundation layer inherited by the subsequent layers of the framework, facilitates formal semantic-based methods at the ontology mapping layer during ontology matching.

4. The framework uses a heavyweight ontological approach to benefit in the explicit and expressive representation of physiological parameters and exploiting of context pertinent to semantics in health monitoring systems.

5. The framework uses a modular ontology architecture that allows easy maintenance, and scalability for querying data and reasoning on the ontology

4.6 Description of the se-HISIF Components

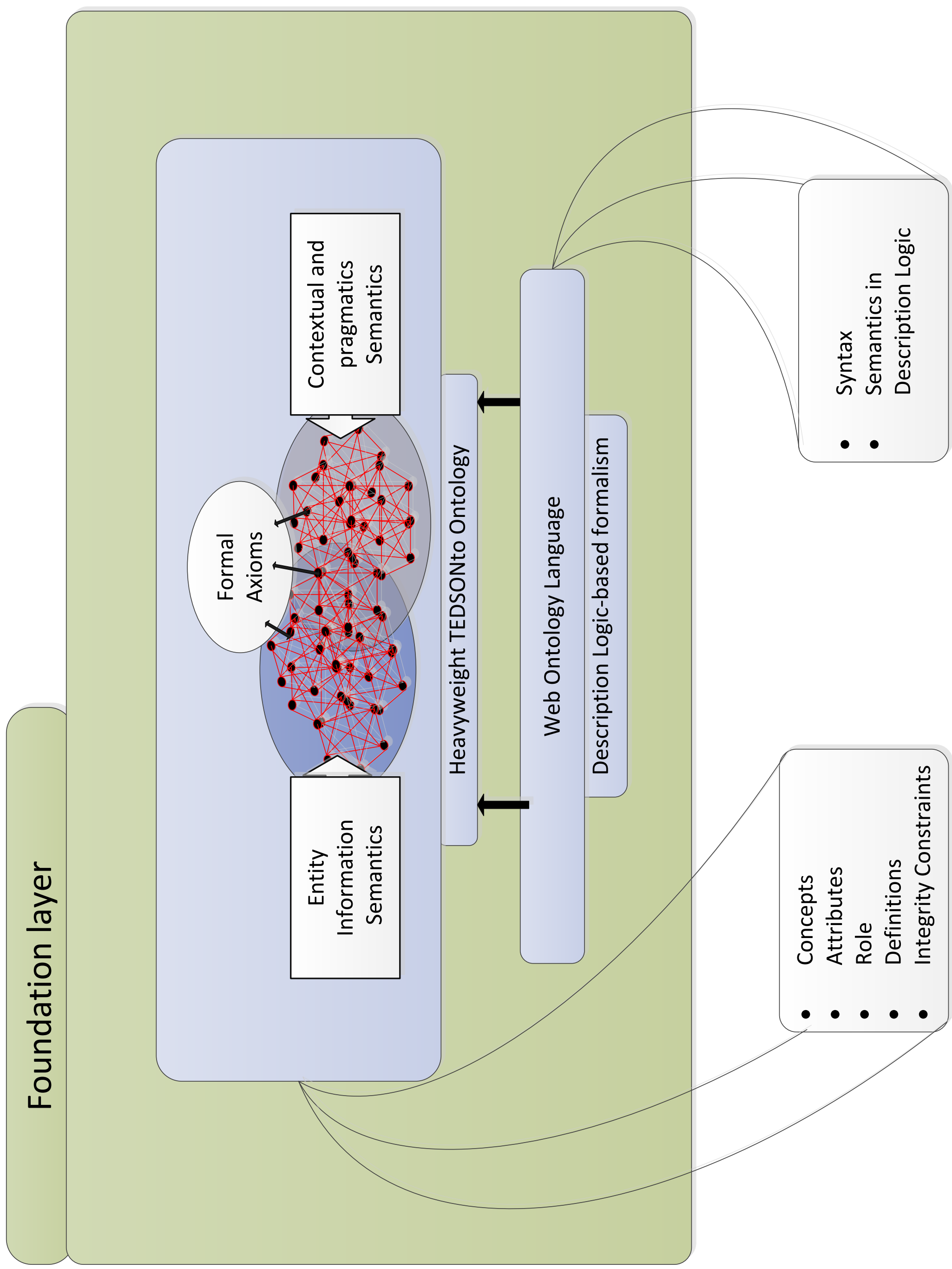

Figure 4.8: The TEDSOnto Layer

4.6.1 Transducers Electronic Data Sheets (TEDS) Ontology Layer -(TEDSOnto Layer)

The Heavyweight Transducer Ontology (TEDSOnto) layer is at the first level of the se-HISIF, and it forms the bedrock for the subsequent layers of the framework at the monitoring device layer. This level is composed of the description logic-based ontological formalism over which the heavyweight transducer ontology is constructed. Fig. 4.8 shows the details components of the foundation layer - TEDSOnto layer.The figure shows the rigorous Web Ontology Language, a description logic-based formalism, which provides the syntax and the description logic semantics, that governs how the heavyweight TEDS ontological foundation formalization occurs at the computation level. The description logic offers concepts, roles (attributes), negation (complement) and has the primary focus of decidability i.e. on always get an answer to a query.

The SIOp4se-HIS contains in its first layer due to the adoption of the multi-layered ontology approach (see Chapter 2, Section 2.6.1.B). This layer forms the ontological foundation; the heavyweight ontology constitutes the novel effort of this study towards the imposed definition of foundation ontologies for sensors in wearable health monitoring devices in a mobile or wearable health monitoring system. It was developed from a low level granularity of context and entity information, for semantics computation in sensors systems for health monitoring. The foundation layer comprises of the full description of the sensor using the TEDS as recognised in the IEEE21450 family of standards.It also accommodates the context and location semantics, with the formalization of relevant concepts from the IEEE 21450 standards. Concepts based on the transducer electronic data sheet and their relationship are clearly stated in Appendix C TEDS taxonomy.

The TEDSOnto was developed using the IEEE 21450 families of standards; Russomanno [226] suggested the development of TEDS as an ontology. This ontology helps to redefine a transducer to cover sensor and actuator which is of great importance for monitoring and capturing vital signs. The sensors assist in capturing the data while the actuator helps to execute commands on the side of the patient as instructed or programmed by the physician in charge of the patient's monitoring. For example, in the case of a diabetics patient, the domain context involves the different patient's

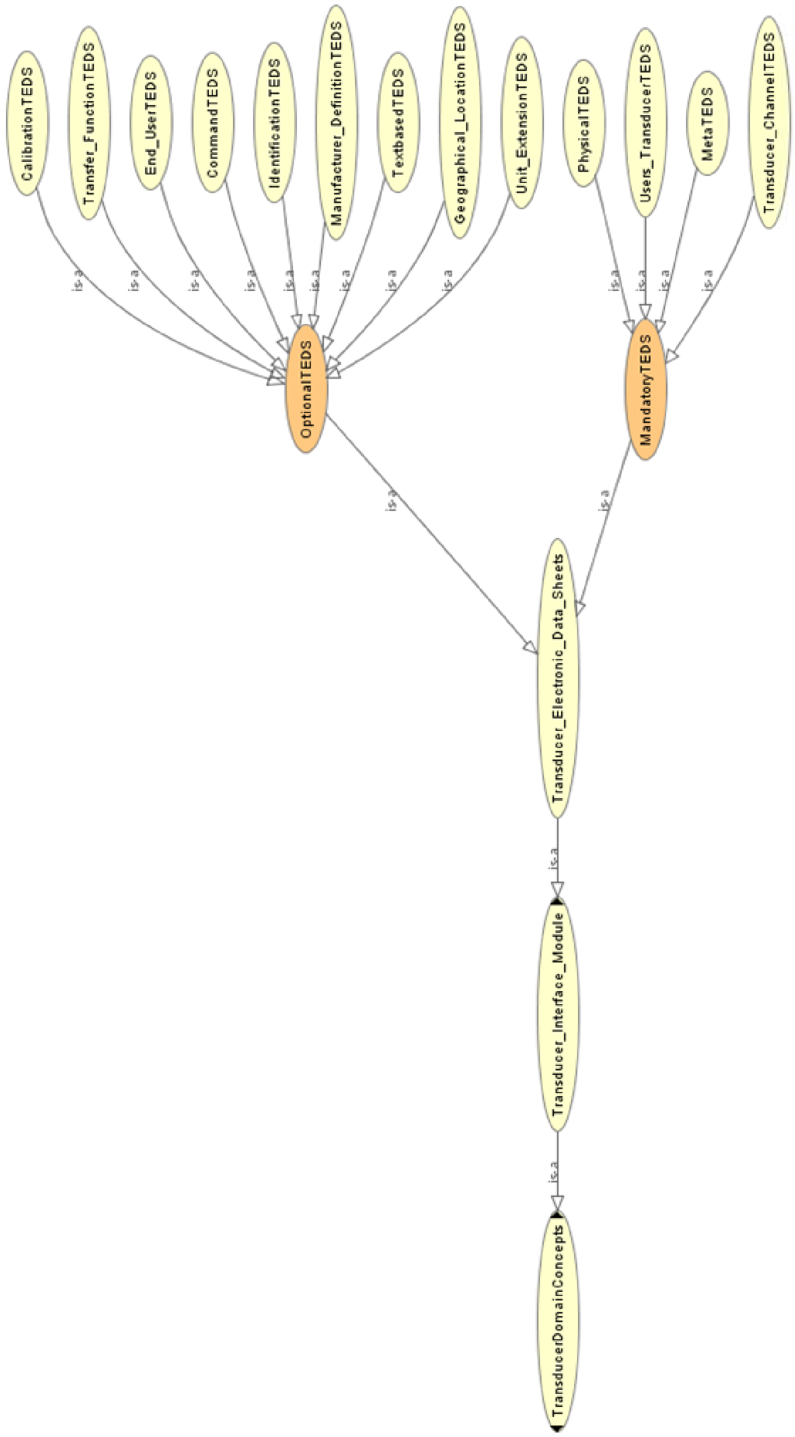

Figure 4.9: TEDS Taxonomy

blood levels of sugar, when it is in the excess, a shot of insulin is injected into the patient's system through an actuator; therefore our framework covers this aspect contrary to previous of existing ontologies.It is functionally capable of handling both actuators and sensors, and this makes it relevant for use in the IoT as discussed in chapter 3 section 3.3.1. The details in Figure 4.9 shows the taxonomy, entities relationships and definition of the ontology see details in Appendix B.

4.6.2 Domain Ontology Layer

The Domain Ontology Layer is at the second level of the SIOp for se-HISIF. At this level, formal axiomatised semantics from the Heavyweight Transducer Electronic Data-sheet ontological foundation can be specialized for the development of the health monitoring domain -specific ontologies and capture of the domain -centric knowledge. The domain layer helps to extract further information from the sensor(s), the extraction of the vital signal (physiological parameters) is dependent on the type of sensor in the wearable system detail list of the various types of physiological parameters is in Table 3.1 in Chapter 3. For example, a sensor that contains an ECG sensor will have a domain layer ontology for this purpose. In this study, we assessed our framework using the ECG, and it is well described in the evaluation section in chapter **??** of this report. TEDSOnto is completely transducer independent; as it can handle different sensors and or actuators which makes it useful even for the IoT architecture.

