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MULTI- SOURCE DATA FUSION FRAMEWORK FOR REMOTE TRIAGING AND PRIORITIZATION IN TELEMEDICINE

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MULTI- SOURCE DATA FUSION FRAMEWORK FOR REMOTE TRIAGING AND PRIORITIZATION IN TELEMEDICINE

By

OMAR HUSSEIN SALMAN

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

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DEDICATION

This thesis is dedicated to:

My Father and Mother (Mr. Hussein and Jenan) , Number One and two for Me , for their love and endless support,

My beloved brothers (Ali and Ahmmed), The Shoulders to Lean On

My lovely sisters (Amal, Ibtehal, Alaa and Doaa), The Greatest Gifts My Parents Ever Gave Me

My lovely wife (Israa), My Soul Mate , for her patience and encouragement,

My beloved sons (Abdul Rahman and Yasser), The Reasons to Get Through Another Day.

Every Member in Mr. Hussein Family Tree,

My Supervisor,

All my Supervisory Committee,

All of My Friends,

My beloved first and second country Iraq and Malaysia

"Without Your Support and Encouragement,
My Success Wouldn't Have Been Possible."

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MULTI- SOURCE DATA FUSION FRAMEWORK FOR REMOTE TRIAGING AND PRIORITIZATION IN TELEMEDICINE

By

OMAR HUSSEIN SALMAN

November 2015

Chairman : Mohd Fadlee A Rasid , PhD
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The more the worldwide population gets older, the bigger is the need for technologies, computerized software algorithm and smart devices to monitor and assist patients anytime anywhere so as to give them a more independent lifestyle. Young people and children can also take advantage of the benefits of being monitored by healthcare systems not only in hospitals but also by using telemedicine when they are at their own homes. Consequently, in order to accommodate the increasing number of users, the remote patient monitoring is one of the issues that telemedicine and Wireless Body Area Networks (WBAN), have to tackle on, and it constitutes the main focus of this research. In order to provide healthcare services for a huge number of users, the healthcare providers triage the patients. Triaging involves an initial sorting of patients who arrive at the Emergency Department (ED) in order to prioritize the most emergency patients and to ensure providing them the appropriate and rapid healthcare services. Triage is a complex decision-making process, and as a result several triage scales have been designed to guide the triage nurse inside ED to a correct decision.

This thesis proposes a multi-sources data fusion framework to improve the healthcare scalability efficiency by enhancing the remote triaging and remote prioritization processes for the patients who are in places that are far from the ED and with no triage nurse. The proposed framework is also used to provide users with the compatible healthcare services over telemedicine systems. The proposed framework named Multi Sources Healthcare Architecture (MSHA) considers multi- heterogeneous sources: sensors (ECG, SpO2 and Blood Pressure) and text-based inputs from wireless and pervasive devices of WBAN.

As telemedicine consists of three tiers (Sensors/ sources, Base station and Server), the simulation of the proposed frameworks as fusion algorithm in the base station and as healthcare services algorithm in the server was demonstrated. In order to save more lives especially for the users who have the most emergency case, the research main goals were set to be for the achievement of a high level of accuracy in prioritizing and triaging remote patients. The role of multi sources data fusion in the telemedicine healthcare services systems in terms of estimating the patients' medical status has been demonstrated.

Five triage levels, which are different levels of medical emergency (risk, urgent, sick, cold state and normal), were presented in this study. The advantages and the role of each level in term of triaging and prioritizing the remote patients were discussed. The research methodology were presented in four connected phases (preliminary study, modelling, development and evaluation) and each phase has certain goals. In addition to that, the demonstration on how MSHA can be applied in a healthcare telemedicine environment was presented using a proposed scenario.

