INTEROPERABILITY-BASED STANDARDS FOR SENSOR ENHANCED HEALTH INFORMATION SYSTEMS

BY

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A thesis submitted in fulfilment of the requirement for the degree of Doctor of Philosophy in Computer Science

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September 2020

ABSTRACT

This research work focuses on examining, analysing and classifying the difficulties of using sensors to improve the working standards of systems that are used in healthcare commonly referred to as Healthcare Information Systems. This constitutes an active research area because the cost of healthcare services is rising and the world population is growing older (population aging) whose need for HIS is paramount. Quite a number of researchers are investigating how to use sensors in order to provide healthcare services efficaciously and how to monitor healthcare systems remotely. A major challenge affecting integrating sensors in healthcare is interoperability, and in order to address this issue in the present environment where devices are expected to interact with each other more smoothly in what is popularly known as 'the internet of things', Interoperability as a Property (IaaP) has been proposed as a new paradigm. In this thesis, the enabling factors (or criteria) for Interoperability as a Property of a system (IaaP) were refined and a framework based on IaaP was proposed. To pave the way for further investigation, experimental scenarios for implementing each enabling criteria was examined, where environmental temperature was simulated as the Independent Variable (IV) and blood pressure was simulated as the dependent variable (DV). DEMATEL (DEcision-MAking Trial and Evaluation Laboratory) was used as a multiple-criteria decision analysis method to identify the interdependence among IaaP enabling criteria. Furthermore, DEMATEL was used to categorize IaaP enabling criteria as either being part of the causal or the effect group. Multi-criteria decision making results show that Intelligence Criteria (INT) constitute the most important IaaP enabling criteria followed by Communication Criteria (COM), the least important being Trace Criteria (TRC). Evaluation of results indicates that the IaaP framework constitutes a useful approach for bridging the interoperability gap in HIS. The contribution of the research lies with the effect of the main interoperable criteria for the huge amount of devices that are connected to the internet, it is outrageously difficult for device to smoothly interoperate, but Intelligence Criteria as well as the other criteria have been able to efficiently make interoperability possible. Even though a lot of research has been conducted with the aim of making devices used in HIS more interoperable, interoperability remains a challenge to most healthcare providers. In this research, interoperability as a property of a system is further confirmed to dwells on seven enabling requirements. All the seven requirements are used as building blocks for 'Interoperability as a Property Framework' (IaaPF). In addition to the medical sensory data, IaaPF should be able to receive other useful signals from sensors in its vicinity.

