CHALMERS
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Autumn Leaves: Automatic Fall Detection, Alert and Assessment to Improve Pre-hospital Emergency Care Response

Master's Thesis in Biomedical Engineering

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Gothenburg, Sweden 2020

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Abstract

The World Health Organization (WHO) stated in 2018 that accidental falls are the second leading cause of injuries worldwide. Injuries on a severe magnitude due to a fall are not very common, but occur in 1 out of every 5 fall accidents. This results in broken bones or injuries to the head. Severe injuries as a result of fall cause a mortality of about 646 000 people every year, affecting adults aged over 65 years the most. Approximately 70 000 people in Sweden suffer a fall annually. Both severe and non-severe injuries due to fall add about SEK 25 billion as a cost to the society. Many cases do not get optimal treatment in-time, mainly due to delays in the alert and care processes. A major contributing factor to improve the situation is to enable a quicker and more precise pre-hospital care response-typically by ambulance. This thesis addresses this challenge by proposing and theoretically evaluate a Digital Health solution that includes automatic fall detection, logical alert routing, data fusion, clinical decision support and data sharing among the involved stakeholders. Exploratory studies on existing devices and technology that could aid in the detection of fall was performed. Further, semi-structured interviews were conducted with professionals in healthcare services to understand the current scenarios and care chains following a fall incident in an elderly person's home. The aggregated information was used to model and design a proposal for a Digital Health solution covering the complete care chain from incident via alert handling and triage to the ambulance en-route and arriving at scene.
The proposed solution detects fall incidents automatically in the home of the elderly, and through logical alert routing, involving relevant stakeholders, and information gathering from various sources, it improves the decision precision in providing an optimal pre-hospital care response. As part of this response the ambulance en-route is provided with information preparing for the arrival at scene. By combining, analyzing and modeling all the information aggregated from the different sources, e.g. data fusion, in an intelligent manner, the pre-hospital care provider is presented with decision support. This will help to make an informed decision with high precision on what are the most suitable actions to take including dispatching an ambulance if appropriate. The proposed solution was finally analyzed and evaluated using specific personas illustrating pros and cons in the solution.
In order to get practical experience on fall detection devices, the fall detection feature in Apple Watch Series 5 were briefly studied. The tests showed that the thresholds set for detecting fall were rather high and that this, together with the user interface of the device and battery capacity, may be significant obstacles, or even hindrance, for using this device when considering the types of falls and individuals addressed in this project.

Keywords: Digital Health, fall detection, automatic fall detection, elderly, vital parameters, pre-hospital care chain, fall incident, fall injuries, hip fracture, ambulance dispatch, alert and assessment.

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Tejas Venkatesh, Gothenburg, August 2020

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Acronyms

AI Artificial Intelligence. 19, 21, 22, 32, 38, 39, 60
API Application Program Interfaces. 37

BHK Bedroom-Hall-Kitchen. 44, 49

CDSS Clinical Decision Support System. 11, 38–40, 42, 43, 59–62, 67

DSS Decision Support Systems. 9, 38

ECG Electrocardiography. I, II, IV, 7, 14, 18, 25, 26
ED Emergency Department. 5, 7, 24, 39
EHR Electronic Health Records. 11, 37–39, 43, 55, 59–62

FHIR Fast Healthcare Interoperability Resources. 37

GPS Global Positioning System. 34, 36, 57

HIS Healthcare Information Systems. 38
HL7 Health Level 7. 37

ICT Information and Communication Technologies. 2, 3, 8, 37, 38, 60, 67
IEEE Institute of Electrical and Electronics Engineers. 11, 37

ML Machine Learning. 23, 38

PICTA Prehospital ICT Arena. 11
PPG Photoplethysmography. I, IV, 25–27, 33, 58

RFID Radio Frequency Identification. 34

SNOMED CT Systematized Nomenclature of Medicine Clinical Terms. 37
SvLc Sjukvårdens Larmcentral. xv, 7, 12, 24, 55

ToF Time-of-Flight. 21, 22

VIPHS the stepwise Verified Innovation Process for Healthcare Solutions. 11

WHO World Health Organization. v, 2
WiFi Wireless Fidelity. 14, 21, 36, 42, 53

1
Introduction

1.1 Scope

Fall injuries are one of the most common and dangerous injuries requiring ambulance transport to hospital. They are also the cause of major problems in the elderly population who often live alone, either independently or with support from home-help services, and also are generally fragile. In most cases, the elderly fall on losing balance, which commonly leads to injuries in extremities and head. In case of a fall injury, it can take hours before help arrives due to difficulties for the sufferer to call for help themselves. During these hours, the person in need may remain lying on the floor, experiencing severe pain and stress. Hip fracture and head trauma stand for most of the injuries. Complications after a fall trauma is common and lead to serious consequences such as death, or severe life-long immobility among the elderly. Therefore, it is of great importance to provide quick assistance at a fall incident in order to enable a rapid and optimal care that can improve the medical outcome of their injury. Due to the growing elderly population in the society, this problem is expected to increase in the future with an expected increasing care and economic burden to society. Developments in Digital Health solutions with focus on fall detection have increased recently. Current solutions for fall recognition mostly automatically detect fall incidents and warn relatives or caregivers. However, connecting automatic fall detection solutions to pre-hospital emergency care management seems to be a missing link. Introducing fall detection solutions with automatic alarm and transfer of incident information to a pre-hospital dispatch center for triage, evaluation and prioritizing, with potential call-out of an ambulance, could streamline the care process. Faster notification and intelligent information gathering from various sources at an incident, followed by quicker received assistance from the pre-hospital emergency care organization, should be beneficial to decrease poor medical outcomes for elderly people suffering from fall injuries. This is the scope of this work.