The various concepts explored in the healthcare domain ontology layer contribute to the new knowledge about the health of the patient by consolidating the understanding behind the ontological mechanism that ensures the integrity -driven development of the domain models based on the same foundation TEDSOnto Ontology. It helps to provide vocabularies of concepts within a specific health monitoring domain. The vocabularies are the terminologies, for example, non-communicable diseases terminologies, their relationships, activities taking place in that domain, and of the theories and elementary principles governing that domain [227–229]. In the context of this study, the domain ontology layer is where models about the domains are based (i.e. domain ontologies and their related knowledge bases); the Ontologies are bound to the preferences, practices, and terminologies of individual domains.

4.6.3 Context for Semantics

The introduction of context for data in the foundation layer involves the formalization of relevant concepts from the analysis of requirement for semantics in health monitoring system. The contextual domain in our framework helps to extract the contextual information for the extracted domain data captured from the sensor through the TEDSOnto. It provides further information on the patient's states of; when, where, who, and why as the functional requirements for semantics in health monitoring. For example, a patient wearing an ECG monitoring sensor carrying out some activities such as running or walking or sitting down will have his or her ECG varying due to the different activities to reflect the actual state of the patient's heart condition at the time of physiological data collection.

The context helps the physician to answer the questions such as the when, where, who, and why while the domain ontology presents response for the what; all these depends on information extracted from the TEDS Ontology at the foundational level. The contextual information provides intuitions for reasoning about various states of the patient's body when the physiological parameter collection; it implies that information collected from patients should not only be data but must capture specific circumstances during the data capture to enhance semantics. According to chapter 4 section 3.5 the five W's of context is put into consideration through our Novel TEDSOnto Ontology where more than one channel of the sensor can be monitored. The IEEE 21450 standard has the ability to recognise all the channels of sensors present in the transducer unit.

Aligning the framework with semantic requirements: In chapter 5 we established during the requirement analysis - chapter 5 section 3.4, the different elements we put into consideration for the semantics interoperability for SIOp4se-HIS. This section discusses how the various elements of the framework, as well as the entirety of the framework, satisfy these requirements. Figure 4.10 shows the framework and its components to the set of requirements.

Figure 4.10 establishes the framework and the components to the set requirements. Requirement 1 through the combined approach of building an ontology the HL7 ontology was developed. Capturing the semantics, from these

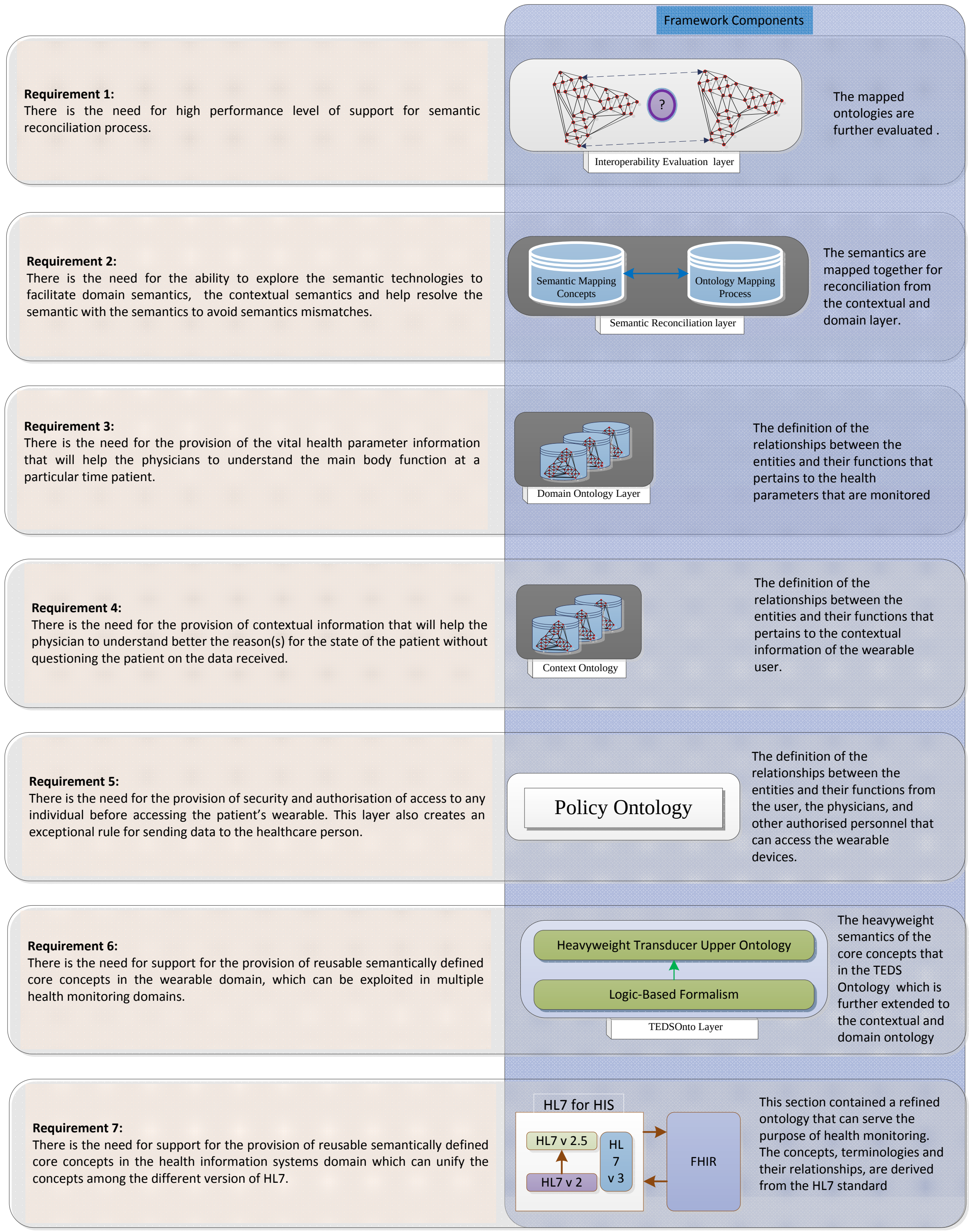

Figure 4.10: Elements of SIOp4Se-HIS framework

methods enables the consideration of some viewpoints in the sensor systems and health monitoring. These viewpoints include, for example, the identification of the device, patient's identity, the vital parameters, and contextual information. Semantic relationship between differences and overlapping viewpoint is the target, through the specification of entity information, contextual semantics and the relationships that hold between them based on the combined approach used to meet requirement 3, this, therefore, helps to satisfy requirements 6. We exploit the heavyweight transducer ontological framework to support an efficient basis for the provision of shared meaning. Ontological approaches have been pursued, whenever there is need to provide a shared meaning in a system, therefore, the ontology-based slant within this framework is better. The types of semantics explored in the ontological foundation pertains to an array of core feature -based concepts that can be used. It can also be extended for a multiple of health monitoring application domains, and this depicts that the foundation layer and the interactions that are supported with the domain ontology layer help meet the requirement 3. To be able to harness the appropriate semantic technologies to facilitate the capture of domain semantics and to support shared meaning across domains, the SIOp4se-HIS harmonizes the distinct layer which adopts specific semantic technologies into a single framework. Appropriate semantic for context computation the SIOp4se-HIS harmonizes four different dimensions i.e. four separate layers which adopt specific semantic technologies into a single framework, thereby satisfying requirement 4. Furthermore, one of the purposes of the Semantic Reconciliation layer is to deal with semantic heterogeneity across domain model,that is , sensor systems and health information systems that HL7 standard, the layer also helps provide the mechanism by which mismatches can be identified and possibly resolved (Requirements 2). The specification of rigorous semantic mapping concepts SIOp4se-HIS satisfy the need for improved methods for specifying ontology matching relationship. The implementation of interactions between the Semantic Reconciliation and interoperability Evaluation layers help to support higher performance levels as far as semantics reconciliation process are concerned and optimized for the SIOp4se-HIS.

4.6.4 Policy Ontology Layer

Our framework offers a simple way to share information, and it is also careful about the protection of patient's sensitive health, personal identification data and unauthorised remote access to patient's resources. It is noteworthy that in the semantic web environment parties connect, interact, anonymously to each other; therefore, for patient's wearable system to interact with the physician in the HIS, there must be trust to a certain level. This layer contains the ontology-based reasoning to understand important policy concerning access from the actors in the healthcare provider domain and access by the patient to necessitate enrichment of the knowledge base to fill the gap between the abstraction levels of accessibility.The ontology-based policy representation supports two main policy types - the authorisation and obligation policy which is of great importance for our health monitoring system to protect the patient's health information;

4.6.5 Authorisation Policy

This policy segment is responsible for the specification of the various permitted actions and their actors. It entails positive authorisation, that is, the actions that an individual or a group of actor is allowed to carry out, while the policies that restrict actor(s) from performing a particular action(s) is known as negative authorisation in any given context.

4.6.6 Obligation Policy

The Obligation policy is responsible for the specification of mandated actions that an actor or a group of actors are to perform known as positive obligations while the one that for which the is not compulsory is a negative obligation. Other types of policies built from these basic primitive types (authorisation and obligation policy), and they all are mapped easily with the HL7 Ontology through our semantic reconciliation layer.

4.6.7 Semantic Reconciliation Layer

The semantic reconciliation section of the framework includes the applied ontology-based techniques that are important to enable the reconciliation of the domain semantics with the context. In the situation that there is the need for knowledge sharing between the ontology layers intra-systems and inter-systems (that is between wearable and HIS), this layer comes to the rescue by employing a combination of matching techniques. Techniques used in the layer to attain reconciliation are the computation of contexts for domain ontologies proposed by Stumme [230], ontology mapping by Noy and Musen [231], and semantic alignment by Euzenat [232], was used in the layer to attain reconciliation. This combination is carried out by taking into account the followings:

- Cross-domain arguments that share equal terms semantically because similarity does not necessarily imply equivalence.
- Progression towards heavyweight common logic-based semantic alignment process to reinforce current knowledge on semantics alignment and the related methods to verify the integrity of cross-domain mappings.