خلاصة البحث

يركز هذا العمل البحثي على فحص وتحليل وتصنيف صعوبات استخدام أجهزة الاستشعار لتحسين معايير العمل للأنظمة المستخدمة في الرعاية الصحية والتي يشار إليها عادةً باسم نظم معلومات الرعاية الصحية .يمثل هذا مجالًا نشطًا للبحث ، لأن تكلفة خدمات الرعاية الصحية آخذة في الارتفاع وتزايد عدد سكان العالم (شيخوخة السكان) الذين تعتبر حاجتهم إلى نظام المعلومات الصحية له أهمية قصوى .يبحث عدد كبير من الباحثين في كيفية استخدام أجهزة الاستشعار من أجل توفير خدمات الرعاية الصحية بفعالية وكيفية مراقبة أنظمة الرعاية الصحية عن بعد .يتمثل أحد التحديات الرئيسية التي تؤثر على دمج المستشعرات في الرعاية الصحية في إمكانية التشغيل المتداخل، ومن أجل معالجة هذه المشكلة في البيئة الحالية حيث يُتوقع أن تتفاعل الأجهزة مع بعضها البعض بشكل أكثر سلاسة في ما يُعرف باسم "إنترنت الأشياء"، قابلية التشغيل البيني كملكية (IaaP) تم اقتراحه كنموذج جديد .في هذه الأطروحة ، تم تنقيح العوامل التمكينية (أو المعايير) الخاصة بقابلية التشغيل البيني كخاصية للنظام (IaaP) و اقترح إطار عمل يستند إلى IaaPلتمهيد الطريق لمزيد من البحث ، تم فحص سيناريوهات تجريبية لتنفيذ كل معايير التمكين .تم استخدام DEMATEL مختبر التجارب والتقييم في صنع القرار (كطريقة لتحليل القرارات متعددة المعايير لتحديد الترابط بين معايير تمكين IaaP .علاوة على ذلك ، تم استخدام DEMATEL لتصنيف معايير تمكين IaaP إما كجزء من السببية أو مجموعة التأثير .تُظهر نتائج اتخاذ القرارات متعددة المعايير أن معايير الذكاء (INT) تشكل أهم معايير تمكين IaaP متبوعة بمعايير الاتصال (COM)، وأهمها معايير التعقب (TRC) .تشير نتائج التقييم إلى أن إطار عمل IaaP يمثل نهجًا مفيدًا لسد فجوة التشغيل البيني في نظام HIS .تكمن مساهمة البحث في تأثير المعايير الرئيسية القابلة للتشغيل البيني للكم الهائل من الأجهزة المتصلة بالإنترنت ، ومن الصعب للغاية أن يتفاعل الجهاز بسلاسة ، لكن معايير الذكاء تمكنت من جعل قابلية التشغيل البيني ممكنة .على الرغم من إجراء الكثير من الأبحاث بهدف جعل نظام المعلومات الصحية الخاص به أكثر قابلية للتشغيل البيني ، فإن إمكانية التشغيل البيني لا تزال تشكل تحديًا لمعظم مقدمي الرعاية الصحية .في هذا البحث ، يتم التأكيد بشكل أكبر على قابلية التشغيل البيني كخاصية للنظام على سبعة متطلبات تمكين .جميع المتطلبات السبعة هي "قابلية التشغيل البيني كإطار خاصية (IaaPF) . "إن مضمون النتيجة يكمن في تصميم IaaPFبطريقة تستخدم فقط المستشعرات الطبية .يجب أن توفر الأبحاث المستقبلية حاجة إلى أجهزة استشعار محيطة لقراءة البيانات البيئية .بالإضافة إلى البيانات الحسية ، ينبغي أن يكونIaaPF قادرًا على استقبال إشارات أخرى مفيدة من أجهزة الاستشعار في المنطقة المجاورة لها.

APPROVAL PAGE

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DECLARATION

I hereby declare that this thesis is the result of my own investigations, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

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Signature .... Date ....

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This thesis is dedicated to my family

ACKNOWLEDGEMENTS

I would like to start by praising Allah S.W.T for all HIS favours, which are so numerous; so much so that it is practically impossible to count them. Without Allah's help and guidance, I wouldn't have been able to achieve anything in life, which includes this PhD work. May Allah continue to guide and protect us, and may His peace and blessings be upon prophet Muhammad (SAW).

My heartfelt gratitude goes to my one and only wife, Amina Muhammed Magaji and our lovely kids Musab, Layla and Masud for their patience, prayers and understanding during the research. You guys mean a lot to me; you are truly a source of joy and happiness to me.

I wish to express my sincere appreciation to those who helped me, in any way, while I was working on the research. To mention some, I would like to thank my friends at RCYCI Dr.Adnane Habib and Mr. Ali Al-Khaldi for their brotherly and technical advice. I would also like to thank my other colleagues at RCYCI such as Dr. Adel Babtain, Engineer Tareq Shafi, Dr. Emad Nassar, Dr. Zahir Hussain, Mr. Ghulam Ghous, and Engineer Abdulmohsen for their indirect support.

I am indebted to my brothers Abdullah Mekano and Adamu Muhammed Mekudi and to my sisters Hajiya Kulu Adamu and Aishatu Adamu for always being there for me, no matter what. May Allah strengthen our brotherly bond here on earth and in Jannatul Firdaus. I would also like to appreciate the motherly support I always get from my stepmother (Hajiya Habiba); thank you mama for always praying for my success in life.