1.2 Background

1.2.1 Digital Health in a National and International Perspective

Subjects on healthcare have been the most explored topics since the availability of internet in the 1990s [1]. Modern day digital technologies such as the computers, internet and mobile devices aid in the development to provide better healthcare services [2]. Defined as the reinforcement of healthcare through using Information and Communication Technologies (ICT), Digital Health can be termed as an umbrella under which different health information concepts, such as telemedicine, ePublic Health, eMental Health and mHealth are delivered digitally. The advantage of Digital Health therefore is that prevention, training, diagnosis, therapy and care can all be delivered by means of digital technology irrespective of time and place [1].

An increased need for documentation to track the health of patients and the procedures performed on them promoted the growth of Digital Health to what it is today. Surging healthcare costs and continuous advancement in digital technology over the years have inspired the progress of electronic tracking systems for major healthcare needs. The development of Digital Health technologies have promoted the terrain of telemedicine, a major player in Digital Health where telecommunication technology is used to provide healthcare remotely [2]. A huge disparity in the cost, quality and availability of healthcare throughout the world has had an impetus to assimilating digital technology as solutions to improve health globally. The World Health Organization (WHO), along with its 191 affiliated member countries, is leading the way to integrate digital solutions to provide healthcare [3].

A substantial advancement in digital technology has made it possible for Sweden to profit from it's potential in digitization. Being one of the most forward countries with digitally seasoned inhabitants, most public sectors and enterprises deal with the consumers' activities digitally. International progress within digitization has been possible largely with the support of established information and communication companies from Sweden [4]. Implementation of projects such as the *Vision eHealth 2025* to improve digitization in healthcare and social services have provided impetus by proposing vast opportunities to strengthen digitization [5]. Further, a large part of the public expenditure is in the areas of social services and healthcare whereby a large proportion of the population seek services from agencies associated to social services and healthcare at one time or another. Development and integration of digital services for target groups for fall incidents could help ease the living conditions, especially of the elderly, allowing them to participate more effectively and independently in the society [4]. Although Digital Health can be a beneficial tool to providing quality healthcare services to the elderly, interaction between the different stakeholders in a digital care chain and operational structures within different organizations could be seen as major contributors to implementation challenges.

1.2.2 Fall Detection Solutions

Advancement in technology has allowed Digital Health solutions utilizing fall detection to record data and automatically send alarms to the dispatch center. This feature is however not being utilized to its fullest potential. Instead, they are linked to care services provided by the respective manufacturers, community care or are directly linked to communicate with the users' relatives in one way or another.

Monitoring devices for detecting fall in elderly can be divided into wearable and non-wearable solutions, with wearable solutions further being branched into automatic and manual. A limited number of the available monitoring devices are able to monitor some of the vital signs, such as heart rate and respiratory rate. A requirement of a wearable solution is that it obligates the person under monitoring to wear some sensors. Sensors in wearable solutions accurately estimate the behavior before, during and after a fall [6] [7]. As effective as this method of fall detection seems to be, it is distressing and burdensome to the person wearing it. Alternatively, non-wearable solutions such as cameras, infrared sensors and ultrasonic sensors are less burdensome and can estimate the behavior of the person under monitoring without having to wear the sensors [8] [9].

Data fusion technology is another trend that has been discussed when proposing fall detection solutions in various studies [10]. As a technology, data fusion integrates multiple unrelated data sources to increase the performance, accuracy and reliability in fall detection solutions [11]. The prevalence using these technologies among the elderly and their ability to interact with them, however, could indicate to be a hurdle in implementing them.

1.2.3 Technology and the Elderly

The elderly is a diverse group with a lot of different possible disabilities and physical conditions. Poor memory, visual impairment, frequent dizziness and impaired cognition are examples of disabilities. The disabilities can act as a restriction to them utilizing ICT services, and thereby also affecting their effective interaction within the society. In addition, there are also healthy elderly people who are well versed in dealing with the technology that exists today in a skillful manner [12]. In the perspective of research, the elderly are often divided into two groups, where old people within from of 65 to 79 are termed as young-old and old people above the age of 80 are called older-old [12]. A survey made by *Kairos Future* found that there was little or no difference between the young-old and the population younger than them [13].

Trust in novel technologies to aid in daily activities has shown great interest among elderly within the European region, whereby digitization in healthcare is being welcomed warmly. However, it has also been seen that the adoption and use of digital healthcare solutions is low [14]. Based on a European survey conducted by the technology company *Doro*, several insights have been obtained on the perception of new technology by the elderly. A thousand Swedish elderly were included in the survey along with four thousand more elderly from various other countries. One of the conclusions from the survey was that 84% of the Swedish elderly would want to live independently by themselves at their private residences, although a worry still remains that they would not be able to take care of themselves, along with some issues with respect to security [15]. The survey also found that 37% of the elderly in major European countries would fully believe in smart home solutions to help them in enhancing their living condition using smart home solutions, while 40% of them reported that they would trust them partly [15].

Although surveys report good numbers, the reality is much different, with very low adoption of smart home technologies. At present it is seen that only 14% of the elderly use technical solutions, such as security alarms, fall sensors, remote monitors and mobile health applications, to aid their daily living [15]. Three-fifths of this 14% reported to have felt guarded using these technologies. Additionally, these technologies contribute to making 58% of the families of the elderly using smart sensors feel secure. In all, digitization is viewed positively among the elderly in Europe with 49% Swedish elderly endorsing that digitization of healthcare is a progressive approach to better quality living [15].

1.2.4 Living Conditions of the Elderly

When people grow older, it is not unusual for them to go through different changes, having to deal with physically, socially and mentally conditions. A need to be taken care of in a different manner when they experience changes could therefore arise. In several countries, it is very common for families and relatives to take the primarily responsibility to care for their elderly. However, Sweden being a welfare state, the main responsibility to take care of the elderly population lies with the social services, while the families act as backup although more or less involved in the care [16].

A large proportion of the elderly in Sweden prefer to continue living independently in their own homes for as long as possible. The Swedish welfare system aids the elderly to have the possibility of remaining in their homes and receive assistance from their respective municipalities social service [17]. There are, however, other types of support available to the elderly who do not have the possibility to take care of themselves on their own, and therefore requiring additional support [17]. Various living conditions, currently, of elderly in Swedish society are described below: [17].