Figure 4.11 illustrates the basic concepts involved in the mapping of domain model at the semantic reconciliation layer. The process of semantic reconciliation is performed

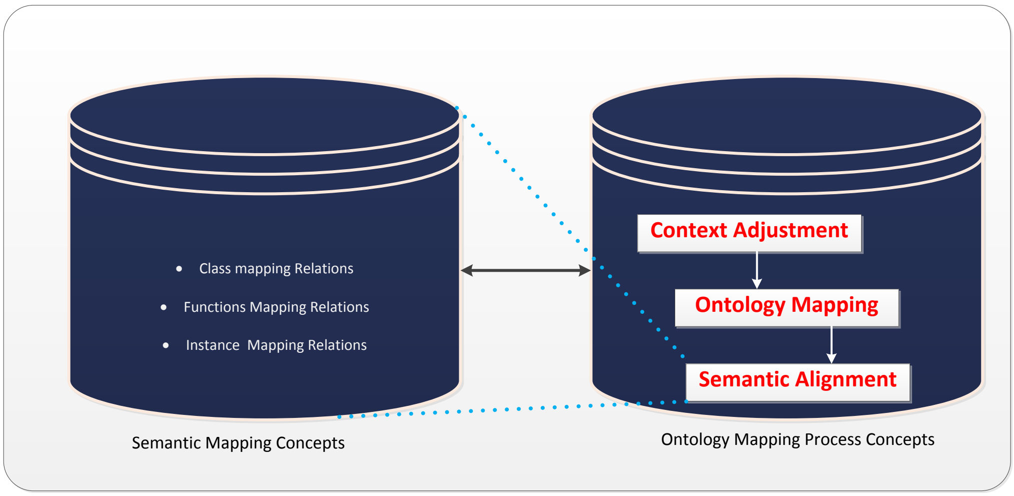

Figure 4.11: Semantic Reconciliation layer

between pairs of models at a time, as can be encountered with almost all current ontology mapping frameworks and methodologies as in the study of Kalfoglou and Schorlemmer, [233] which involved three stages: semantic alignment, ontology mapping and context. adjustment.

4.7 Interoperability Evaluation Layer

This layer is at the last level of the SIOp4se-HIS framework; it uses semi-automatic mechanism for enabling mapping discovery. It builds on the semantic reconciliation layer and uses the capabilities achieved in the third level to help evaluate the commonalities difference and uncertainties (i.e. correspondences) across domain models.

4.7.1 Part Sensor Family Semantics

The extent to which the heavyweight transducer electronic data sheet ontological foundation captures entity information semantics inevitably dictates the types of transducers or families of sensors for monitoring health parameters that can use to monitoring patients health. The complexity of the transducer electronic data sheet ontology semantics allows concepts like representation of the patient, sensors identity, the physiological parameters and standard information about the sensor.

4.7.2 Foundation Layer: TEDSONTO

The TEDSONTO is dependent of the web ontology language (OWL), based on OWL, for the formal specification of a heavyweight transducer ontological foundation. Such an ontological foundation, as perceived in this work is regarded as an integration of intuitions that provide effective meta-concepts, with well-established human perceived meaning, for modelling domain ontologies. The heavyweight transducer ontological foundation possesses the property of capturing generic but constrained entity information and context semantics (process semantic)together with the participation relationship that holds between entities and processes.

4.7.3 HL7 Ontology

The HL7 has different versions: version 2, version 2.5, 2.6 and version3, these versions (v2 and v2.5) are not compatible with version 3, despite being cumbersome for developers to through it for implementation. However, many systems have been developed based on the v2 and v2.5 while v3 has remained mostly unused. Also, the two version does not cover elements of stream data, the FHIR is built on v2,2.5 and 3. Therefore to build the HL7 ontology the study extracted universal concepts from all the versions and FHIR. The concepts, their relationships and axioms were captured and responsible for the HL7 ontology model in the framework. The ontology contains the information for the patient demography, clinical observations, observation reporting from the sensor, patient care and problem-oriented records, the date/time data type model among many others concepts and terminologies that supports the detailed information from the sensor monitoring units.

4.8 Chapter Summary

Regarding the functionalities of the applications, the following requirements are necessary:

- (Patients) Demography Requirement: demography of the patient (like the patient's identification with well defined semantic) this must be a unique identifier and type. The demography information will help to answer the question "who "as stated in the five Ws of context in Table 3.5.

- (Patients environment) Requirement: The location of the patient as at when the information is captured in case of an emergency or for further understanding of the patient's vital signs.

- (Patients vital signs) Requirement: The vital sign that is monitored.

- (Patients affective state) Requirement: the "why "question is answered here. The patient condition that could have led to the vital sign record abnormalities is considered here too

- (Sensor Details) Requirement: The handling of personal information, location-based information (geolocation and local location of the sensor on the patient's body, must always be transparent and traceable, through an authorised personnel.

- (Sensor Product Details) Requirement: The required information about the device information, like the manufacturer, the calibration etc. must be assignable to the device.

- (Sensor) Requirement: Authentication objects must be supported (like RFID-Card, NFC-Device).

5

Evaluation of the SIOp Framework for Se-HIS

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5.1 Introduction

This chapter details the summary of the discussion on the review and assessment of the output of this research - the SIOp4se-HIS. The evaluation is carried out at two major levels; at the first level we reviewed and assessed our novel artefacts produced in this study, that is, the SIOp framework for se-HIS, by analysing the ontologies and semantic representations in the multi-layered ontology system using series of test cases. Finally, at the second level we evaluated the whole framework itself based on design science research evaluation guidelines as fully described in Chapter 2 section 2.2, using a modified De Lone and McLean evaluation model as discussed in Chapter 2 Section 2.7. The result and discussion followed immediately in next sections, while, the case study was set to test the research hypothesis identified in Chapter 1 below:

- The specification of a heavyweight transducer ontological foundation based on the transducer data sheet can form a basis for an integrity-driven specialisation of the various health parameters domain models while supporting the capability to evaluate and verify the interoperability of data between the wearable system and the se-HIS.

The framework is a conglomerate of multi-ontologies based on standards in the domains, integrated together through the foundational layer ontology - TEDSOnto; to assess the functionality, the richness in concepts and their relationships, we use different test cases within the frame of our case study based on identified aim and objectives for each instance. In section 5.2 the lists of the intended test cases as well as the identification of important case study boundaries and assumptions is reported. Analysis was carried out using seven (7) test cases in sections 5.2.1. In section 5.6.1 using the modified De Lone and McLean success evaluation model to evaluate the whole system; as fully discussed in Chapter 2 Section 2.7.1.

5.2 Evaluation of the SIOp4se-HIS Framework

The main concern of our framework is restricted to the formal representation of semantics information from the wearable for health monitoring system to the se-HIS, to facilitate interoperability at the semantic level. The framework contains domain models that we developed to comply with the controlled functional approach and this was accomplished through the use of Protege as an implementation platform. It is researchers opinion that the formalised domain integrity and constraints accurately captured the intended informal meaning; therefore, this forms our boundaries and assumptions in our case study.

The framework span through two main domains: the wearable units system and the health information system domain. The wearable or health monitoring domain has a multi-layered ontology that helps to represent and transfer semantic information from the wearable domain to the se-HIS domain. Therefore seven test cases were set up to assess the framework during the evaluation. The test cases are;

5.2.1 Test Cases

- **Test case 1:** the assessment is to verify the integrity-driven development of the Transducer ontology derived from the TEDS i.e. the Transducer Ontology extracted from the heavyweight semantics within the foundation layer (TEDSOnto) of our framework.
- **Test case 2:** this case assessment checks the integrity-driven development of the Application domain (i.e. the physiological parameters (diseases) ontology that the system is monitoring). In this study, we use ECG for the heart monitoring as a case study except, otherwise stated the ECG was used throughout our assessment.
- **Test case 3:** this case aimed to help assess the reconciliatory ability of the sensor's features for ECG, the ECG ontology, the contextual ontology and mapping with the HL7 ontology. However, it was driven through semantic mapping of concepts based on an external feature computation.

5.3 Design and Method:

The evaluation was approached using a mixed method.The research carried out survey during the seminar in a conference on Health Communication to explain and describe the purpose and function of the framework, and afterwards, believed the participants understood the use and purpose of the framework. A quantitative study followed after that, through the administration of questionnaire to sixty (60) participants at the seminar through an online survey platform. The evaluators affirmed that they understood the purpose of the framework in an information system such as Se-HIS for interoperability case, and the study lasted two months.

5.3.1 The Constructs

In other to measure the success of our framework we selected items from prior studies to maintain the content validity. However, we choose elements that are unique to SIOp4se-HIS contexts, such as the measure of information quality, users satisfaction, intention to use and systems quality see Appendix A for details of the constructs, the questionnaire and data collection method.

5.4 Results and Discussion

The success of the SIOp4se-HIS framework was evaluated using the combinations of constructs from prior similar studies to ascertain the content validity. Five major constructs: Information quality, user's satisfaction, Intention to use, Individual impact and systems quality were used to evaluate the success of the framework, which is due to the nature of the DSR approach.

The constructs from Petter and Fruhling [234] (15 items were adapted from this study for four constructs - system quality, user satisfaction, intention to use and individual impact). The information quality construct was adapted from the CobiT v4.1 framework for governance where the emphasis was more on effectiveness, efficiency, confidentiality, compliance and reliability and integrity. All these constructs are reflective models because the reflective model is best suited for perceptual measures [235]. A five-point Likert scale from 1- Strongly disagree to 5 - strongly agree was used for all the items. Appendix A lists the elements utilised in the evaluation instrument.

The multidimensional model for information Systems success proposed by DeLone and McLean [47] combined with Mardiana's model with [7] was adopted for the SIOp4se-HIS framework evaluation. The DeLone and McLean model stated that the overall quality of the information systems is measured across three dimensions - quality of IS, information quality, and service quality; and they influence the intention to use and user's satisfaction positively. In addition to DeLone and McLean model [47] it can be affirmed that the user satisfaction enhances the intention to use an information system.

5.4.1 Data Collection procedure

The research model test data was obtained through an online database. And the questionnaire was administer online, an approach that has been proven to have a high speed, low cost, and improved response quality [236]. The survey contains questions related to the evaluation of the SIOp4se-HIS framework and the user's demographics.

5.4.2 Data analysis

The population of the evaluators was small, thus a small sample size, therefore the use of structural equation model would be inappropriate [237]. The elements of each construct were averaged to get a single value for each construct, and the mean score was used to test each hypothesis using standard multiple regression analysis in IBM SPSS v 24 [238].

5.5 Evaluation Results

Total sixty (60) questionnaires were sent out via the on-line survey platform known as SurveyMonkey `www.surveymonkey.co.uk` and only forty-one (41) were returned answered to result in a response rate of 68.33%. Majority of the respondents were medical doctors (27%), followed by nurses (14%), systems developer (12%), researchers (12%), programmers (10%) and others were (10%). Figure 5.1 presents the summary of the respondents (evaluators) job distribution in bar chart, while Table 5.1 shows details of the respondents job sector and their education level.

5.6 Research model and hypotheses

The overall purpose of the design of the framework for SIOp4se-HIS is to bring additional value to health monitoring in the healthcare domain. The additional values including but not limited to improving the efficiency of patient health monitoring, lowering the cost of healthcare delivery, monitoring patient's safety and complying with regulations guiding the healthcare delivery.Also, the primary reason for the evaluation of the study output is to enable the organisation to determine the advantage of the framework and assess if it achieved the main goal as well as identify how to make progress for better implementations or learn from any prior mistakes as proposed in Yusof's study [239].