Finally, I am most grateful to my supervisor Dr. Adamu Abubakar, and Dr. Murni Mahmud, co-supervisor for their guidance, support, patience and constructive criticism. Their contribution helped in shaping this research into what it is today.

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LIST OF ABBREVIATIONS

6LoWPAN	IPv6 over Low-Power Wireless Personal Area Networks
BAN	Body Area Network
CDSS	Clinical Decision Support System
DEMATEL	DEcision-MAking Trial and Evaluation Laboratory
HL7	Health level seven
IaaP	Interoperability as a Property
IoT	Internet of Things
LoRa	Longe Range protocol
MBU	Mobile Base Unit
MCDA	Multi-Criteria Decision Analysis
mHealth	Mobile Health
MQTT	Message Queuing Telemetry Transport
NB-IoT	Narrowband Internet of Things
PAN	Personal Area Network
PDA	Personal Digital Assistant
RFID	Radio-frequency Identification
SE-HIS	Sensor Enhanced Health Information System

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND OF THE RESEARCH

It is important to highlight the fact that even though most literatures refer to HIS as Health Information system, some use the term Hospital Information System or Healthcare Information System (Grandia, 2017). To correctly and thoroughly understand what Health Information Systems are, it would be interesting to first look at the three keywords that are used, which are health, information, and system. According to Oxford learner's dictionary, "health is the condition of a person's body or mind. Health could also be defined as the work of providing medical services". Cambridge dictionary defines information as facts about a situation, person, event, etc. System is defined by Oxford learner's dictionary as a group of things, pieces of equipment, etc. that are connected or work together. Considering all these definitions, we can see that HISs is a group of things, which include devices and people, that are working together to efficaciously manage data about the medical condition of patients. In simple terms, HIS are systems that manage healthcare data, and all the activities revolving around it. According to Brook (2019), a health information system refers to a system designed to manage healthcare data. This includes systems that collect, store, manage and transmit a patient's electronic medical record (EMR), a hospital's operational management or a system supporting healthcare policy decisions.

Measure Evaluation reports of 2018 highlight the importance of differentiating a strong HIS from other kinds of health information systems. A strong HIS does not only serve patients and hospital practitioners but also cater for the population and the government it serves. A strong HIS should have a Well-defined strategy with standards and principles; defined health indicators and data sources used consistently; a user-friendly structure; and standard operating procedures for data collection, analysis, and use. HIS should captures and monitors all health services and functions (e.g., medicines, human resources, technology); encompasses all data sources (e.g., routine records, population surveys, civil registration, and vital statistics). HIS should be functional, it should use appropriate technology (including paper records) for the context; has a plan for data quality checks and strategies for using and sharing data; has appropriate training for health workers (Grandia, L. (2017). HIS should be adaptable and scalable. It should have the in-country capacity to redesign, reform, expand, or roll out the HIS through procedures and standards which govern the regular review of evolving health sector information needs, measures to support sustainability, ongoing human capacity building, and methods to evaluate new interventions. HIS should be resilient: Is able to withstand social, political, and biological crises through mechanisms for resilience, coordination with other health system functions, and regular assessments to determine system capacities and weaknesses (Liashiedzi, 2018).

HIS does not only have to do with health, but they also they cover wide areas that affect stakeholders in a verity of ways. Therefore, there are numerous types of HISs. Levin, D. (2019) identifies some of the most common types to include: “Strategic or Operational Systems”, “Clinical and Administrative Systems for Managing Patient Information on an Administrative Level”, “Electronic Health Record and Patient Health Record”, “Subject- and Task-Based Systems”, “Financial and Clinical Health Information Systems”, and “Decision Support Systems”. There are many specific HIS, most of which can be classified as one of the types listed above.