Simulation results, based on datasets for different symptoms of heart diseases, demonstrate the superiority of MSHA algorithms as compared to benchmark algorithms in terms of triaging and prioritizing patients remotely and also in terms of data fusion processing in healthcare application. The accuracy of MSHA in triaging the patients who are in Risk level was 100%, while it was 77% for benchmark improvement method, 84% for two sources fusion and 85% for three sources fusion. Moreover, the MSHA accuracy of triaging patients for Sick level was 100%, while it was (54%, 61% and 63%) for the other algorithms respectively. In addition, the MSHA accuracy for triaging the patients who are in Normal level was 100% and it was (66%, 87% and 88%) for the other algorithms respectively.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Doktor Falsafah

RANGKA KERJA DATA FUSION PELBAGAI SUMBER UNTUK SARINGAN JARAK JAUH DAN KEUTAMAAN DALAM TELEPERUBATAN

Oleh

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Semakin ramai penduduk di seluruh dunia menjadi semakin tua, semakin besar keperluan teknologi, algoritma perisian berkomputer dan peranti pintar untuk memantau dan membantu pesakit-pesakit pada bila-bila masa dan dimana sahaja untuk menjadikan mereka lebih berdikari dalam kehidupan. Golongan muda dan kanak-kanak turut mengambil kesempatan daripada manfaat yang dipantau oleh sistem penjagaan kesihatan ini bukan sahaja di hospital tetapi juga menggunakan teleperubatan apabila mereka berada di rumah mereka sendiri. Oleh itu, untuk menampung peningkatan dalam bilangan pengguna, pemantauan pesakit dari jarak jauh merupakan salah satu isu yang perlu ditangani oleh teleperubatan dan *Wireless Body Area Networks* (WBAN) dan ia merupakan tujuan utama kajian ini. Dalam usaha untuk menyediakan perkhidmatan penjagaan kesihatan bagi sejumlah besar pengguna, pusat penjagaan kesihatan menyediakan saringan ke atas pesakit. Langkah saringan ini melibatkan pengasingan awal pesakit yang tiba di Jabatan Kecemasan (ED) agar memberi keutamaan kepada pesakit kecemasan yang paling kritical teruk dan bagi memastikan mereka menyediakan perkhidmatan penjagaan kesihatan yang sesuai dan pantas. Saringan adalah satu proses membuat keputusan yang kompleks, dan hasilnya beberapa skala saringan telah direka untuk membimbing jururawat saringan di Jabatan Kecemasan bagi membuat keputusan yang betul.

Oleh itu, tesis ini mencadangkan satu gabungan rangka kerja dari pelbagai sumber data untuk meningkatkan penjagaan kesihatan yang diukur dari segi kecekapan dengan meningkatkan proses saringan dari jarak jauh dan keutamaan kawalan dari jauh untuk pesakit yang berada di tempat yang jauh daripada Jabatan Kecemasan dan tanpa jururawat saringan. Rangka kerja yang dicadangkan juga digunakan untuk menyediakan kepada pengguna perkhidmatan penjagaan kesihatan yang lebih sesuai dengan sistem teleperubatan. Rangka kerja yang dicadangkan ialah *Multi Sources Healthcare Architecture (MSHA)* yang terdiri daripada pelbagai sumber: sensor (ECG, SpO2 dan Tekanan Darah) dan sumber berasaskan teks dari peranti tanpa wayar dan peluasan WBAN. Sebagai teleperubatan terdiri daripada tiga peringkat (penderia / sumber, Stesen Pangkalan dan pelayan), simulasi rangka kerja yang dicadangkan sebagai algoritma gabungan di dalam stesen pangkalan dan algoritma perkhidmatan penjagaan kesihatan di dalam pelayan ditunjukkan. Dalam usaha untuk menyelamatkan

lebih banyak nyawa terutama bagi pengguna yang mempunyai kes kecemasan yang paling teruk, kami menetapkan matlamat utama kami untuk mencapai tahap ketepatan yang tinggi dalam memberi keutamaan dan saringan pesakit dari jauh. Peranan pelbagai gabungan sumber data dalam sistem perkhidmatan teleperubatan penjagaan kesihatan ini dari segi menganggarkan status kesihatan pesakit telah ditunjukkan.

Lima tahap *triage*, yang berbeza dalam tahap kecemasan perubatan (risiko, segera, sakit, negeri sejuk dan biasa), telah dibentangkan dalam kajian ini. kelebihan dan peranan setiap peringkat dalam *triaging* dan mengutamakan pesakit jauh telah dibincangkan. Metodologi kajian telah dibentangkan dalam empat fasa yang bersambung (kajian permulaan, model, pembangunan dan penilaian) fasa, setiap fasa mempunyai matlamat tertentu. Selain itu, menunjukkan bagaimana MSHA boleh digunakan dalam persekitaran teleperubatan penjagaan kesihatan yang menggunakan senario yang dicadangkan. Selain itu, rangkakerja yang dicadangkan telah menunjukkan bagaimana MSHA boleh digunakan dalam persekitaran teleperubatan penjagaan kesihatan yang menggunakan keadaan suasana yang dicadangkan.