Figure 5.1: Job characteristics of the Respondents

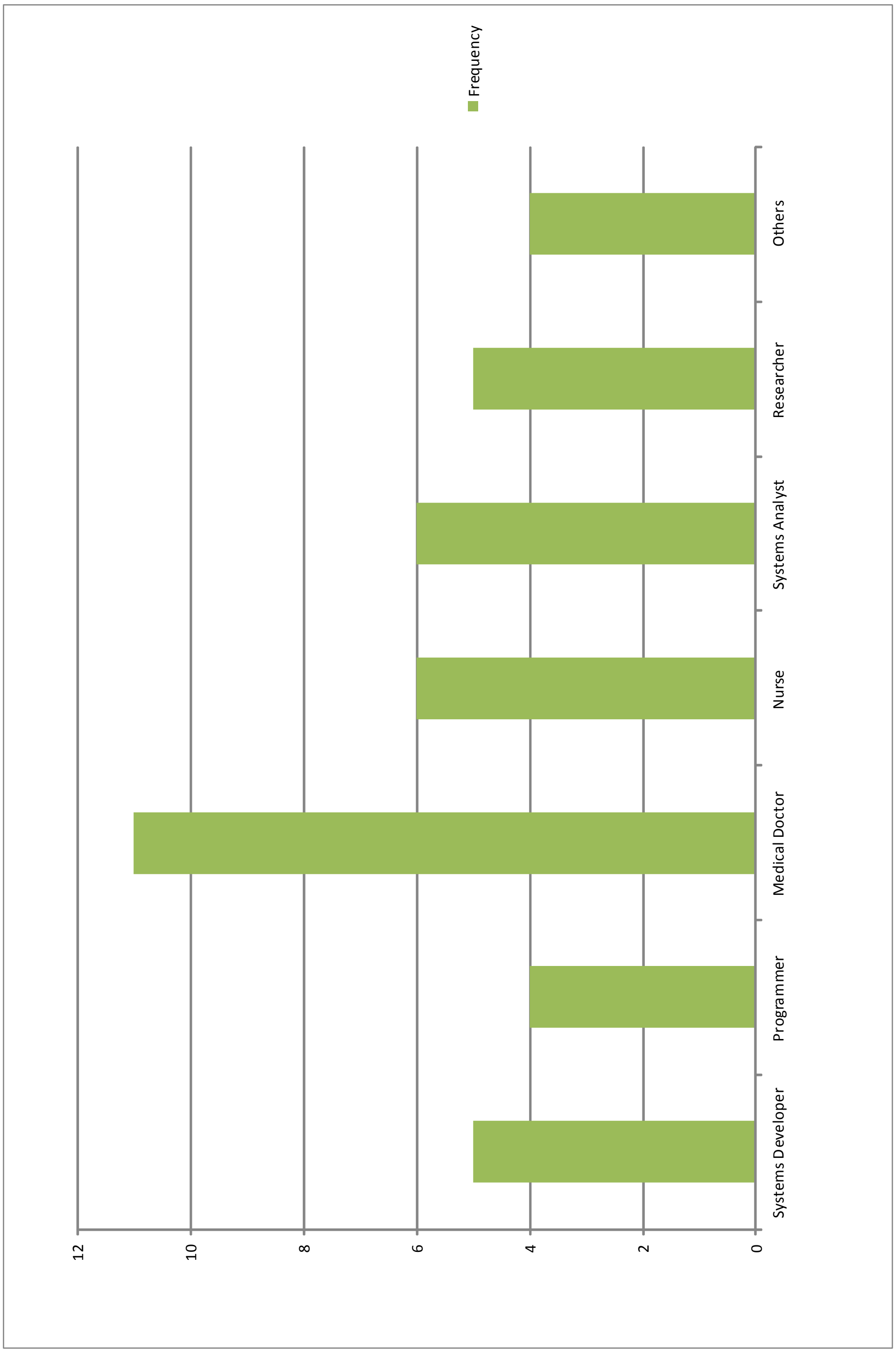

Table 5.1: The characteristics of the Respondents

	Frequency	**Percentages(%)**
Job Sector		
Health Sector	27.00	65.00
Information Technology	7.00	65.90
Education	5.00	12.20
Science Pharmaceutical	2.00	4.90
Total	**41.00**	**100.00**
Education		
BSc	8.00	19.51
MSc	18.00	43.90
NVQ	8.00	19.51
PhD	4.00	9.76
Others	3.00	7.32
Total	**41.00**	**100.00**

The evaluation based on modified D & M IS success model as fully discussed in Chapter 2. The model stated that the quality of information system impacts on other variables of IS success model in a positive way. The Information quality includes the technical quality of the system, (that is, system quality) the quality of the information systems output (that is, the information quality) and the quality of the support provided to the system users (that is the service quality). These types of information systems quality are posited to impact the user's satisfaction positively when they use an information system. It, therefore, follows that users that believe that the framework SIOp4se-HIS has the higher level of Systems quality and information quality will also have higher levels of satisfaction with the SIOp4se-HIS framework. The above understanding led to the first hypothesis (H_1) as stated in Table 5.3, while the usage (intention to use or not use) of the systems is a common measure of information systems success - hypothesis H_2. However, for the SIOp4se-HIS framework, if primarily utilised by the developer or the programmer the possibility is high that the Medical doctors and nurses will also use the system in their hospitals. Therefore for this also we hypothesised H_3. The study do expects that not only the evaluators perception of the quality of the framework that affects the evaluators intention to use the system, but also how satisfied the evaluators are with the framework yielded hypothesis H_3.The design and implementation of Information systems have the primary goal of providing some benefits to the users, the individuals, organisation and stakeholders [5].The satisfaction that the framework provides the users impact value on the framework users and perceive a stronger benefit from using the framework, this forms hypothesis H_4. Furthermore, users that are more likely to use the framework after developing the system based on the framework, are also more likely to accept that the SIOp4se-HIS has impacted them individually this gave us hypothesis H_5. See details in Table 5.3.

Table 5.2: Spearman's Correlation

	Spearman's Correlations					
		System Quality	User Satisfaction	Intention To Use	Individual Impact	Information Quality
1	System Quality	1.000				
2	User Satisfaction	0.511*	1.000			
3	Intention To Use	0.935*	0.604*	1.000		
4	Individual Impact	0.895*	0.497*	0.856*	1.000	
5	Information Quality	0.885*	0.744*	0.958*	0.822*	1.000

* Correlation is significant at the 0.01 level (2-tailed).

5.6.1 Intention to use

The result of the Spearman correlation coefficient (Table 5.2) of the success of the framework revealed that the framework (Systems) quality, information quality, users satisfaction and individual impact have significantly direct relationship with the intention to use the framework by the respondents / evaluators. After, the study accepted the modified model to evaluate the artefacts due to the methodological approach to the study - DSR; the success of DeLone & McLean (DM) IS success model to assess different types of information systems met the expectation, that it would be useful in SIOp4se-HIS framework context with the slight modification clearly discussed in Chapter 2, section 2.7.1, and fully represented in Fig. 2.8.

Table 5.3: Hypothesis for Evaluation

Hypothesis		Description
H_1	H_1	The overall quality of the framework impacts the user's satisfaction positively
	H_{1a}	The systems quality has a positive impact on the the user's satisfaction
	H_{1b}	The information quality is positively associated with user's satisfaction
H_2	H_2	The overall quality of the framework impacts the intention to use positively
	H_{2a}	The systems quality has a positive impact on the intention to use
	H_{2b}	The information quality is positively associated with intention to use
H_3	H_3	The user satisfaction is positively associated with the intention to use
H_4	H_4	The user satisfaction is positively associated with the individual impact
H_5	H_5	The intention to use is positively associated with the individual impact

This study further confirms the appropriateness of the modified model for evaluating DSR outputs - artefacts, in this study's case - SIOp4se-HIS framework. The revised D & M model was useful and relevant for assessing SIOp4se-HIS, due to the construct's focus on "intention to use "as a formative construct. The weighted sum of Independent Variable (IV) (indicators) -information quality, user's satisfaction, systems quality, and individual impact all have a positive influence on the "intention to use "as the Dependent Variable (DV). The tabulation in Table 5.5 summarised the effects (positively or negatively) of each of the variables on one another as stated in our hypothesis in Table 5.3.

This is impacted on through IV of D & M Fig. 2.8 as illustrated in Figure 5.2. The empirical result demonstrated support for the model that the measurement of overall intention to use can be computed from information quality, user satisfaction, systems quality, and individual impact influenced the intention to use.

Table 5.4: Descriptive Statistics

Variables	Mean	Std Deviation	N
Intention To Use	13.10	2.20	41.00
System Quality	29.76	5.15	41.00
User Satisfaction	08.15	1.59	41.00
Individual Impact	12.63	2.07	41.00
Information Quality	17.10	2.77	41.00

Table 5.5: Regression Analysis Results

Regression results						
Hypothesis	**IV / Constructs**	**Impacts**	**DV Construct**	**Beta (β)**	**R^2**	**Result**
H_1	Overall Quality	positively impacts	User Satisfaction	**0.750**[a]	**0.563**	Supported
	Information Quality	positively impacts	User Satisfaction	0.864	0.747	Supported
	Systems Quality	positively impacts	User Satisfaction	**0.664**	**0.441**	Supported
H_2	Overall Quality	positively impacts	Intention to use	0.986	0.971	Supported
	Information Quality	positively impacts	Intention to Use	0.941	0.885	Supported
	System Quality	positively impacts	Intention to Use	0.977	0.955	Supported
H_3	User satisfaction	positively impacts	Intention to Use	**0.725**	**0.525**	Supported
H_4	Users Satisfaction	positively impacts	Individual impacts	**0.624**	**0.390**	Supported
H_5	Intention to use	positively impacts	Individual impacts	0.897	0.805	Supported

[a] Predictors (Constant, Systems Quality, Information Quality, User's Satisfaction, Individual Impacts is significant at the 0.01 level (2-tailed).

The standard multiple regression analysis resulted from using the overall average between of the DV and the constructs - system quality, Information Quality, Individual impact and the user's satisfaction as IV. Table 5.5 gives details of the regression results. The data satisfied the assumptions of the multicollinearity, normality of residuals and homoscedasticity while no outliers were identified.

The data satisfied the assumptions of the multicollinearity, normality of residuals and homoscedasticity while no outliers were identified.