The major reasons for implementing HIS is simply to improve the quality, safety, and services of healthcare. Rahimi, Vimarlund, and Timpka (2009) identified eleven areas as being important for the implementation of HIS. These areas can be divided into three domains with regard to the time span of the decision-making process: “The long-term strategic domain: management involvement, motivation and rationales, surveillance of system effectiveness, and information needs assessments”. The medium-term tactical domain: education and training support, the implementation process and methods, work routine and workflow integration, and system integration. The day-to-day operational domain: trust, user participation and involvement, and technical system performance.

1.2 ARCHITECTURAL AND CONCEPTUAL FRAMEWORKS OF SENSOR ENHANCED-HIS

The theories and concepts associated with Sensor-Enhanced Health Information Systems are presented in Table 1.1. The architectural and conceptual frameworks of Sensor Enhanced-HIS (SE-HIS) are presented in Figure 1.2 and Figure 1.3 respectively.

Table 1.1 SE-HIS theories and concepts

Based on the research papers published that are related to Health Information Systems (HIS) in ubiquitous computing environments, the challenges that motivate researchers to work in this area of research include:	• Unobtrusiveness • Sensitivity and calibration • Energy • Data acquisition efficiency • Error resilience and reliability • Interoperability • Bandwidth • Security • Privacy • User-friendliness • Ease of deployment and scalability • Mobility
HIS frameworks and architectures are proposed based on sensors that are (i) wearable or attached in the vicinity of the patient; (ii) implanted in the body of the	• WBAN • Smart Shirt • Internet of Things

patient. Generally, the frameworks are presented in THE form of:	
It is worth mentioning here that the technologies used in building Health Information Systems (HIS) in ubiquitous computing environments include:	• Sensors embedded in body area network • Wireless communication technologies (Wifi, Bluetooth, etc) • A local processing unit (mobile phone or Personal Digital Assistant (PDA))

Based on Maslow's hierarchy of needs (Maslow, 1943), the necessary major components for building SE-HIS are identified and the components are presented in a hierarchy of importance as shown in Figure 1.1.

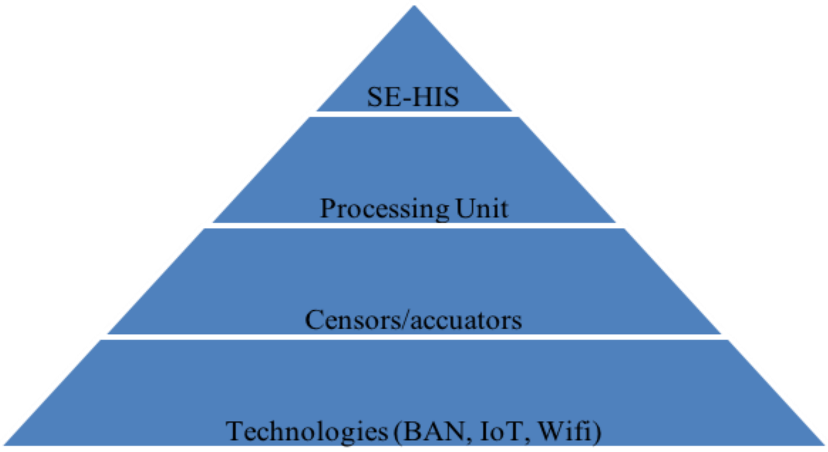

Figure 1.1 SE-HIS hierarchy of importance

As indicated by the hierarchy in Figure 1.1, the most important aspect to consider when building health information systems is that of technology such as BAN, Wifi and IoT that form the basis or the foundation. Closely following technology in the hierarchy of importance are the sensors and actuators. Without the sensors and the actuators, the physiological data cannot be measured from the body of the patient. They are thus considered as the second most important aspect in building SE-HIS followed by the local processing unit (such as mobile phone or PDA) that allows the collected data to be processed and sent to the healthcare personnel or directly to the main HIS at the hospital and finally the SE-HIS. Based on the hierarchy of importance presented in Figure 1.1, an architectural framework is developed as shown in Figure 1.2.