Keputusan simulasi, berdasarkan set data untuk gejala yang berbeza daripada penyakit jantung, menunjukkan keunggulan algoritma MSHA berbanding algoritma penanda aras dari segi saringan dan keutamaan pesakit dari jarak jauh dan juga dari segi pemprosesan gabungan data dalam aplikasi penjagaan kesihatan, Ketepatan MSHA dalam saringan pesakit yang berada pada tahap Risiko adalah 100%, manakala ia adalah 77% untuk peningkatan penanda aras, 84% untuk dua sumber fusion dan 85% untuk tiga sumber fusion. Selain itu, ketepatan MSHA bagi saringan pesakit untuk tahap Sakit adalah 100%, manakala ia adalah (54%, 61% dan 63%) bagi algoritma lain masing-masing. Tambahan pula, ketepatan MSHA untuk saringan pesakit yang berada pada tahap normal adalah 100% dan ia adalah (66%, 87% dan 88%) bagi algoritma lain-lain.

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My beloved wife and sons were beside me throughout my journey facing many hard moments. I really appreciate your patience, dedication, and true support for me.

I certify that a Thesis Examination Committee has met on 19 November 2015 to conduct the final examination of Omar Hussein Salman on his thesis entitled "Multi-Source Data Fusion Framework for Remote Triaging and Prioritization in Telemedicine" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

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LIST OF ABBREVIATIONS

ANNs	Artificial Neural Networks
ATA	American Telemedicine Association
BEWS	Bispebjerg Early Warning Score
Bp	Blood Pressure
CDSSs	Clinical Decision Support Systems
CEP	Complex Event Processing
CFCM-ESI	Competitive Fuzzy Cognitive Map Emergency Severity Index
CMS	Center of Medicare and Medicated Services
CO	Coordinators
CRT	Capillary Refill Time
CTAS	Canadian Triage and Acuity Scale
CVD	Cardio-Vascular Disease
DS	Dempster Shafer
DST	Dempster Shafer Theory
EC	Emergency Call
ECG	Electrocardiogram
ED	Emergency Department
eMEWS	Electronic Modified Early Warning Scorecard
EMS	Emergency Medical Services
ESI	Emergency Severity Index
ETS	Emergo Train System
EWS	Early Warning Scorecard
FCM	Fuzzy Clustering Means
FCM-MDSS	Fuzzy Cognitive Map Medical Decision Support System
FN	False Negative
FP	False Positive
GDP	Gross Domestic Product
GSM	Global System for Mobile communication
GUI	Graphical User Interface
GW	Gateway
HFEA	Hybrid Feature Extraction Algorithm

HOCA	Healthcare Aware Optimized Congestion Avoidance
HWSNs	Healthcare Wireless Sensor Networks
IMDs	Interoperable Medical Devices
JTAS	Japanese Triage and Acute Scale
KB	Kilo Byte
KDS	Khoja Durrani Scott
LED	Light Emitting Diode
MAC	Media Access Control
MAS	Multi Agent System
MCIs	Mass Casualty Indicates
MEWS	Modified Early Warning Scorecard
MIs	Medical Institutes
MSHA	Multi-Source Healthcare Architecture
MTS	Manchester Triage System
NSCs	Non Specific Complaints
PC	Priority Code
PDAs	Personal Digital Assistants
PSI	Patient Status Index
QoS	Quality of Service
RHMSs	Remote Health Monitoring Systems
SMS	Short Message Service
SOA	Services Oriented Architecture
SpO2	Oxygen Saturation
START	Simple Triage and Rapid Treatment
TC	Trauma Call
TCP/IP	Transmission Control Protocol Internet Protocol
TN	True Negative
TP	True Positive
U.S.	United State
USSD	Unstructured Supplementary Services Data
WBAN	Wireless Body Area Network
WBSN	Wireless Body Sensor Network
WHEATS	Wearable personal Healthcare and Emergency Alerts and