The use of the summative scale of that of the items measuring the constructs are formative rather than reflective; it is not necessary to assess the reliability of the items within the scales. This inability to evaluate the reliability is consistent with other studies like that have examined the success of medical information systems. The means for each of the construct in Table 5.4 was above the scale midpoint of 3.5, and the Spearman correlation coefficients among the construct consisted of both

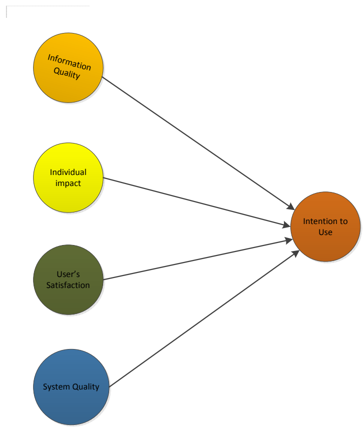

Figure 5.2: Formative Construct for Intention to Use

high and low values; because some of the constructs were non-normal with problems with both skewness and kurtosis, a Spearman correlation matrix is reported in Table 5.2. Furthermore, most of the correlations between the variables were significant as summarised in Table 5.2.

5.7 Information Quality

The quality of the framework (Information quality) has a significant direct relationship with user satisfaction (H_1) the beta value is 0.864 and R^2 of 0.747; these values are also consistent with the relationship between the systems quality and the intention to use the framework (H_2). The beta value for (H_2) is 0.977 while the R^2 is 0.955. As predicted in the null hypothesis, that systems quality does affect the intention to use the framework (systems), the result supported it. The systems quality impacts on the user satisfaction, however, the value of beta is 0.664 while the value of the R^2 is 0.441 indicating a lower impact on user's satisfaction.

The observed relationship between systems quality and user satisfaction was not unexpected; this is because most of the evaluators were medical doctors and nurses (41%), and because the application interface for the ontologies visualiser are not interactive like what they are used to when an application has been developed fully. The query execution was done through the Simple Protocol and Resource Description Framework Query Language (SPARQL) an interface that is not graphically developed.

The reason above is probably responsible for the smaller impact reported in our evaluation.

5.8 Discussion

This study evaluation helps to ascertain the contribution of the framework to bridge the interoperability gap at the semantic level. The framework success is based on the updated DM IS success model which captures the multidimensional and interdependent nature of the ontological framework, and it also provides the implications at the theoretical and individual levels.

5.8.1 Theoretical Implications

The studies of Scheepers et al. [240]; Coombs et al. [241] and Teo & Wong [242] supports the outcome of the evaluation of information quality of the framework having a positive impact on user satisfaction (β = 0.864, $p < 0.001$). It also confirms that the confirmed that the quality of the system (framework) has a positive impact on the user satisfaction which agrees with the previous studies result of IS success at the systems level of analysis by Petter & Fruhling [234]. The R^2 associated with the variable user satisfaction is very acceptable, and it is 44.1%.The evaluation data further confirms that information quality, systems quality and user satisfaction according to our hypotheses suggested that they have positive influence on the intention to use with β =0.941, $p < 0.001$, β =0.977, $p < 0.001$and β = 0.725, $p < 0.001$ respectively. The above result also conforms with the previous studies from Fitzgerald & Russo [243]; Caldeira & Wand [244], and Gill [245].

Finally, the data support the two hypotheses that the high levels of intention to use and users satisfaction positively affects the impact of the framework on the individual (β =0.897, $p < 0.001$, and β =0.0.624 $p < 0.001$ respectively). Research studies from Leclercq [246], Zhu & Kraemer [247], Devaraj & Calhoun [248] and Petter [234] are in support of this outcome.

5.8.2 Individual Implications

The purpose of designing the framework SIOp4se-HIS is to provide some benefits to the users (the patients and the physicians). Also, to facilitate semantic data interchange between the health monitoring units and the HIS which ultimately facilitates the exchange of organisational data and provide efficient patient health monitoring system that is interoperable at the semantics level. By evaluating SIOp4se-HIS after the design, the different groups (developers), the physicians, and others were able to determine if the framework achieved its goals as well as suggest how to improve the framework further. The results of the current evaluation indicate that the user's satisfaction, intention to use, information quality, systems quality, individual impacts are valid measures of SIOp4se-HIS framework success. Finally, according to the inner model, information quality had a significant impact on intention to use, user's satisfaction, individual impact and systems quality. This study, therefore, concludes that the quality of information provided through queries and/or interaction with the framework, further, confirms that the ontological concepts, their relationships and axioms have been carefully extracted and adopted for the semantic interoperability between health monitoring systems and the HIS.

5.9 Chapter Summary

This chapter details the result of the evaluation of the SIOp4se-HIS framework using the updated DM IS success model, the output confirms that the framework is a success. As the empirical results indicated that information quality of the framework is excellent, it also affirms that the information quality has a positive impact on variables - intention to use, user's satisfaction, individual impact and systems quality; ultimately the intention to use the framework by system and software developers among others.

6

Summary,Conclusions, Discussion and Future Work

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6.1 Introduction

This final chapter summarised the solutions to the problems and how the objectives set at the outset of the project was delivered; alongside the experience gained during the period of executing the project. We compiled here the overall understanding developed in this study and succinctly put in our discussion the outcome of the evaluated framework concerning various issues and concerns raised in the integration of data between sensors and HIS and, finally, we suggested a future path to extend the framework.

6.2 Research Summary

The study has been able to present a novel framework for the design of an ontology-based information systems for facilitating interoperability between wearable and HIS, otherwise known as se-HIS. The structure is driven by ontology at each layer of its modules for health monitoring information systems that are focused on delivering person-centered health care, powered by wearable devices in se-HIS. Ontology is widely accepted due to its ability, and its role in the current generation of information systems irrespective of the domain. It has not only enabled better, but smarter retrieval facilities, unlike the current HIS based predominantly on relational data model (cf. the vision of the semantic web [249]). It plays an essential role in supporting data and information quality checks in HIS-wearable interoperability and information integration. This study presented a formal and generic framework for building se-HIS based on ontology, therefore, offering platform that accommodates wearable devices applications (i) the extensional layer, (ii) Intensional layer and (iii) query component that is supported by the RESTful API.

The se-HIS framework being an ontology-based framework is strongly influenced by Description Logic (DL) and offers the novel solution for certain problems of integrating sensors or wearable with HIS especially with heterogeneous data and stove pipe health monitoring systems. The problems iterated in chapter 1 was solved by means of a case study ; design and implementation of an ontology-based ECG monitoring information systems. Based on the framework an empirical solution was successfully presented for problems in the ECG monitoring domain. The case study focused on ontology-based interoperability of systems, semantic presentation of context-aware application and se-HIS framework to support query answering for ECG with machine-processable format that are inherent in the health monitoring domain constraints and their interrelationships being properly represented.

Solutions to the identified problems, as set at the outset of this study are met through the framework. Although, some difficulties encountered during the implementation was due to safety and privacy rules therefore, the applications test was laboratory based.

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The framework provides solutions to all the problems in the following ways;

- **P1:** The foundation layer of the framework as described in Fig. 4.8 comprising of the heavyweight TEDSOnto layer built on the description logic formalism helps to provide detailed information about the various devices that are connected to the health information systems as extracted from the IEEE 21450 family of standards for devices.

- **P2:** This problem solved through the context modelling proposed using ontology as it has gain ground as a standard because of its expressivity and interoperability capabilities. The context ontology based on the simple context modelling consists of the 5Ws (who, when, what, where and why), with enough information to reason and learn from.

- **P3:** The interoperability and middle-ware problem was solved; this is due to the Ontology-based systems being built on a substrate data model to provide the abstraction layer. The substrate does offer caching mechanisms, and abstract from remote and local API procedure calls, the substrate can also play the role of mediator or semantic middle-ware.

- **P4:** The framework reliance on the Attributive (Concept) Language with Complements (ALC) and transitive roles(S), role hierarchy(H), inverse roles (I), and qualified number restrictions(Q) (SHIQ) solves the data and expressivity scalability problem. The scalability solution is attained through the deployment of simpler DLs, or RDF(s), as the study considered both the knowledge level and symbols level by allowing language specific provers services which is available to the framework.

- **P5:**The framework addressed the extensibility problem because it is an open architecture based on the "open-closed principle," i.e. an architecture in which software entities (classes, modules, functions, etc.) are open for extension, but closed for modification; this because of the dual-model approach to the design of the framework. Although, generally, framework reuse is known for some problematic cases because of its inheritance-based reuse, which is "white box use" that requires knowledge about the internals of the class machinery which can be solved through the domain specific languages.

6.3 Reflection on the research

In the last few years of rigorous study and working on this project, it has enriched my knowledge in many ways; during the project, I have acquired different skills, expertise and capabilities. Project management skill, social interaction with experts and professionals concerning the study has taught me how to carry out the study from the scratch to finish. The essential skills acquired during the study is how to build an ontology from the beginning in situation where one can not find any ontology in any repository suitable for one's research. The multidisciplinary nature of the study helped to learn, understand and relate with the full stack for semantic interoperability while acquiring the use of tools such as OWLAPI, Jena, Weka, Java and SPARQL among others.

6.4 Implications of the study

In this research the detail presentation of the elements of the framework for SIOp for se-HIS for health monitoring systems is discussed, the framework is based on a dual model architecture, concretely; the family of standards IEEE 21450, and the HL7 standard. The choice of these standards is because most available health monitoring devices and HIS designs are based on them. Semantic interoperability of electronic healthcare records systems is a major challenge in eHealth, but when achieved, it helps health professionals to manage the complete information with its right contexts independently of the domains that generated the data or information directly from the patients.

However, organisations set up to create standards and to make sure the standards meet user's requirements nonetheless, despite the considerable amount of time and effort spent to develop standards it mostly useful at the syntactic interoperability level; and usually become cumbersome for developers/programmers to apply them during the systems development process. This research provided the framework that fosters semantic interoperability by building ontologies from available relevant standards in the wearable and HIS domains, create a better quality ontology, and consequently, greater semantic interoperability, which provides a means to save time and money for healthcare practitioners and the users.

This approach also brings economic benefits by providing more efficient interoperability and easy patient health monitoring. Using TEDSOnto and getting familiar with its semantic will facilitate more clinical application development that can accommodate both sensors and actuators as semantics aspects of both are complete in the framework for SIOp4Se-HIS. This study and its artefacts provide practitioners in the industry with a valuable ontology that is customisable for design, implementation and delivery of quality semantic interoperability in health applications and a model that is reusable. The heavyweight transducer ontology is applicable for application development, service discovery, identification of both user and sensor which is compatible with the elements in the IoT, therefore, it will provide the semantic interoperability and further enhances the extraction of knowledge for required services, help in the discovery and use resources such as data analysis.

6.5 Limitations

The process and the delivery of artefacts reported in this thesis were done with its peculiar challenges like any other research; we encountered some difficulties in areas such as:

- **Evaluation Method:** It was a bit difficult to establish the evaluation method for our study as it was designed from the perspective of design science research. The difficulty was in the aspect of evaluating the outputs of research from such perspectives because the DSR community does not have a definitive agreement about the appropriate method. To establish metrics to evaluate our study, we conducted a thorough literature review in DSR publications and scrutinised the reported ways in the literature that have been used to evaluated or proposed for the evaluation of methods, standards, conceptual model and ontologies.