The architectural framework presented in Figure 1.2 clearly shows that three components are required in building SE-HIS which are (i) network technologies; (ii) sensors and actuators; and (ii) processing unit. The process of building SE-HIS usually involves numerous challenges that can be classified into (a) security-related (b) communication-related (c) user acceptance related, and (d) challenges that are related to the function of the system in its entirety. Such challenges affect the performance, integrity, and acceptability of SE-HIS. Therefore, when proposing an effective framework, it is important that the challenges are carefully and thoroughly studied and considered beforehand.

Figure 1.3 attempts to put together all the concepts and theories in a conceptual framework, which is based on the architectural framework presented in Figure 1.2. The conceptual framework has three layers: (i) basic factors; (ii) underlying factors; and (iii) outcomes. The layer tagged as ‘outcomes’ is sitting on top of the framework and represents what is desired to be achieved by building the SH-HIS. The goal is to achieve independent living for people that usually depend on others for their daily activities. In order to achieve the objectives mentioned in the ‘outcomes’ layer, all the necessary factors for an independent living must be identified. Such factors are presented in the ‘underlying factors’ layer. The ‘basic factors’ layer is considered as the most important layer as it shows the components and the structure of the systems required to support the other two layers.

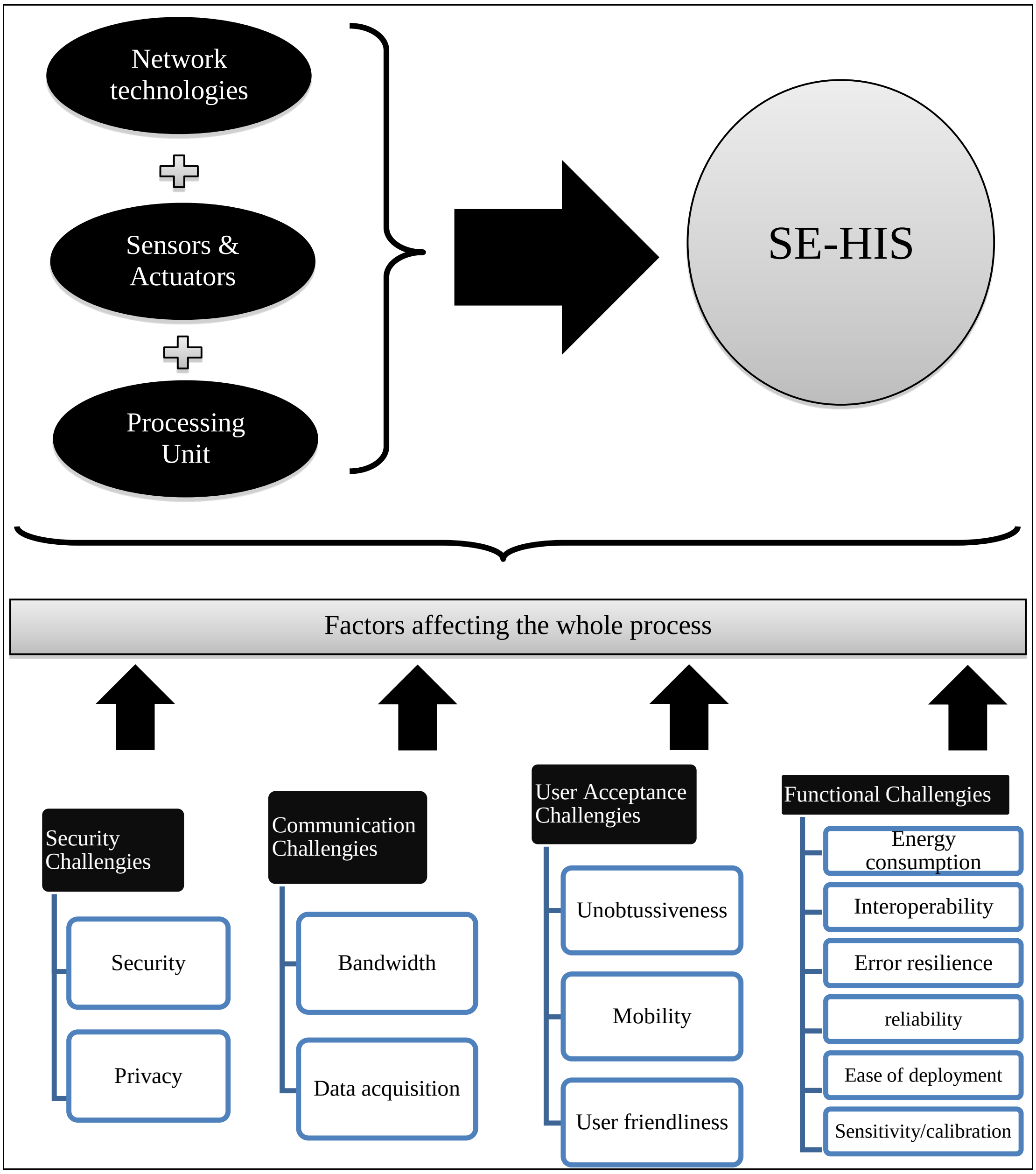

Figure 1.2 Architectural Framework

It is worth mentioning here that the discussion about the factors affecting integrating sensors in healthcare remains incomplete if the organizational policies and politics are not considered. The organizational policies and politics play a vital role in minimizing the gap created by interoperability among health-related devices.