	Tracking System
WSN	Wireless Sensor Network
WT	Wavelet Transform
XAMPP	Xcross Apache Mysql Php Perl

CHAPTER 1

INTRODUCTION

The increase in aging population and the number of chronic diseases have prompted society to increase health consciousness and patients to EHFRPH KDOWK FRQVFLRXV´ looking for enhanced health management [1]. Recent advances in computing and sensors network have piqued the interest of the healthcare industry in accordance with streamlining its processes to offer timely and effective services to patients. Computerized software algorithm and smart devices can streamline the relation between users and doctors by providing services in smart healthcare frameworks.

The new era of smart living is an emerging application of sensor networks and information fusion. For example, a user with cardiovascular disease may wear biological sensors that monitor vital signs, such as pulse rate and blood pressure; when the blood pressure and pulse rate are detected as unstable, the smart healthcare service notifies and stops the user [2]. Moreover, monitoring and detecting SDWLHQWV¶ activities and conditions normally requires the use of external sensors and sources around the body, thus imposing a significant burden on the overall system requirements. This condition, along with the large amount of sensor data from real-time continuous sampling, has raised the need for appropriate multi-sensory data fusion techniques (e.g., application-specific classifiers) and feature selection [3].

1.1 Evolution of Healthcare Services by Telemedicine

In healthcare services, measuring and monitoring body functions, parameters, and characteristics is crucial for human health. Methods based on telemedicine were developed and are being refined for this purpose [4]. Telemedicine is defined by the ,QVWLWXWH RI 0HGLFLQH DV ³WKH XVH RI HOHFWURQLF LQIRUPDWLRQ DQG FRPPXQLFDWLRQ technologies to proYLGH DQG VXSSRUW KHDOWK FDUH ZKHQ GLVWDQFH VHSDUDWHV SDUWLFLSDQWV´ [5]. Its purpose is to improve patient care by improving medical communication processes between patients and healthcare providers. The use of telemedicine will continue to increase in the future. A related concept is telehealth, which usually refers to clinical and non-clinical services, such as education, administration, or research [6]. Telemedicine generally means the provision and delivery of clinical services, and telesurgery enables physicians to invasively treat patients who are spatially separated from them. 9LUWXDO SUHVHQFH DQG UHPRWH GHOLYHU\ RI VHUYLFHV H[KLELW JUHDW VFLHQWLILF DQG commercial potential in health care [7]. Figure 1.1 illustrates the various domains of telemedicine. Telemedicine systems monitor human vital signs and provide services in different environments and conditions. According to [1], [4], and [8], a general three-tier pervasive telemedicine system based on a wireless body area network (WBAN) enables real-time and continuous healthcare monitoring. In Tier 1, users can obtain their vital signals through sensors (e.g., electrocardiogram [ECG] and

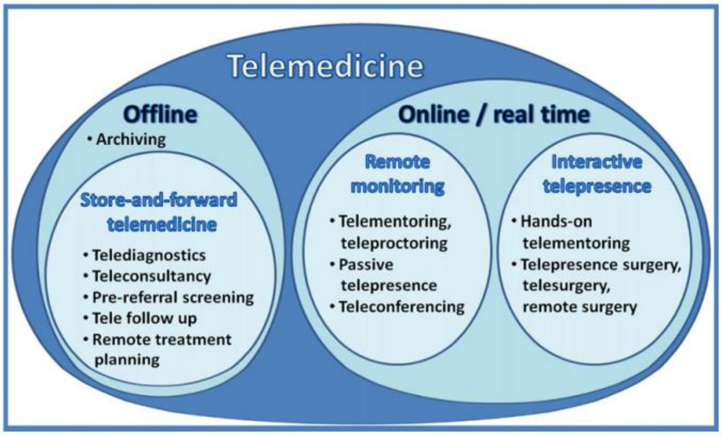

Figure 1.1 Various domains of telemedicine and the different categories of remote monitoring [7]

oxygen saturation [Spo2]) and send them to Tier 2, which is the personal gateway (e.g., handheld devices, personal digital assistants, and laptops) through small area network protocols (e.g., Bluetooth and Zigbee) and the WBAN. Medical data are sent from Tier 2 to Tier 3, which is the healthcare provider in medical institutes (MIs), through wide area wireless communication protocols or Internet services. Healthcare providers in Tier 3 apply certain processes and generate services that are sent back to users as responses. This process is shown in Figure 1.2.