  The literature analysis generated a set of metrics as discussed in section 2.7 of chapter 2 to evaluate the ontological conceptual models which are the elements of the SIOp4Se-HIS framework. In the bid to overcome this challenge, the approach used was to check the structure and practice of the world, instead of whether it is true or false, this is based on the practical adequacy of methods [250], combined with the utility theory in Walls et al. [251]. Sayer's proposed that knowledge should be judged for its usefulness rather than being true or false and must generate expectations of the world that are real; and inter-subjectively intelligible and acceptable. Therefore, for the evaluation of this research, the view that if the application of this framework resulted in a high-quality Se-HIS, it could be inferred that the constituting elements of the framework are are practically adequate.

- **Real World Evaluation:** The evaluation of our artefacts was based on the utility theory [251] and the following metrics: Information quality, the intention to use, user's satisfaction and system quality, these were used to evaluate the framework. However, we could not integrate our framework into an existing infrastructure in the healthcare domain because of the nature of the domain. Therefore, further evaluation is required for the framework in an experimental evaluation to observe and emphasise its importance on a large scale.

- **Use and Maintenance of the Ontologies:** The issues of use, maintenance and storage of the ontologies were not addressed in this study, however, TEDS can reside in an embedded memory of the transducer's EEPROM, or it can be virtually stored in data files accessible by the measurement instrument or control system. The virtual TEDS and embedded TEDS'performance in the framework needs to be tested to evaluate the efficiency of the devices concerning the location of the TEDS. Research into the forward compatibility of our framework with the new proposed FHIR standard that supports sensor network should also be tested.

- **Test Using other Vital Signs:** The case study chosen - the ECG is the most commonly used in health monitoring devices due to its importance in health monitoring, and it involves the use of more than one sensor for an expressive surveillance of the patient's health. The ECG monitoring system includes the vital sign monitoring sensor that captures the ECG, sensors such as an accelerometer, gyroscope for capturing the micro- and macro activities of the patient, and sensors that capture location coordinates like the GPS in case of an emergency. However, there is need to test other virtual sign that will involve response such as the injection of insulin into the patient's body through an actuator in the case of the rise in the patient's blood sugar level when reported through the sensor. A further test is required in this direction for further understanding and exploitation of the framework.

6.6 Future Research Directions

The study presented a dual-model approach to creating interoperability in se-HIS, the dual approach, based on information and knowledge modelling; while the state of the art as discussed in chapter 3 is based on single approach methods such as standards and archetypes. Our approach defines both the clinical concepts, describes the devices and the vital signs and also represent the knowledge they capture, unlike the state of the art systems.

The existing systems operate on the syntactic archetypes, and they do not conform to an ontological representation and requires some technical solution involving grammar, semantics and model-driven engineering.However, our proposed framework can solve this problem, and we suggest in the future that works, that further testing is carried out using the "white box approach" to establish and verified the design details of applications using our framework. Future research can look into the means for the extensional layer to accommodates other devices responsible for other vital signs apart from ECG; the intentional layer and extent of the query component. The study where the focus will be ontology-based query answering, this is because the state of the art se-HIS domain still uses simple thesaurus-based retrieval models which are rather inexpressive formalisms.

6.7 Conclusion

This study began with the aim of promoting semantic interoperability in the se-HIS due to the advancement in technology and the change in demography causing a rise in the ratio of adult to care workers. To do this, we proposed the use of se-HIS driven by ontologies that are based on standards in the health monitoring domain and the healthcare delivery domain. The framework relies on the utilisation of a heavyweight ontology built on the IEEE 21450 family of standards; this helped us put forward conceptual models which will help Se-HIS designers to understand and use it as a construct (building blocks). The study is a progress towards the goal of semantic interoperability with an incremental increase in the re-usable knowledge resources.

The SIOp framework for se-HIS to the best of our knowledge is the first framework that is ontology-based and based on existing standards (at this time) and therefore cannot be compared with any other similar framework for further comparative analysis and evaluation. The framework is dynamic as it can handle both sensors and actuator due to its foundation on the TEDSOnto.

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A

The Questionnaire

Dear Sir / Ma,

This survey is a follow-up for the evaluation of the framework for Semantic Interoperability for Sensor-enhanced Health Information System (SIOp4Se-HIS). Seven cases were set up, and demonstrations have been carried, in the case that you did not participate in all the test cases please kindly notify the researcher through e-mail. The answers will help us make improvements to the framework and prioritise new features. The survey should only take 5-10 minutes, and your responses are completely anonymous.

Table A.1: Survey Items

Construct	Items	Measure
System Quality	SysQ1	I am knowledgeable on how to use the SIOp4Se-HIS framework.
System Quality	SysQ2	The SIOp4Se-HIS framework has all of the features that I need for remote health monitoring, consultations and interactions.
System Quality	SysQ3	The SIOp4Se-HIS framework provides me appropriate information about patient,patients environment, and vital parameters and the body network availability.
System Quality	SysQ4	The SIOp4Se-HIS framework always does what I expect it to do.
System Quality	SysQ5	The SIOp4Se-HIS framework performs quickly enough to commands.
System Quality	SysQ6	In terms of overall quality, I would rate the SIOp4Se-HIS framework highly
System Quality	SysQ7	Overall, I am satisfied with SIOp4Se-HIS framework
User's Satisfaction	USat1	Overall, I am satisfied with SIOp4Se-HIS framework
User's Satisfaction	USat2	I like to build my Se-HIS application on SIOp4Se-HIS framework
Intention to use	IUse1	I am likely to use the SIOp4Se-HIS framework in my Se-HIS.
Intention 2to use	IUse2	I intend to use the SIOp4Se-HIS framework in the future.
Intention to use	IUse3	Should a situation arise, I plan to use SIOp4Se-HIS framework
Individual Impact	Ind1	Using the SIOp4Se-HIS framework improves my decisions
Individual Impact	Ind2	I found the SIOp4Se-HIS framework useful for my job
Individual Impact	Ind3	In general, the SIOp4Se-HIS framework is a positive impact on my work.
Information Quality	InfoQ1	The information presented by SIOp4Se-HIS framework is efficient (it contributes to the outcome of the health monitoring success and at a lower cost
Information Quality	InfoQ2	The information presented by SIOp4Se-HIS framework is impartial (it corresponds to the reality of the situation)
Information Quality	InfoQ3	The information presented by SIOp4Se-HIS framework is confidential (it is protected from unauthorised access)
Information Quality	InfoQ4	The information presented by SIOp4Se-HIS framework is relevant (the control information is relevant)

B

The Ontologies, Mapping and Alignment Code

Heavyweight ontologies according to Mizoguchi [227] is

> "It is an ontology built with serious attention to the rigorous meaning of the individual concept, semantically rigorous relations between concepts. The instance models are built based on the ontologies to model a target world, which requires careful conceptualization of the world to guarantee consistency and fidelity of the model ".