- Municipalities assist elderly people who wish to remain at their own homes by providing care services, called *Hemtjänst*, to facilitate an ease in living [17].
- *Senior housing* is an option for elderly who require features adapted to their needs in their own homes. This type of housing is, which is not very common, is designed for people older than 55 years of age wishing additional service facilities [17].
- *Service houses/nursing homes* are another option for the elderly who do not feel safe at their own homes and requiring extensive assistance for living and healthcare. Service houses are administrated by municipalities whom the elderly can rent from [17].

1.2.5 Home-help Services

Home-help services are provided to the elderly citizens based on decisions made by the municipality [17]. Home-help services offered by municipalities is called *Hemtjänst*, where the purpose is to assist older people to have an independent, safe life involving meaningful social activities in their own homes [17] [18]. This service includes also elderly with severe problems, somatic and psychological, which needs visits from social service and sometimes also healthcare several times a day including nights.

To make it easier for elderly to call for help, they have an option to be facilitated with individual alert solutions connected to an alarm reception called *Trygghetslarm* (safety alarm). These safety alarms enable the elderly to call for help round the clock in case of emergency such as a fall incident [18] [19].

1.3 Fall Injuries

Fall injuries among elderly population are a major societal problem [20]. Injuries caused due to low-energy trauma is the reason for most deaths, visits to the Emergency Department (ED) and a majority of hospital admissions. The majority of these injuries occur in or near the home. Common consequences are head injuries and hip fractures and underlying causes of mortality after a fall. Head injuries are prevalent among those under the age of 85 while hip fractures dominate the population above this age. Nine out of ten injuries to a fall incident are attributed to ages over 80 years [21]. Cases of serious injuries of the head and cervical vertebrae associated with elderly people have increased, with about 300 000 people requiring comprehensive care after experiencing a fall [22]. According to The Swedish Civil Contingencies Agency, injuries after fall incidents are among the most expensive type of injuries in Sweden. A statistical report from the year 2014 revealed a huge economic burden of nearly SEK 25 billion as the cost to society due to fall incidents [23].

1.3.1 Hip Fracture and its Complications

A major problem to the well-being among elderly throughout the world can be attributed to hip fractures caused due to a fall [24]. Tendency to fall and osteoporosis are the main reasons for hip fractures. The average age of people affected by hip fracture is 82 years with 65% being women and 35% being men. The reason of higher proportion of women is longer life expectancy and more pronounced osteoporosis. However, the number of males has slowly increased in recent times. Elderly women affected by hip fracture often live by themselves and suffer from multiple concomitant diseases, such as dementia, and disabilities [25].
Postoperative complications for patients having suffered hip fractures are common, and lead to a longer stay at the hospital, increased mortality and suffering. The guidelines in Sweden recommend the start of the surgery for 80% of the patients within 24 hours of their arrival into the hospital in order to decrease postoperative complications [25].

Hip fractures are generally classified into three different types, as represented in **Figure 1.1**, based on their anatomical location on the femur bone, viz. femoral neck fractures, intertrochanteric fractures and subtrochanteric fractures. Femoral neck fractures and intertrochanteric fractures are the most common types of fractures corresponding to nearly half of the reported fractures [25]. The method of diagnosing and classifying hip fractures into different groups is done by X-ray examination [25]. Permanent disability post a hip fracture is seen to be 50% more than before a fracture [27] [28]. The prevalence of hip fracture seems to be increasing at a startling rate in many countries throughout the world [29], with the estimate of

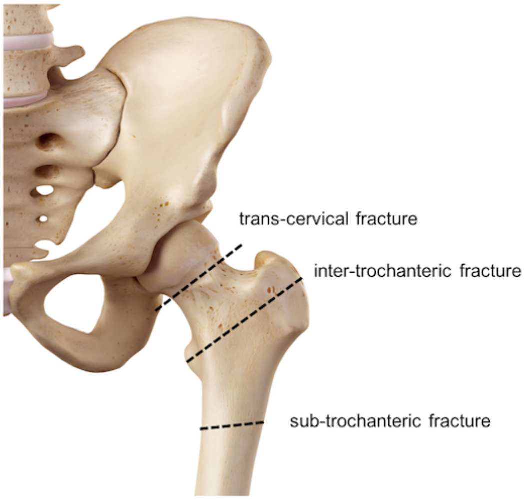


Figure 1.1: Classification of hip fractures [26].

hip fractures to go up to more than 5 million by the year 2050 [30]. As for Sweden, about 18 000 patients suffer each year from hip fractures. Although this figure has been reported to be constant through the years, it is expected to increase to 30 000 by the end of 2050 due to an increasing aging population [25].

The CHANCES project, a study made to find out the mortality rate of hip fractures, found that 30% of the adults over 50 years of age die within a period of 12 months after suffering from a hip fracture [31]. The risk for older adults dying within 3 months after a hip fracture increases five-to-eight fold when compared to the same age group without having suffered a hip fracture [32].

Social, economic and physical distress due to hip fracture often accompanies post trauma. The living conditions of people having suffered from a hip fracture drastically changes from the one they had pre-trauma, with many having a loss of normal physical function, inactive social life, heightened dependence on others and therefore, a poor quality of life leading to a need for relocation into an elderly care facility [33].

1.3.2 Ambulance Dispatch in Sweden

SOS Alarm, an organization in charge of the national emergency number *112* also handles the incorporated emergency services in Sweden. All incoming calls to SOS Alarm is taken care of by an operator. Depending on the type of emergency, the call is connected to various departments, namely the ambulance, police, fire brigade and other rescue services. According to SOS Alarm, the company handles about 3.5 million calls every year over entire Sweden [34]. Among the received calls, one third of them are emergency medical calls.