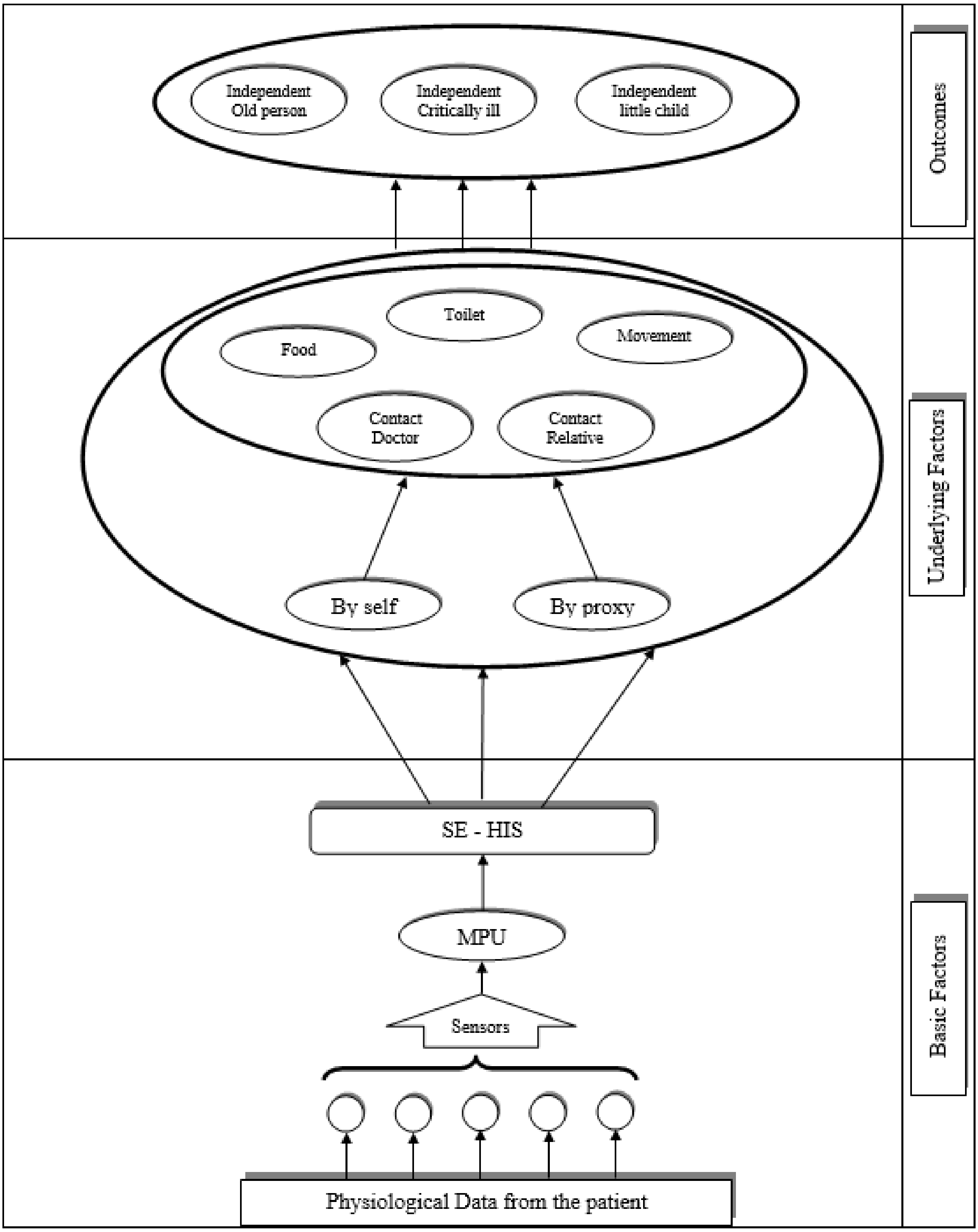

Figure 1.3 Conceptual framework

1.3 PROBLEM STATEMENT

One major misconception is that people generally consider HIS as a panacea for all medical problems and difficulties. A major implication derived from the meta-analysis of Rahimi, Vimarlund, and Timpka (2009) was that HIS is a means and not an end. By merely implementing a HIS will not automatically increase the efficiency of a clinical organization. Expecting a HIS implementation to solve organizational problems is completely wrong. Stakeholders must understand that when implementing a HIS, they cannot compromise over what is needed to achieve system adoption. For example, the use of HIS for elderly people.