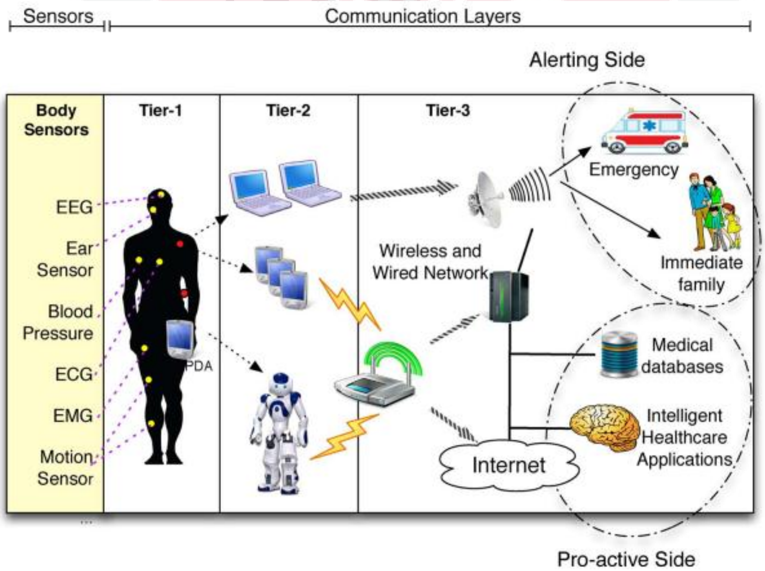

Figure 1.2 Three-tiered architecture of a WBAN telemedicine system for healthcare monitoring [8]

Telemedicine is useful, but many challenges and issues confront telemedicine systems. One of these issues is healthcare scalability [9], which relates to the increase in number of users per unit area. Without telemedicine system, users (patients) go to a hospital to obtain healthcare services. The increasing number of patients brings challenges to healthcare service providers, specifically challenges related to prioritizing the most urgent of emergency cases to save lives and the limited medical resources available in hospitals. To solve these problems, patients are triaged and prioritized at the emergency department (ED) by triage nurses. These challenges acquire increased significance when patients are far from hospitals and use remote healthcare services (telemedicine system).

1.2 Triaging and Prioritizing Patients

The term ³triage´ comes from the French word ³trier,´ ZKLFK PHDQV ³WR sort´ The concept was first used in warfare when a system was needed to prioritize all casualties and give immediate care to the most badly injured. In the hospital domain, triage has traditionally relied on the ability of nurses to prioritize cases. Vital signs have proved to be very important in the triage setting because they provide an objective complement to the nurses¶ professional judgment and optimize inter-rater consistency [10].

Triaging involves initially sorting patients who arrive at the emergency room (usually called ED) by quickly identifying patients who require immediate care because of urgent, life-threatening conditions. It also entails assessing the severity of the problems. Triaging is conducted to ensure that care is given in an appropriate and timely manner [11]; early identification of critically ill patients and stratification into priority levels upon admission to the ED is important for the quality and the safety of emergency medicine [8, 9]. Therefore, a primary aim of ED triage is to identify patients who can safely wait and those who cannot [13]. As triaging is a complex decision-making process, several triage scales were designed (presented in [11], [14]±[18]) to achieve triaging goals and to guide triage nurses in making correct triage decisions for patients who are physically inside the ED. However, in the case of telemedicine users or patients, neither triage nurses nor triage doctors are physically available to help them. Therefore, triaging and prioritizing processes are more complex in telemedicine than in actual ED situations. Such processes raise questions about how telemedicine users can be triaged, and how patients can be prioritized in most emergency cases. These concerns directly related WRSDWHQWV¶ are considered as the research problems. This study aims to improve telemedicine efficiency by improving triaging and prioritizing processes.