Sweden consists of twenty one regions and SOS Alarm dispatches emergency medical calls in eighteen regions. The remainder regions dispatch emergency medical services by themselves, where the call is responded by SOS Alarms at first, consecutively being transferred to the emergency medical dispatch center [35].

1.3.3 Ambulance Dispatch in Region of Västra Götaland

Västra Götaland county is one the three regions in Sweden where emergency medical dispatching is performed by the region's emergency medical dispatch center. Since April 2019, this task is being handled wholly by *Sjukvårdens Larmcentral (SvLc)*.In case of a medical emergency, the initial contact is made with SOS Alarm, thereafter being directed immediately to a registered nurse at SvLc [35] [36]. The nurse, on assessing the patient's condition, assigns priority based on the need for an ambulance. The ambulance assignments are categorized in four priorities [36]:

- **Priority 1**: Acute life-threatening symptoms or injury.
- **Priority 2**: Acute, but not life-threatening.
- **Priority 3**: Other assignments with care or monitoring needs, where reasonable waiting time is not considered to affect the patient's condition.
- **Priority 4**: Since the nature of the case is not acute, it does not require any immediate medical attention. Additionally, *Priority 4* is assigned to cases when treatment during transport is not necessary.

According to SvLc, injuries to extremities and suspicious hip fractures are prioritized as priority 1 or priority 2, respectively, requiring immediate dispatch of an ambulance.

In 2016, about 1 million ambulance missions were undertaken in Sweden, where a majority of patients transported to hospitals were 65 years or older [37]. In order to provide continued care to the patient after an ambulance mission, the patients are admitted at EDs at hospitals. In the Region of *Västra Götaland*, where 209 852 ambulance missions were performed in 2018, about 80% of the patients who were attended to were transported to the hospital [38]. The main task of the ambulance personnel is to evaluate the state of the patient and provide appropriate care and treatment. In some cases, the provided care on the location of the incident is not sufficient. Therefore, transportation of the patient, to receive higher levels of treatment, to the nearest and the most suitable hospital becomes the subsequent task for the ambulance personnel [36].

In Sweden, a pre-hospital fast track care process has been developed to take care of patients with suspected hip fracture. The ambulance staff start preoperative management, such as pain relief, blood test, Electrocardiography (ECG) and oxygen therapy at the scene followed by transportation of the patients directly to X-ray examination instead of an ED. In case of verified hip fracture, the patient is transferred to the orthopedic department for registration and planning of surgery. [25]

1.3.4 Summary of the Problem

Early detection and evaluation of a fall incident could decrease the delay time from incident to being assisted by ambulance services, and thereby signifying the start of a pre-hospital intervention. It can be inferred that, with the aid of modern ICT, it would be possible to effectively enhance the quality of care to this patient group by shortening time from fall incident to appropriate care at a hospital. Designing and testing a Digital Health solution including automated fall detection and transmission of vital data and other information related to a fall detection event to dispatch center for assessment and prioritizing, and thereafter to an ambulance en-route is the task of this thesis.

2
Aim and Objectives

2.1 Aim

The aim of the project is to produce a demonstrator for a Digital Health solution including automatic fall detection, logical alert routing, sensor fusion, clinical decision support and data sharing among involved stakeholders.

2.2 Objectives

- A literature study on current solutions and sensors for fall detection.
- An analysis regarding information / vital parameters / needs that are essential for the emergency care providers at dispatch center, and in the ambulance services to improve their handling of the alert.
- An investigation into Decision Support Systems (DSS) to interpret and apply cutting-edge technology in the design of a Digital Health solution for fall incidents.
- Design proposal of a concept of a Digital Health solution for a complete pre-hospital care chain in case of indoor fall.
- Evaluate the demonstrator through a simulation of the pre-hospital care chain from fall case to the arrival of an ambulance.

3
Methods

3.1 Method

This project was intended to follow the first step of the project model, the stepwise Verified Innovation Process for Healthcare Solutions (VIPHS) defined by Prehospital ICT Arena (PICTA), described in the **Appendix B**. The main steps carried out during this project can be divided into five steps i.e. literature study, interviews, proposal of system design, creation of personas and evaluation of the proposed system. The project started with a literature study to clarify the problem and review preexisting and under development solutions- in short, ' *to understand state of the art'*. Interviews with healthcare professionals were then carried out to understand the needs and challenges in the healthcare system. Finally, a solution, based on the literature study and conducted interviews, to tackle the defined problem was designed and theoretically tested. A part of this was to create personas to be able to evaluate the designed system in this project.

3.1.1 Literature Study

Literature studies and investigations of already existing solutions as well as solutions under development were carried out, in order to determine scientific facts and gain more information about techniques used to detect and assess a fall. Digital libraries and Scientific Journals such as ScienceDirect, IEEE Xplore, Elsevier, Google Scholar, Hindawi, PubMed and NCBI were searched in order to understand the topic and discover information about solutions being developed in different project. For this reason, an extensive search on the internet was also made by looking into various companies' websites, various government agency websites and Digital Health magazines. Keywords such as *eHealth, fall, incidents, hip fracture, detection, vital parameters, monitoring, IT infrastructure, information cloud, emergency services, privacy, sensors, ethics, elderly, living conditions, technology, alarm, Clinical Decision Support System (CDSS), Electronic Health Records (EHR)* and *ambulances* were used, either independently or in conjunction with one or more words, to populate results from the digital libraries, journals and on Google's search engine.

3.1.2 Interviews

Interviews with individuals representing various organizations related to already existing solutions were conducted to gain information about the needs and challenges within pre-hospital emergency healthcare and detection of falls in the homes of the elderly. Representatives from public healthcare organizations with technological expertise were also interviewed to understand the current process and to further discern the road map that exists for the future. Interview was performed with *Åsa Högstedt*, a Business Developer at SvLc to understand the process of handling medical emergency calls in the region *Västra Götaland*. Another interview was conducted with *Johan Rindeborg*, Chief Executive Officer at a nursing home called *Tre Stiftelser*, to obtain a better picture of the elderly's health condition and their needs. *Ulrika Björner*, an Occupational Therapist at *Göteborgs stad* actively engaged in the elderly care and handling of falls, was interviewed to identify developments areas in elderly healthcare and processes, and identify possible limitations at the organizational level. All the interviews carried out were based on semi-structured methods where the interviewees talked about both predecided topics and other related subjects. Meanwhile, the interviewer had the opportunity to guide the interview by asking questions.