Heavyweight ontologies can formally define concepts, control their use, capture knowledge and provide a route to share across design and production. They offer better reasoning capability compared to databases with fixed from and formats and they have the potential to provide a rigorous common semantic base. Below are the excerpts for the ontologies, mapping and alignment:

```
package Tedsonto;
import java.net.URI;
import java.util.Collection;
import javax.xml.datatype.XMLGregorianCalendar;
import org.protege.owl.codegeneration.WrappedIndividual;
import org.semanticweb.owlapi.model.OWLNamedIndividual;
import org.semanticweb.owlapi.model.OWLOntology;
/**
 *
 * <p>
 * Generated by Protege (http://protege.stanford.edu). <br>
 * Source Class: Actuator <br>
 * @version generated on Sun Jul 31 16:04:54 PDT 2016 by Olusolo1
 */
public interface Actuator extends TransducerChannel_Type_Description {
   /* ***************************************************
    * Property http://www.semanticweb.org/ajigboyeolamidipupo/ontologies/2016/2/untitled-
ontology-15#hasAccessCode
    */
   /**
    * Gets all property values for the hasAccessCode property.<p>
    *
    * @returns a collection of values for the hasAccessCode property.
    */
   Collection<? extends AccessCommandCodes> getHasAccessCode();
   /**
    * Checks if the class has a hasAccessCode property value.<p>
    *
    * @return true if there is a hasAccessCode property value.
    */
   boolean hasHasAccessCode();
   /**
    * Adds a hasAccessCode property value.<p>
    *
    * @param newHasAccessCode the hasAccessCode property value to be added
    */
   void addHasAccessCode(AccessCommandCodes newHasAccessCode);
   /**
    * Removes a hasAccessCode property value.<p>
    *
    * @param oldHasAccessCode the hasAccessCode property value to be removed.
    */
   void removeHasAccessCode(AccessCommandCodes oldHasAccessCode);
   /* ***************************************************
    * Property http://www.semanticweb.org/ajigboyeolamidipupo/ontologies/2016/2/untitled-
ontology-15#hasAccessCommand
    */
  /**
```

```
 * Gets all property values for the hasAccessCommand property.<p>
 *
 * @returns a collection of values for the hasAccessCommand property.
 */
Collection<? extends WrappedIndividual> getHasAccessCommand();
/**
 * Checks if the class has a hasAccessCommand property value.<p>
 *
 * @return true if there is a hasAccessCommand property value.
 */
boolean hasHasAccessCommand();
/**
 * Adds a hasAccessCommand property value.<p>
 *
 * @param newHasAccessCommand the hasAccessCommand property value to be added
 */
void addHasAccessCommand(WrappedIndividual newHasAccessCommand);
/**
 * Removes a hasAccessCommand property value.<p>
 *
 * @param oldHasAccessCommand the hasAccessCommand property value to be removed.
 */
void removeHasAccessCommand(WrappedIndividual oldHasAccessCommand);
/* ***************************************************
 * Property http://www.semanticweb.org/ajigboyeolamidipupo/ontologies/2016/2/untitled-
ontology-15#hasChannelGroupDetails
 */
 /**
 * Gets all property values for the hasChannelGroupDetails property.<p>
 *
 * @returns a collection of values for the hasChannelGroupDetails property.
 */
Collection<? extends TEDSChannelsGroupDetails> getHasChannelGroupDetails();
/**
 * Checks if the class has a hasChannelGroupDetails property value.<p>
 *
 * @return true if there is a hasChannelGroupDetails property value.
 */
boolean hasHasChannelGroupDetails();
/**
 * Adds a hasChannelGroupDetails property value.<p>
 *
 * @param newHasChannelGroupDetails the hasChannelGroupDetails property value to be added
 */
void addHasChannelGroupDetails(TEDSChannelsGroupDetails newHasChannelGroupDetails);
/**
 * Removes a hasChannelGroupDetails property value.<p>
 *
```

```
     * @param oldHasChannelGroupDetails the hasChannelGroupDetails property value to be removed.
     */
    void removeHasChannelGroupDetails(TEDSChannelsGroupDetails oldHasChannelGroupDetails);
    /* ***************************************************
     * Property http://www.semanticweb.org/ajigboyeolamidipupo/ontologies/2016/2/untitled-ontology-15#hasChannelType
     */
     /**
     * Gets all property values for the hasChannelType property.<p>
     *
     * @returns a collection of values for the hasChannelType property.
     */
    Collection<? extends WrappedIndividual> getHasChannelType();
    /**
     * Checks if the class has a hasChannelType property value.<p>
     *
     * @return true if there is a hasChannelType property value.
     */
    boolean hasHasChannelType();
    /**
     * Adds a hasChannelType property value.<p>
     *
     * @param newHasChannelType the hasChannelType property value to be added
     */
    void addHasChannelType(WrappedIndividual newHasChannelType);
    /**
     * Removes a hasChannelType property value.<p>
     *
     * @param oldHasChannelType the hasChannelType property value to be removed.
     */
    void removeHasChannelType(WrappedIndividual oldHasChannelType);
    /* ***************************************************
     * Property http://www.semanticweb.org/ajigboyeolamidipupo/ontologies/2016/2/untitled-ontology-15#hasEventOccurr
     */
     /**
     * Gets all property values for the hasEventOccurr property.<p>
     *
     * @returns a collection of values for the hasEventOccurr property.
     */
    Collection<? extends EventTime> getHasEventOccurr();
    /**
     * Checks if the class has a hasEventOccurr property value.<p>
     *
     * @return true if there is a hasEventOccurr property value.
     */
    boolean hasHasEventOccurr();
```

```
    /**
     * Adds a hasEventOccurr property value.<p>
     *
     * @param newHasEventOccurr the hasEventOccurr property value to be added
     */
    void addHasEventOccurr(EventTime newHasEventOccurr);
    /**
     * Removes a hasEventOccurr property value.<p>
     *
     * @param oldHasEventOccurr the hasEventOccurr property value to be removed.
     */
    void removeHasEventOccurr(EventTime oldHasEventOccurr);
    /* ***************************************************
     * Property http://www.semanticweb.org/ajigboyeolamidipupo/ontologies/2016/2/untitled-
ontology-15#hasEventOperationMode
     */
    /**
     * Gets all property values for the hasEventOperationMode property.<p>
     *
     * @returns a collection of values for the hasEventOperationMode property.
     */
    Collection<? extends OperationMode> getHasEventOperationMode();
    /**
     * Checks if the class has a hasEventOperationMode property value.<p>
     *
     * @return true if there is a hasEventOperationMode property value.
     */
    boolean hasHasEventOperationMode();
    /**
     * Adds a hasEventOperationMode property value.<p>
     *
     * @param newHasEventOperationMode the hasEventOperationMode property value to be added
     */
    void addHasEventOperationMode(OperationMode newHasEventOperationMode);
    /**
     * Removes a hasEventOperationMode property value.<p>
     *
     * @param oldHasEventOperationMode the hasEventOperationMode property value to be
removed.
     */
    void removeHasEventOperationMode(OperationMode oldHasEventOperationMode);
    /* ***************************************************
     * Property http://www.semanticweb.org/ajigboyeolamidipupo/ontologies/2016/2/untitled-
ontology-15#hasEventSensorOutput
     */
     /**
     * Gets all property values for the hasEventSensorOutput property.<p>
     *
```

```
     * @returns a collection of values for the hasEventSensorOutput property.
     */
    Collection<? extends EventSensorOutput> getHasEventSensorOutput();

    /**
     * Checks if the class has a hasEventSensorOutput property value.<p>
     *
     * @return true if there is a hasEventSensorOutput property value.
     */
    boolean hasHasEventSensorOutput();
    /**
     * Adds a hasEventSensorOutput property value.<p>
     *
     * @param newHasEventSensorOutput the hasEventSensorOutput property value to be added
     */
    void addHasEventSensorOutput(EventSensorOutput newHasEventSensorOutput);
    /**
     * Removes a hasEventSensorOutput property value.<p>
     *
     * @param oldHasEventSensorOutput the hasEventSensorOutput property value to be removed.
     */
    void removeHasEventSensorOutput(EventSensorOutput oldHasEventSensorOutput);
    /* ***************************************************
     * Property http://www.semanticweb.org/ajigboyeolamidipupo/ontologies/2016/2/untitled-
ontology-15#hasEventSensorType
     */
     /**
     * Gets all property values for the hasEventSensorType property.<p>
     *
     * @returns a collection of values for the hasEventSensorType property.
     */
    Collection<? extends EventSensorType> getHasEventSensorType();
    /**
     * Checks if the class has a hasEventSensorType property value.<p>
     *
     * @return true if there is a hasEventSensorType property value.
     */
    boolean hasHasEventSensorType();
    /**
     * Adds a hasEventSensorType property value.<p>
     *
     * @param newHasEventSensorType the hasEventSensorType property value to be added
     */
    void addHasEventSensorType(EventSensorType newHasEventSensorType);
    /**
     * Removes a hasEventSensorType property value.<p>
     *
     * @param oldHasEventSensorType the hasEventSensorType property value to be removed.
```

```
  */
  void removeHasEventSensorType(EventSensorType oldHasEventSensorType);


  /* ***************************************************
   * Property http://www.semanticweb.org/ajigboyeolamidipupo/ontologies/2016/2/untitled-
ontology-15#hasEventStatus
   */

  /**
   * Gets all property values for the hasEventStatus property.<p>
   *
   * @returns a collection of values for the hasEventStatus property.
   */
  Collection<? extends EventSensorStatus> getHasEventStatus();

  /**
   * Checks if the class has a hasEventStatus property value.<p>
   *
   * @return true if there is a hasEventStatus property value.
   */
  boolean hasHasEventStatus();

  /**
   * Adds a hasEventStatus property value.<p>
   *
   * @param newHasEventStatus the hasEventStatus property value to be added
   */
  void addHasEventStatus(EventSensorStatus newHasEventStatus);

  /**
   * Removes a hasEventStatus property value.<p>
   *
   * @param oldHasEventStatus the hasEventStatus property value to be removed.
   */
  void removeHasEventStatus(EventSensorStatus oldHasEventStatus);
  /* ***************************************************
   * Property http://www.semanticweb.org/ajigboyeolamidipupo/ontologies/2016/2/untitled-
ontology-15#hasEventTime
   */
    /**
   * Gets all property values for the hasEventTime property.<p>
   *
   * @returns a collection of values for the hasEventTime property.
   */
  Collection<? extends WrappedIndividual> getHasEventTime();

  /**
```

```
 * Checks if the class has a hasEventTime property value.<p>
 *
 * @return true if there is a hasEventTime property value.
 */
boolean hasHasEventTime();

/**
 * Adds a hasEventTime property value.<p>
 *
 * @param newHasEventTime the hasEventTime property value to be added
 */
void addHasEventTime(WrappedIndividual newHasEventTime);

/**
 * Removes a hasEventTime property value.<p>
 *
 * @param oldHasEventTime the hasEventTime property value to be removed.
 */
void removeHasEventTime(WrappedIndividual oldHasEventTime);


/* ***************************************************
 * Property http://www.semanticweb.org/ajigboyeolamidipupo/ontologies/2016/2/untitled-
ontology-15#hasEventTimeInbetween
 */

/**
 * Gets all property values for the hasEventTimeInbetween property.<p>
 *
 * @returns a collection of values for the hasEventTimeInbetween property.
 */
Collection<? extends BetweenEventsTime> getHasEventTimeInbetween();

/**
 * Checks if the class has a hasEventTimeInbetween property value.<p>
 *
 * @return true if there is a hasEventTimeInbetween property value.
 */
boolean hasHasEventTimeInbetween();

/**
 * Adds a hasEventTimeInbetween property value.<p>
 *
 * @param newHasEventTimeInbetween the hasEventTimeInbetween property value to be added
 */
void addHasEventTimeInbetween(BetweenEventsTime newHasEventTimeInbetween);

/**
```

```
     * Removes a hasEventTimeInbetween property value.<p>
     *
     * @param oldHasEventTimeInbetween the hasEventTimeInbetween property value to be
removed.
     */
    void removeHasEventTimeInbetween(BetweenEventsTime oldHasEventTimeInbetween);


    /* ***************************************************
     * Property http://www.semanticweb.org/ajigboyeolamidipupo/ontologies/2016/2/untitled-
ontology-15#hasEventTransitionReport
     */

    /**
     * Gets all property values for the hasEventTransitionReport property.<p>
     *
     * @returns a collection of values for the hasEventTransitionReport property.
     */
    Collection<? extends TransitionReport> getHasEventTransitionReport();

    /**
     * Checks if the class has a hasEventTransitionReport property value.<p>
     *
     * @return true if there is a hasEventTransitionReport property value.
     */
    boolean hasHasEventTransitionReport();

    /**
     * Adds a hasEventTransitionReport property value.<p>
     *
     * @param newHasEventTransitionReport the hasEventTransitionReport property value to be
added
     */
    void addHasEventTransitionReport(TransitionReport newHasEventTransitionReport);

    /**
     * Removes a hasEventTransitionReport property value.<p>
     *
     * @param oldHasEventTransitionReport the hasEventTransitionReport property value to be
removed.
     */
    void removeHasEventTransitionReport(TransitionReport oldHasEventTransitionReport);


    /* ***************************************************
     * Property http://www.semanticweb.org/ajigboyeolamidipupo/ontologies/2016/2/untitled-
ontology-15#hasEventsSensorDetails
     */
```

```
/**
 * Gets all property values for the hasEventsSensorDetails property.<p>
 *
 * @returns a collection of values for the hasEventsSensorDetails property.
 */
Collection<? extends WrappedIndividual> getHasEventsSensorDetails();

/**
 * Checks if the class has a hasEventsSensorDetails property value.<p>
 *
 * @return true if there is a hasEventsSensorDetails property value.
 */
boolean hasHasEventsSensorDetails();

/**
 * Adds a hasEventsSensorDetails property value.<p>
 *
 * @param newHasEventsSensorDetails the hasEventsSensorDetails property value to be added
 */
void addHasEventsSensorDetails(WrappedIndividual newHasEventsSensorDetails);

/**
 * Removes a hasEventsSensorDetails property value.<p>
 *
 * @param oldHasEventsSensorDetails the hasEventsSensorDetails property value to be removed.
 */
void removeHasEventsSensorDetails(WrappedIndividual oldHasEventsSensorDetails);


/* ***************************************************
 * Property http://www.semanticweb.org/ajigboyeolamidipupo/ontologies/2016/2/untitled-
ontology-15#hasField
 */

/**
 * Gets all property values for the hasField property.<p>
 *
 * @returns a collection of values for the hasField property.
 */
Collection<? extends WrappedIndividual> getHasField();

/**
 * Checks if the class has a hasField property value.<p>
 *
 * @return true if there is a hasField property value.
 */
boolean hasHasField();
```

```
    /**
     * Adds a hasField property value.<p>
     *
     * @param newHasField the hasField property value to be added
     */
    void addHasField(WrappedIndividual newHasField);

    /**
     * Removes a hasField property value.<p>
     *
     * @param oldHasField the hasField property value to be removed.
     */
    void removeHasField(WrappedIndividual oldHasField);


    /* ***************************************************
```