1.3 Research Problem

The increasing demand for healthcare services has led to the urgent need for effective and scalable healthcare services [5, 6] and healthcare surge according to [20] (scalability represents the ability to evaluate and care for an increasing volume of patients). Given the relation between healthcare surge capacity and patient volume, most current initiatives focus on identifying the adequate services, such as ambulance units, hospital beds, recipes, personnel, pharmaceuticals, supplies, and equipment. In the telemedicine environment, the increase in number of users causes a telemedicine scalability challenge that can be viewed from four perspectives. First, as the number of patients continuously increases, the finite set of healthcare professionals should effectively use any developed system to accommodate such a growing system demand [9]. The aging population inside healthcare service frameworks is a problem mentioned by many researchers [11, 20–25]. Second, the number of casualties increases during disasters, and the main problem is how to remotely prioritize and determine the order of casualties for treatment and transportation [16]. Third, mass casualties overwhelm available medical facilities in the battlefield; thus, accurate triaging and prioritizing are needed [26, 27]. Finally, the scalability problem is also related to the connection between a wireless sensor network and the Internet. Increase in the number of users means increase in the amount of queries. This sensor system is subjected to a scalability problem [29] and congestion occurs. In life-critical applications that involve large numbers of patients, congestion is undesirable and may cause death among patients [30]. Moreover, pervasive healthcare monitoring systems generally require the simultaneous use of several sensor devices and software. Software as a service approach can be used for scalability and ease of deployment, along with small and easily configurable sensor devices [31].

In large numbers of critically ill or injured patients, critical care triage — which includes both prioritizing patients for care and rationing scarce resources — is required [31, 32]. The triage system should be able to define patient care needs based on the acuity of their conditions and identify the manner of sorting patient care and treatment based on the severity of illness or injury [17]. This principle is specifically true if patients are assigned a lower triage priority than required, as their health may be jeopardized. However, over-triage can contribute to the less-than-optimal use of ED resources [34]. Balancing the patients' needs with healthcare prioritization may be one of the most complex and challenging tasks faced by today's physicians [35]. In the field of telemedicine and from the perspective of delivering healthcare services, one of the main problems in this domain is healthcare personalization, that is, enabling personalized healthcare services to be delivered to individuals at any place and any time [3].

The following is a brief description of the research problems:

1. Urgent need for effective and scalable health care services model [5,6].
2. Increase in the number of patients because of four main dilemmas, namely, population aging [11, 20–25], disaster scene [16], battlefield and seafaring [26, 27], and network congestion [28, 29], as shown in Figure 1.3. Therefore, the healthcare service providers in telemedicine are emphasized as requests increase by users.
3. Increase in remote patient requests that require critical care triage, including prioritizing patients for care and rationing scarce resources [16, 17, 31, 32].
4. Complex balancing of patient … level [33, 34].
5. Increased need for innovative solutions that meet the special needs of the elderly [36] and for appropriate multi-sensory data fusion techniques for providing remote healthcare services, including application-specific classifiers and feature selection [3].
6. Enabling personalized healthcare services to be delivered to individuals [3].