3.1.3 Prototype Development

Based on the findings from literature studies, reviewed solutions and acquired information during interviews, an theoretical/abstract prototype of a Digital Health solution for a complete pre-hospital care chain was proposed. In product and system development, physical and virtual prototyping is commonly utilized in both modeling and evaluating stages while abstract prototyping is a relatively new concept [39]. Abstract prototyping is an essential tool when presenting concept solutions in demonstration phases as well as evaluation phases involving different stakeholders [39].

Personas

Three personas were created based on the gathered information e.g. with focus on demographics, health and living condition. A persona is a general profile which represents a broader group of individuals with specific characteristics [40]. The purpose of creating personas was to understand the needs of potential target users of the proposed system, and also to test the complete proposed Digital Health solution's performance and characteristics from *A* to *Z*.

3.1.4 Evaluation

To fulfill the project aim, theoretical simulations of the proposed Digital Health solution prototype in a complete pre-hospital care chain were carried out using the personas. Relevant vital parameters were assumed to have been recorded and sent to an information cloud service accessible from the dispatch center automatically at fall detection. By using "data fusion" various information from stakeholders in the care chain were added to this cloud service. This includes health record information, administrative information and individual information.

4

Results

The results chapter presents the results from the literature study. This chapter includes information about the current solutions for fall detection purposes. Additionally, the following chapter displays an analysis regarding the essential vital parameters for the healthcare providers in pre-hospital care as well as the current technologies to extract those.

4.1 State of the Art for Fall Detection

Literature study in this project shows that the state of the art for fall detection solutions can broadly be divided into wearable and non-wearable solutions, **Table 4.2**. Wearable solutions are further branched into automatic and manual and can be worn by the target users as pendants, wristbands and belts with implemented sensors. Using wearable solutions, fall incidents are detected by measuring sudden changes in acceleration and orientation or any other changes that impacts the state of the user. Non-wearable solutions are typically installed in the user's most used environment and detect if the user has fallen by measuring different items, depending on the type of implemented sensor. Based on the findings in the literature review, fall detection by radio frequency technology is one of the unique solutions among the identified technologies. Fall detection with radio frequency technology is special, since it can be implemented as both wearable solution and non-wearable solution. The identified products on the market can also be categorized based on the integrated sensors and their functionality, **Table 4.1**.

Healthcare Assistance Devices	Vision-based Sensors	Smartwatches	Radio Frequency Technology	Artificial Inteligence	Mobile Applications
Philips lifeline MobileHelp Tunstall Medical Guardian MariCare OY, Vevios	Alleato Fearless	Apple Watch Bellpal	Origin wireless Walabot Home Vayyar Kardian Contactless Nectarine	Livio AI CareEye	Salus Mea

Table 4.1: State of the art for fall detection solutions based on the integrated sensors and functionality.

Device	Country of origin	Available in Sweden	Monitoring of vital signs	Automatic	Manual	Sensors	Wearable/Non-wearable?	Wearing options
Philips Lifeline	Netherlands	✗	✗	✓	✓	Accelerometer, Barometer	Wearable	Pendant, Wristband
MobileHelp	U.S.	✗	✗	✓	✓	Unavailable	Wearable	Pendant, Wristband
Tunstall	England	✓	✗	✓	✓	Pressure sensor	Wearable	Wristband, Worn around the neck, on a belt or as a brooch
Medical Guardian	U.S.	✗	✗	✓	✓	Unavailable	Wearable	Pendant, Wristband, Worn on the belt or tucked into the pocket
MariCare OY	Finland	✓	✗	✓	✗	Capacitive and motion sensors	Non-wearable	✗
Alleato	Sweden	✓	✗	✗	✗	Camera	Non-wearable	✗
Vevios	Sweden	✓	✗	✗	✓	Patented panic grip	Wearable	A mobile phone bracelet
Fearless	Austria	✓	✗	✓	✗	3D technology	Non-wearable	✗
Apple Watch	U.S.	✓	Heart rate, ECG	✓	✓	Accelerometer, Gyroscope	Wearable	Smart Watch
BellPal Watch	Sweden	✓	✗	✓	✓	Motion sensors	Wearable	Wristband
Origin Wireless	U.S.	✗	Respiratory rate	✓	✗	WiFi signals	Non-wearable	✗
Walabot Home	U.S. and Israel	✗	✗	✓	✗	Low-power radio wave technology	Non-wearable	✗
Kardian Contactless	Norway	✗	Resting heart rate, Respiratory rate	✓	✗	Impulse radio ultra-wideband radar technology	Non-wearable	✗
Nectarine	Sweden	✓	✗	✓	✓	Ultra low power signals	Wearable	Wristband
Livio AI	U.S.	✗	✗	✓	✓	Motion sensors	Wearable	Hearing aid
CareEye	Sweden	✓	✗	✓	✗	Unavailable	Non-wearable	✗

Table 4.2: State of the art for fall detection solutions.