For Sensors

```
package Tedsonto;

import java.net.URI;
import java.util.Collection;
import javax.xml.datatype.XMLGregorianCalendar;

import org.protege.owl.codegeneration.WrappedIndividual;

import org.semanticweb.owlapi.model.OWLNamedIndividual;
import org.semanticweb.owlapi.model.OWLOntology;

/**
 *
 * <p>
 * Generated by Protege (http://protege.stanford.edu). <br>
 * Source Class: Sensor <br>
 * @version generated on Sun Jul 31 16:04:58 PDT 2016 by Olusolo1
 */

public interface Sensor extends TransducerChannel_Type_Description {

    /* ***************************************************
     * Property http://www.semanticweb.org/ajigboyeolamidipupo/ontologies/2016/2/untitled-
ontology-15#hasAccessCode
     */

    /**
     * Gets all property values for the hasAccessCode property.<p>
```

```
 *
 * @returns a collection of values for the hasAccessCode property.
 */
Collection<? extends AccessCommandCodes> getHasAccessCode();

/**
 * Checks if the class has a hasAccessCode property value.<p>
 *
 * @return true if there is a hasAccessCode property value.
 */
boolean hasHasAccessCode();

/**
 * Adds a hasAccessCode property value.<p>
 *
 * @param newHasAccessCode the hasAccessCode property value to be added
 */
void addHasAccessCode(AccessCommandCodes newHasAccessCode);

/**
 * Removes a hasAccessCode property value.<p>
 *
 * @param oldHasAccessCode the hasAccessCode property value to be removed.
 */
void removeHasAccessCode(AccessCommandCodes oldHasAccessCode);


/* ***************************************************
 * Property http://www.semanticweb.org/ajigboyeolamidipupo/ontologies/2016/2/untitled-
ontology-15#hasAccessCommand
 */

/**
 * Gets all property values for the hasAccessCommand property.<p>
 *
 * @returns a collection of values for the hasAccessCommand property.
 */
Collection<? extends WrappedIndividual> getHasAccessCommand();

/**
 * Checks if the class has a hasAccessCommand property value.<p>
 *
 * @return true if there is a hasAccessCommand property value.
 */
boolean hasHasAccessCommand();

/**
 * Adds a hasAccessCommand property value.<p>
```

```
     *
     * @param newHasAccessCommand the hasAccessCommand property value to be added
     */
    void addHasAccessCommand(WrappedIndividual newHasAccessCommand);

    /**
     * Removes a hasAccessCommand property value.<p>
     *
     * @param oldHasAccessCommand the hasAccessCommand property value to be removed.
     */
    void removeHasAccessCommand(WrappedIndividual oldHasAccessCommand);


    /* ***************************************************
     * Property http://www.semanticweb.org/ajigboyeolamidipupo/ontologies/2016/2/untitled-
ontology-15#hasChannelGroupDetails
     */

    /**
     * Gets all property values for the hasChannelGroupDetails property.<p>
     *
     * @returns a collection of values for the hasChannelGroupDetails property.
     */
    Collection<? extends TEDSChannelsGroupDetails> getHasChannelGroupDetails();

    /**
     * Checks if the class has a hasChannelGroupDetails property value.<p>
     *
     * @return true if there is a hasChannelGroupDetails property value.
     */
    boolean hasHasChannelGroupDetails();

    /**
     * Adds a hasChannelGroupDetails property value.<p>
     *
     * @param newHasChannelGroupDetails the hasChannelGroupDetails property value to be added
     */
    void addHasChannelGroupDetails(TEDSChannelsGroupDetails newHasChannelGroupDetails);

    /**
     * Removes a hasChannelGroupDetails property value.<p>
     *
     * @param oldHasChannelGroupDetails the hasChannelGroupDetails property value to be
removed.
     */
    void removeHasChannelGroupDetails(TEDSChannelsGroupDetails oldHasChannelGroupDetails);
```

```
    /* ***************************************************
     * Property http://www.semanticweb.org/ajigboyeolamidipupo/ontologies/2016/2/untitled-
ontology-15#hasChannelType
     */

    /**
     * Gets all property values for the hasChannelType property.<p>
     *
     * @returns a collection of values for the hasChannelType property.
     */
    Collection<? extends WrappedIndividual> getHasChannelType();

    /**
     * Checks if the class has a hasChannelType property value.<p>
     *
     * @return true if there is a hasChannelType property value.
     */
    boolean hasHasChannelType();

    /**
     * Adds a hasChannelType property value.<p>
     *
     * @param newHasChannelType the hasChannelType property value to be added
     */
    void addHasChannelType(WrappedIndividual newHasChannelType);

    /**
     * Removes a hasChannelType property value.<p>
     *
     * @param oldHasChannelType the hasChannelType property value to be removed.
     */
    void removeHasChannelType(WrappedIndividual oldHasChannelType);


    /* ***************************************************
     * Property http://www.semanticweb.org/ajigboyeolamidipupo/ontologies/2016/2/untitled-
ontology-15#hasEventOccurr
     */

    /**
     * Gets all property values for the hasEventOccurr property.<p>
     *
     * @returns a collection of values for the hasEventOccurr property.
     */
    Collection<? extends EventTime> getHasEventOccurr();

    /**
     * Checks if the class has a hasEventOccurr property value.<p>
```

```
     *
     * @return true if there is a hasEventOccurr property value.
     */
    boolean hasHasEventOccurr();

    /**
     * Adds a hasEventOccurr property value.<p>
     *
     * @param newHasEventOccurr the hasEventOccurr property value to be added
     */
    void addHasEventOccurr(EventTime newHasEventOccurr);

    /**
     * Removes a hasEventOccurr property value.<p>
     *
     * @param oldHasEventOccurr the hasEventOccurr property value to be removed.
     */
    void removeHasEventOccurr(EventTime oldHasEventOccurr);


    /* ***************************************************
     * Property http://www.semanticweb.org/ajigboyeolamidipupo/ontologies/2016/2/untitled-
ontology-15#hasEventOperationMode
     */

    /**
     * Gets all property values for the hasEventOperationMode property.<p>
     *
     * @returns a collection of values for the hasEventOperationMode property.
     */
    Collection<? extends OperationMode> getHasEventOperationMode();

    /**
     * Checks if the class has a hasEventOperationMode property value.<p>
     *
     * @return true if there is a hasEventOperationMode property value.
     */
    boolean hasHasEventOperationMode();

    /**
     * Adds a hasEventOperationMode property value.<p>
     *
     * @param newHasEventOperationMode the hasEventOperationMode property value to be added
     */
    void addHasEventOperationMode(OperationMode newHasEventOperationMode);

    /**
     * Removes a hasEventOperationMode property value.<p>
```

```
     *
     * @param oldHasEventOperationMode the hasEventOperationMode property value to be
removed.
     */
    void removeHasEventOperationMode(OperationMode oldHasEventOperationMode);


    /* ***************************************************
     * Property http://www.semanticweb.org/ajigboyeolamidipupo/ontologies/2016/2/untitled-
ontology-15#hasEventSensorOutput
     */

    /**
     * Gets all property values for the hasEventSensorOutput property.<p>
     *
     * @returns a collection of values for the hasEventSensorOutput property.
     */
    Collection<? extends EventSensorOutput> getHasEventSensorOutput();

    /**
     * Checks if the class has a hasEventSensorOutput property value.<p>
     *
     * @return true if there is a hasEventSensorOutput property value.
     */
    boolean hasHasEventSensorOutput();

    /**
     * Adds a hasEventSensorOutput property value.<p>
     *
     * @param newHasEventSensorOutput the hasEventSensorOutput property value to be added
     */
    void addHasEventSensorOutput(EventSensorOutput newHasEventSensorOutput);

    /**
     * Removes a hasEventSensorOutput property value.<p>
     *
     * @param oldHasEventSensorOutput the hasEventSensorOutput property value to be removed.
     */
    void removeHasEventSensorOutput(EventSensorOutput oldHasEventSensorOutput);


    /* ***************************************************
     * Property http://www.semanticweb.org/ajigboyeolamidipupo/ontologies/2016/2/untitled-
ontology-15#hasEventSensorType
     */

    /**
     * Gets all property values for the hasEventSensorType property.<p>
```

```
     *
     * @returns a collection of values for the hasEventSensorType property.
     */
    Collection<? extends EventSensorType> getHasEventSensorType();

    /**
     * Checks if the class has a hasEventSensorType property value.<p>
     *
     * @return true if there is a hasEventSensorType property value.
     */
    boolean hasHasEventSensorType();

    /**
     * Adds a hasEventSensorType property value.<p>
     *
     * @param newHasEventSensorType the hasEventSensorType property value to be added
     */
    void addHasEventSensorType(EventSensorType newHasEventSensorType);

    /**
     * Removes a hasEventSensorType property value.<p>
     *
     * @param oldHasEventSensorType the hasEventSensorType property value to be removed.
     */
    void removeHasEventSensorType(EventSensorType oldHasEventSensorType);


    /* ***************************************************
     * Property http://www.semanticweb.org/ajigboyeolamidipupo/ontologies/2016/2/untitled-
ontology-15#hasEventStatus
     */

    /**
     * Gets all property values for the hasEventStatus property.<p>
     *
     * @returns a collection of values for the hasEventStatus property.
     */
    Collection<? extends EventSensorStatus> getHasEventStatus();

    /**
     * Checks if the class has a hasEventStatus property value.<p>
     *
     * @return true if there is a hasEventStatus property value.
     */
    boolean hasHasEventStatus();

    /**
     * Adds a hasEventStatus property value.<p>
```

```
 *
 * @param newHasEventStatus the hasEventStatus property value to be added
 */
void addHasEventStatus(EventSensorStatus newHasEventStatus);

/**
 * Removes a hasEventStatus property value.<p>
 *
 * @param oldHasEventStatus the hasEventStatus property value to be removed.
 */
void removeHasEventStatus(EventSensorStatus oldHasEventStatus);


/* ***************************************************
 * Property http://www.semanticweb.org/ajigboyeolamidipupo/ontologies/2016/2/untitled-
ontology-15#hasEventTime
 */

/**
 * Gets all property values for the hasEventTime property.<p>
 *
 * @returns a collection of values for the hasEventTime property.
 */
Collection<? extends WrappedIndividual> getHasEventTime();

/**
 * Checks if the class has a hasEventTime property value.<p>
 *
 * @return true if there is a hasEventTime property value.
 */
boolean hasHasEventTime();

/**
 * Adds a hasEventTime property value.<p>
 *
 * @param newHasEventTime the hasEventTime property value to be added
 */
void addHasEventTime(WrappedIndividual newHasEventTime);

/**
 * Removes a hasEventTime property value.<p>
 *
 * @param oldHasEventTime the hasEventTime property value to be removed.
 */
void removeHasEventTime(WrappedIndividual oldHasEventTime);


/* ***************************************************
```

* Property