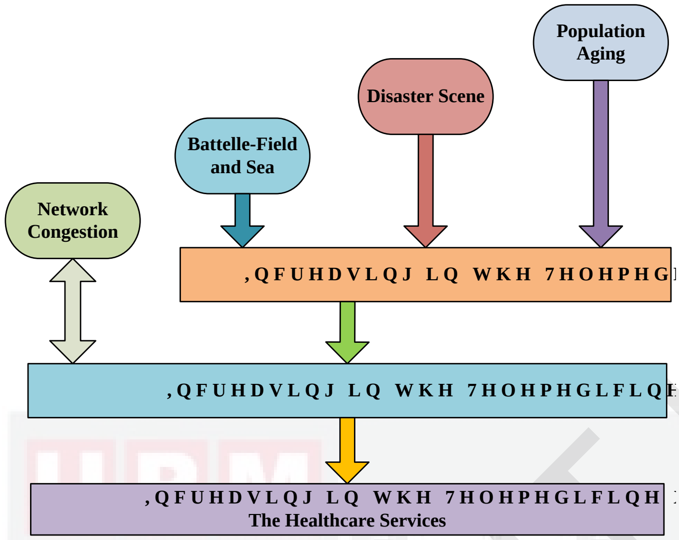

Figure 1.3 Problems that cause the increase LQ XVHUV¶ UHTXHVW LQ telemedicine

1.4 Research Aims and Objectives

This study aims to improve the remote electronic triage system to reduce the waiting time of patients with the most urgent emergency cases by designing and refining an DOJRULWKP WKDW DFFRPPRGDWHV DOO XVHUV¶ UHTXHVWV to subclasses, prioritizes users with severe emergency cases, and reduces the waiting time of those users. The main goal in this thesis is to design and simulate a telemedicine framework that can enhance the scalable efficiency of telemedicine system, triage patients, prioritize them remotely, and provide the proper service package to each user. This framework also provides patients with the ability to use other medical devices other than medical sensors (i.e., use of heterogeneous sources). The proposed algorithms also aim to demonstrate the importance of a data fusion method in wireless healthcare services applications.
The research objectives are as the following:

1. To investigate the scalability, triaging, and priority challenges in the telemedicine environment and to investigate the principles, advantageous, algorithms and applications of data fusion.
2. To specify the technical requirements for constructing new algorithms that can accurately and remotely triage and prioritize patients and provide them with reasonable healthcare service packages.
3. To develop and propose a multi heterogeneous sources (medical sensors and text) data fusion framework that improves telemedicine and accurately triages and prioritizes remote patients.
4. To develop a remote prioritization technique using a multi-source data fusion algorithm that can ensure prioritization of users with the most urgent of emergency medical cases and to reduce waiting time at the telemedicine server.

5. To develop a healthcare service provisioning module based on the output of the data fusion method in the proposed telemedicine framework to provide patients with an appropriate healthcare services package.

1.5 Research Scope

In telemedicine systems, data are processed through three main tiers, as shown in Figure 1.2. From the perspective of computer engineering, the research aim is to improve the performance of telemedicine by improving the remote triage process. The processes of the proposed algorithm are based on receiving data from multiple heterogeneous sources. Although different types of sources are involved in a telemedicine system (e.g., sensors, text, images, and video), only two sensors (ECG and Spo2) were used in the current remote triage system. Moreover, only one feature of each sensor was considered. Therefore, the scope of this research is set to be one step forward from the current research that is based on multi-sensors to future research that will be based on multi-sources. This study uses four sources, three sensors (ECG, blood pressure, and Spo2), and another heterogeneous source (text). Moreover, more than one feature is used from each source. As heart disease affects the health and working performance of patients, especially old people [37], this research includes monitoring patients with chronic heart disease, which is considered the most frequently occurring chronic disease directly related to the healthcare population aging problem.

1.6 Study Module

According to [1, 4, 7, 37], various issues exist in computer engineering and healthcare services based on WBAN. Technically, in healthcare services there are many aspects of challenges and applications one of them is the remote monitoring (telemedicine). Moreover, based on Figure 1.1, telemedicine has two main categories one of them is the real-time (On-line), which is dedicated for remote monitoring, and according to Figure 1.2 the telemedicine architecture includes three tiers. The summary of steps taken in this thesis is illustrated in Figure 1.4. The bold blue lines represent the direction followed by this thesis, and the dotted lines represent other directions that have been considered in other studies. The study module of this thesis is considered as an intersection area between computer engineering direction and telemedicine in healthcare services direction.