4.1.1 Wearable Solutions

Wearable solutions, with aim of detecting fall incidents, are the most utilized technologies on the market and have been around for decades. Wearable devices have been used as event detection systems on the market for a few decades. The captured data through wearable devices such as smartwatches can be used to recognize human activities. One of the main applications of these devices is in the case of fall among elderly [41]. The usage of wearable solutions, especially as automatic fall detectors, is of great importance to help elderly people keep living independently at their own homes for an extended period of time [41].
The identified wearable solutions can be further broken down into two types of devices based on their functionality, automatic and manual. Wearable devices which function manually, have an integrated manual button that can be pressed by the user to inform the caregiver and call for help in case of fall or any other incidents. However, the automatic fall detection solutions are the ones concerned in this project. Currently, the most common sensors included in the automatic fall detection devices are accelerometers, barometers and gyroscopes. An accelerometer is an electromechanical device which is used to measure changes in velocity or speed divided by time. A barometer is a device that measures the barometric pressure. Since the barometric pressure decreases with increasing altitude, any sudden changes in this parameter can be an indicator of falls. A gyroscope is a device that uses the earth gravity to determine orientation. The purpose of using these sensors is to detect fall incidents. These sensors are rarely used alone. In most cases, two different types of these sensors are combined in available devices on the market. Most of the wearable devices offer fall detection feature by integrating multiple combinations of the mentioned sensors. The functionality of a number of wearable fall detection solutions on the market and under development is described below.
Safety Alarm, also called *Trygghetslarm*, comprises of an electronic device connected to an ordinary phone and an emergency button which can either be worn as a pendant or a wristband, as seen in **Figure 4.1**. When the button is pressed, an alarm reaches an alarm reception or relatives. Furthermore, a facility to talk through some of these devices can be enabled, allowing for a conversation between the person handling the alarm and the elderly in need [19]. However, the Safety Alarm would only be effective in the case of the elderly using the device being conscious. Additionally, the mental state and the orientation of the elderly after a fall plays a considerable role in being able to push the integrated button on the device. The device includes a feature that sends an automatic message to the alarm reception and let them know when the battery is running low. This feature helps in notifying the responsible team to replace the battery as soon as possible [42].

Figure 4.1: Safety alarm [43].

Philips Lifeline offers fall detection devices, seen in **Figure 4.2**, using accelerometers and barometers, to respectively measure high acceleration forces and sense changes in barometric pressure from a standing position to a lying position. When a fall is detected by the sensors, an automated alert is sent to Philips Lifeline response center through a base station installed in the home. If the person suffering from fall incident is conscious, the operator will dispatch the appropriate help. Otherwise, the operator contacts the dispatch center directly to assist with required aid. Additionally, most of Philips Lifeline fall detection solutions offer built-in help buttons to trigger an alert manually. The call cannot be canceled by the user if the help button is pressed accidentally. The battery utilized in the device is a long-lasting battery and can be replaced when necessary. [44]

Figure 4.2: Philips Lifeline [44].

Fall detection solutions developed by **MobileHelp**, seen in **Figure 4.3**, can detect fall incidents both automatically and manually. In case of fall, the information and location of the user will be sent directly to MobileHelp's response center through the base station in the home. The operator assists with the suitable help, from contacting a neighbor or a family member to reaching the dispatch center, depending of the severity of the incident. A rechargeable battery is used in the device which lasts for 24 hours after a three hours charge. [45]

Figure 4.3: MobileHelp [45].

Using an integrated pressure sensor, **Tunstall** has developed devices with automatic fall detection feature, as seen in **Figure 4.4**. When a hard fall is detected, an automatic alert is immediately raised to a predefined monitoring center or caregiver through Tunstall's base station. In case of false alarms, the triggered alarm can be canceled by either covering the device or standing up within 20 seconds. A replaceable lithium battery is used in the device that lasts up to two years. [46]

Figure 4.4: Tunstall [46].

Motion sensors are utilized in **Medical Guardian** automatic fall detection devices. In addition, Medical Guardian alert systems offer manual help buttons. In case of fall, the user receives a call from the monitoring center and obtain proper assistance through the installed base station in the home. A rechargeable battery in included in the device that can work for 24 hours on a single charge. [47]
Among the reviewed fall detection solutions, **Vevios** a mobile phone bracelet sticks out with its patented panic grip, seen in **Figure 4.5**. When an alert is activated, the device can call 10 different predefined emergency contacts as the same time. Once the first emergency contact answers the call, a two-way communication is established, and the user can communicate through the integrated microphone and speakers. [48]

Figure 4.5: Vevios [48].

Apple Watch can be considered as a miniature version of iPhone with a smaller screen and built-in sensors, which can be worn around the wrist, seen in **Figure 4.6**. It is possible to receive messages, calls, emails and notifications from different applications when the watch is paired with an iPhone. Apple Watch Series 4 and 5 are smartwatches that, besides all other integrated smart features, can detect fall incidents using accelerometers and gyroscopes. These sensors cooperate with fall detection algorithms to automatically determine hard falls. The integrated accelerometer in Apple Watch measures the user's sudden changes in velocity and the gyroscope determines the user's orientation by using the Earth's gravity [49]. When the watch detects a fall and the user has been immobilized for more than 30 seconds, the watch starts beeping and tapping the user's arm. Thereafter, an automatic massage pops up to check if the user is fine. The fall detection alert can easily be canceled through the cancel button within 60 seconds. Otherwise, a call including the location of the user, is established to the local dispatch center. A paired iPhone is required around the watch to be able to contact the dispatch center. Apple Watch is powered by a battery, based on rechargeable lithium ion technology which lasts up to 18 hours after being fully charged. Apple Watch is capable of monitoring the user's ECG and heart rate. [50]

Figure 4.6: Apple Watch [50].

Salus Mea, is an interesting concept sticking out among the reviewed products, acting as a system solution provider. The safety application, shown in **Figure 4.7**, is compatible with the existing fall detection sensors in Apple Watch and iPhone, i.e. accelerometer and gyroscope. In case of a fall incidents, a connection through the phone would be established with the local dispatch center. Additionally, an alert can be activated manually through the interactive button in the app. [51]

Figure 4.7: Salus Mea [51].

Bellpal watch, shown in **Figure 4.8**, detects falls by using motion sensors and informs prechosen emergency contacts e.g. family members and relatives. The watch sends an alert trough the paired smartphone and application used by the user and family members. In case of false alarms, the user can cancel the alert within 60 seconds. Additionally, Bellpal plans to offer their own alert center to handle the incoming alerts during year 2020. The watch has a battery life of at least sex months. The company sends a new battery to the user if the remaining battery is less than 15%. [52]

Figure 4.8: Bellpal [52].