It has already been identified in Koch, Marschollek, Wolf, Plischke, & Haux, (2009), Lanzieri, (2006) and United Nations (2004; 2009; 2010) that the world population is in the process of aging. According to that article, "Population aging shows the changes in the proportion of different age groups usually based on a three-age-group population model: young age group (<20), working age group (20 – 64), and elderly people (>64)" (Koch, et al., 2009). The statistics are shown in Figure 1.4 as explained in United Nations (2009).

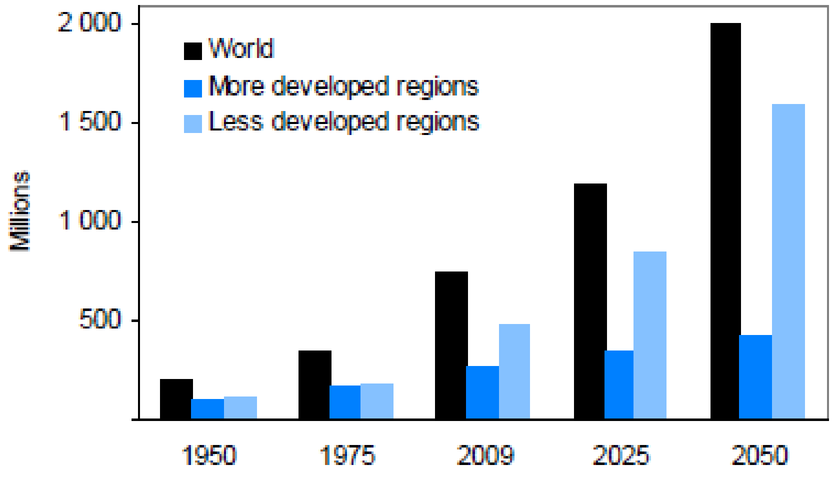

Figure 1.4 Population aged 60 and above