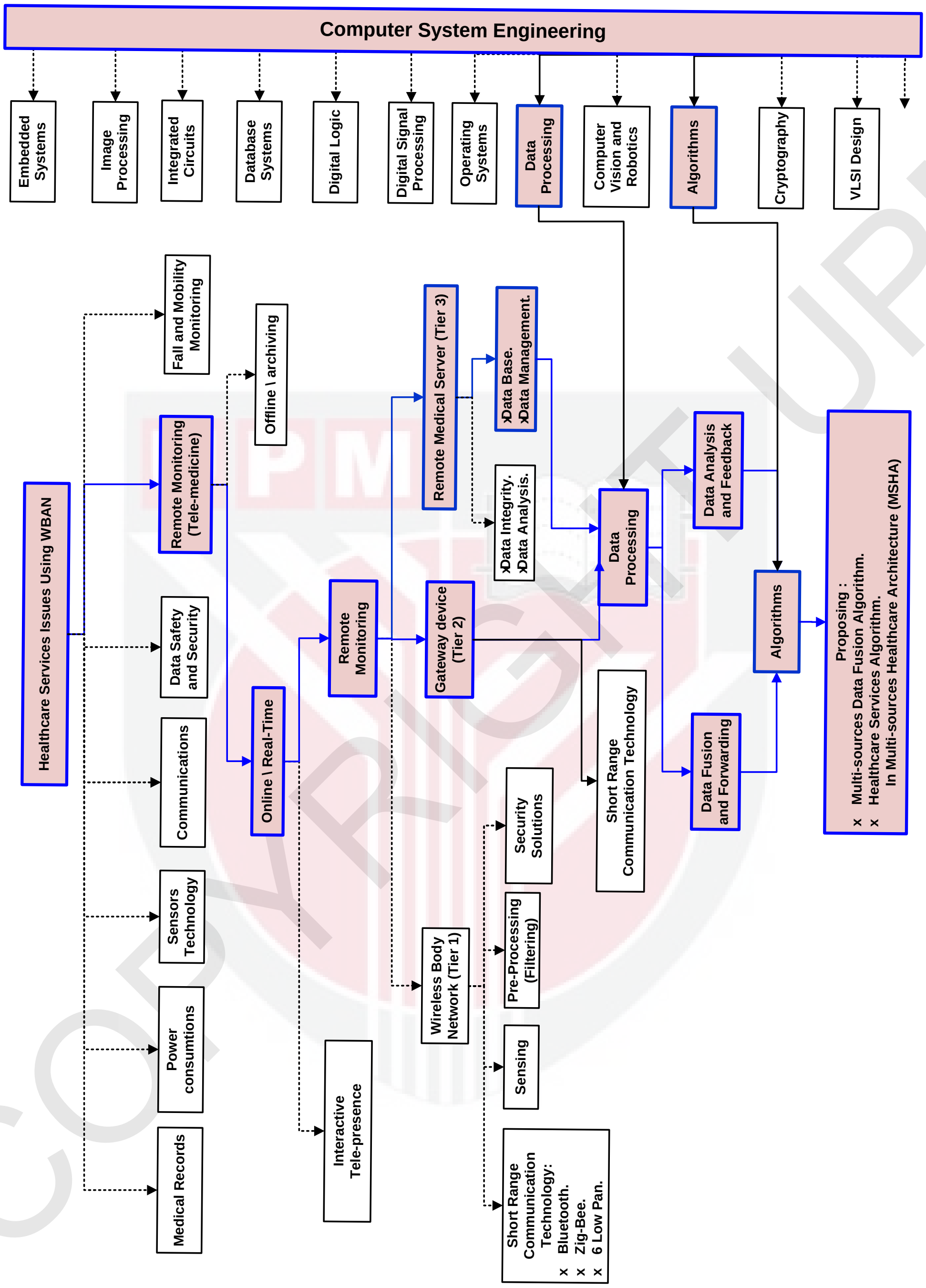

Figure 1.4 Study Module

1.7 Thesis Organization

This thesis is divided into five chapters. Chapter 1 provides the background of telemedicine, triaging and prioritizing patients. Moreover, this chapter demonstrates the motivation, problem statements, research aims and objectives, research scope, and study module. Chapter 2 briefly reviews the research on healthcare scalability and priority problems in the telemedicine service provisioning system. The remote triage system is also reviewed, followed by the role of data fusion in the telemedicine system. This chapter presents a general review of multi-source data fusion theories, applications, and algorithms that have been applied previously. This chapter ends with technical analyses to the research problems and highlights what should be done to solve those problems. Chapter 3 gives the full description of the research methodology, which consists of four phases, namely, preliminary study, modeling, development, and evaluation. Each phase corresponds to and addresses one of the research objectives.

Chapter 4 presents the results based on the proposed performance metrics and discusses the proposed telemedicine framework in seven sections. Each section has its own aims. Finally, Chapter 5 presents the conclusion and the contributions of this research. The areas to be pursued as future works are also suggested.

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