Nectarine uses a wristband and radio frequency technology to detect fall incidents automatically and call for help through a paired smartphone, as seen in **Figure**

4.9. Nectarine fall detection system requires three nodes installed in three different places in user's house. The data is collected by the wristband continuously and is sent to the cloud by the placed nodes in the house. Using Artificial Intelligence (AI) algorithms, the system learns the user's patterns of behavior and responds to any unexpected changes accurately. The battery life in the device is up to twelve months. [53]

Figure 4.9: Nectarine [53].

Livio AI, a hearing aid developed by an U.S. based company named Starkey. This device offers fall detection features using integrated sensors, shown in **Figure 4.10**. The preselected emergency contacts will be notified, through the paired smartphone and the designed app, with an alert including the location of the user. The rechargeable battery in the device lasts for 24 hours after being fully charged. [54]

Figure 4.10: Livio AI [54].

In a research project called **Sphere** at the University of Bristol, *Fafoutis et al.* developed SPHERE Wearable 1. SPHERE Wearable 1 is a low-power consumption wearable activity tracker worn on the wrist. This device uses implemented accelerometer and Bluetooth wireless communication to monitor users on residential environment [55]. The third version of this wrist worn device, called the SPHERE Wearable 3, is integrated with an additional gyroscope, seen in **Figure 4.11**. SPHERE Wearable 3 could aid in the detection of fall with the analysis of data obtained from the sensors. The introduction of a two-way communication between the SPHERE Wearable 3 and a gateway device through a low-energy consuming Bluetooth module enhances the battery life. The battery used in the device is a rechargeable lithium battery. [56]

Figure 4.11: SPHERE Wearable 3 [56].

In another project, *Mauldin et al.* have developed an Android application to alert the caregivers in case of fall. The detection of fall is possible by using integrated accelerometer and deep learning algorithms in a smartwatch paired with a compatible smartphone [57].
Sannino et al. developed a wearable fall detection and prediction approach that obtains data through a tag placed on the subject's chest. Windowing of the data is performed to classify these windows as fall or non-fall. A final window composition is then created to assess whether or not each global action was a fall. This approach was tested on real-world data consisting of fall and non-fall events. The experiment provided a promising and strong foundation for implementation of real-world fall detection systems [58].

In another, *Fortina and Gravina* developed a novel, real-time non-invasive fall detection and alarm notification system using a wearable accelerometer and a smart phone. The system is able to trigger fall events using different alerting modalities enabling quick emergency interventions. Results of the experiment on 20 subjects demonstrated a 97% sensitivity, 83% specificity, and 90% precision. [59].
An integrated manual button is included in almost all of the reviewed wearable devices to call out for help manually. The most noticeable disadvantage of wearable solutions is the need to be worn by the users constantly, otherwise it is impossible to detect fall incidents. Taking this into account, it is of great importance that the wearable fall detection device is designed to be comfortable, light and simple to handle.

4.1.2 Non-wearable Solutions

The second group, non-wearable sensors, generally consists of motion and vision-based sensors both as monitoring systems and mapping systems. The non-wearable devices utilize relatively newer technologies than the wearable ones and are introduced in recent modern solutions. The non-wearable sensors are normally installed in the user's home, e.g. wall, ceiling or floor to alarm the caregiver remotely when fall incidents occur. One of the sensors frequently used in non-wearable solutions is a motion sensor. Vision-based sensors, in fall detection devices, can usually be used in two different ways, monitoring and 3D technology. Monitoring with Vision-based sensors is one of the classical solutions that has been around for a while. However, vision-based monitoring has always raised active discussions about invading users' integrity and privacy. The use of vision-based sensors with 3D technology is an upgrade to monitoring. 3D technology has been around since a few decades back and is meant to detect objects without actually recognizing a clear picture of them, i.e. the fall detection system does not include any invasion of the users' privacy.

Vision-based devices have been one of the fairly new approaches in fall detection systems. A camera is one of the main parts in vision-based solutions. Two different types of cameras are usually used in previous studies presenting vision-based sensors, 2D cameras and 3D Time-of-Flight (ToF) cameras. The latter is a relatively new method which is capable of generating detailed 3D information.
Detection of fall incidents happens wirelessley by **MariCare OY** fall detection solution based on motion sensors installed on the walls. **MariCare OY**'s fall detection solution, eLsa, uses two mounted motion sensors on the walls at different heights, as seen in **Figure 4.12**. The presence of the user is sensed by the upper sensor while the fall is detected by the second sensor mounted further down on the wall. Once a fall incident is detected by the system, an automatic alert is sent to a preselected caregiver's smartphone. [60]

Figure 4.12: MariCare OY [60].

Alleato provides monitoring solutions through cameras mainly towards nursing homes. Using the camera, the staff can monitor the residents actively during day time. The residents are not monitored during night time but if any motion is detected, the camera gets activated and a notification is sent to the staff through an installed app. [61]
Fearless is a fall detection solution, seen in **Figure 4.13** which detects falls based on 3D technology and AI algorithms. Additionally, the technology used in **Fearless** helps in preventing falls by recognizing the critical motions and switching lights on immediately. In case of fall incident, an alert is transmitted to preselected caregivers and relatives. Today, **Fearless** is being utilized in nursing homes and is planned to become available to private people as well. [62]

Figure 4.13: Fearless [62].

Origin Wireless utilizes Wireless Fidelity (WiFi) signals to sense motion recogni-

tion and detection of fall incidents without any attachments to the user's body. In addition, **Origin Wireless** is capable of extracting information about respiratory rate. [63]
Radio frequency technology is used in **Walabot Home**, as seen in **Figure 4.14** mounted on the wall, to detect fall incidents and inform preselected emergency contacts. A two-way communication is established through the integrated speakers and microphones in the device mounted on the wall, when a fall is detected. [64]

Figure 4.14: Walabot Home [64].

Kardian Contactless has been mainly developed towards hospitals and nursing homes. The fall detection feature is based on radio ultra-wide band radar technology. When a fall is detected including sliding falls, the device alerts hospital staff through the paired smartphone, shown in **Figure 4.15**. In addition to fall incidents, the device is able to monitor heart rate and respiratory rate. [65]

Figure 4.15: Kardian Contactless [65].

CareEye detects fall incidents by using built-in sensors and AI. Thereafter, **CareEye** alerts caregivers and relatives immediately through a smartphone and an installed app. [66]
De Miguel et al. propose a vision-based fall detection system, as shown in **Figure 4.16**, combining different computer vision and AI algorithms [67]. According to the authors, the system has shown 96% detection ratio in 50 conducted tests in controlled environment. The proposed camera in this article is a 3D ToF camera. The 3D ToF camera used in fall detection systems is a depth camera that simply calculates the distance between the camera and the user for each point in the image [67].

Figure 4.16: Vision-based fall detection system [67].

Computer vision algorithms such as, background subtractor and Kalman filter are used as inputs to a Machine Learning (ML) decision system to identify fall incidents. It is important to discriminate between the relevant information and the background information in the extracted image. Therefore, One of the first steps is to focus on the human body in each generated frame. The recognition of human body is possible by training specific feature descriptor algorithms such as histogram oriented gradients [67].
Background subtraction is one of the basic methods in computer vision algorithms which subtracts the background image and acquires as much information as possible about the main subject in the image [68]. Another important step in the vision-based fall detection is to track the main subject in each frame. Subject tracking can be possible by using a Kalman filter. Kalman filter uses the obtained data from previous frame to estimate the next position of the user [67]. A further step in the fall detection process is data modeling. The acquired data from the human body is used to create a geometric shape of the human body. Rectangles and ellipses are the most common geometric shapes that are used to extract data about the subjects height, width and angle [67]. **Figure 4.17** shows an example of a generated image in the same project after applying computer vision algorithms [67]. Finally, a ML decision making technique such as Artificial Neural Network is included in the system to detect fall incidents.

Figure 4.17: An example of a generated image from the developed vision-based fall detection system [67].

Non-wearable sensors have proven to have high ease of use for fall detection and prediction. Tests conducted on over 50 different fall videos using a vision-based fall detection system for the elderly at home, have shown a detection ratio of greater than 96%. The system performs with an efficiency of approximately 96% in controlled environments [69]. Looking at different non-wearable devices, the main advantage of these fall detection solutions is their ability to detect fall incidents without any type of attachment to the user's body.

4.2 Essential Vital Parameters in Pre-hospital Care

The vital parameters, heart rate, blood pressure, respiratory rate, blood oxygen saturation, body temperature and level of consciousness have traditionally been measured by physicians and ambulance crew in pre-hospital settings to assess and prioritize patient's condition [70] [71]. Routine assessment is performed by the pre-hospital healthcare providers to assess the urgency of patient's condition and provide the appropriate level of care [72]. According to different studies, abnormalities detected in these vital parameters are one of the major reasons for patient presenting at EDs [73]. The identified vital parameters in **Table 4.3** are traditionally considered as the most essential vital signs to evaluate well-being and health condition of a patient [74].

Heart Rate	Body Temperature	Blood Pressure	Respiratory Rate	Blood Oxygen Saturation	Level of Consciousness
Cardiovascular system's health	Heat balance in the body	Cardiopulmonary system's health	Oxygen delivery to the tissues	Oxygen in the bloodstream	Brain function

Table 4.3: Essential vital parameters in pre-hospital care.

On one hand, the importance of measuring the vital parameters, mentioned in **Table 4.3**, in pre-hospital settings have been emphasized in various articles. On the other hand, *Åsa Högstedt* described the need to extract the parameters, presented in **Figure 4.18**, to improve the judgment and evaluation of the patient's health condition during the medical emergency call. This, in turn, might lead to a higher confidence while prioritizing the received call. The gathered information about the vital parameters helps in estimation of the risk for serious injuries.

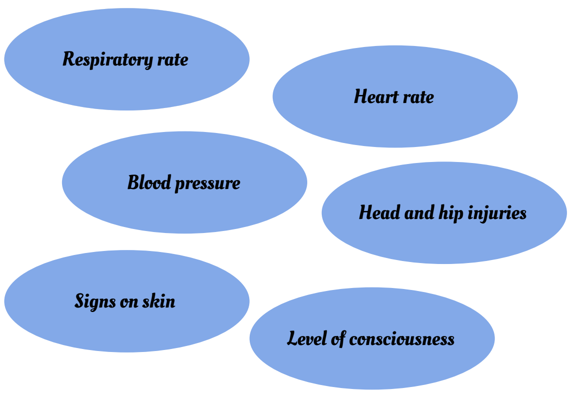


Figure 4.18: Desired parameters expressed by representative from SvLc.

4.3 State of the Art for Measurement of Essential Vital Parameters

Extracting information on human vital parameters has always been important in clinical settings. This information gives a clear picture of the patient's physical health state which is a great guidance in diagnostic as well as potential treatment [75]. Any detected abnormality in vital parameters is an indicator to stressful mental or physical condition. Hence, continuously extracting and analyzing vital parameters is a sufficient way to discover possible underlying diseases [74]. However, vital parameters monitoring such as heart rate and respiratory rate required complex systems in hospital settings. These methods include sensors and wires attached to the patient's body [76]. On the other hand, wireless vital parameters monitoring has increased significantly in recent times, with the usage of fitness and wellness trackers. The devices used in tracking human vital parameters and activities have proven to be a technological revolution, especially in terms of the reliability of scaled down electronic devices used for this purpose [76] [77]. As an example, a wireless wrist worn device with integrated sensors is being used in the SPHERE project to extract dementia-related diagnostic data from Alzheimer's patients [56]. Classifying broadly, there are two main solutions to monitor vital parameters, the wearable systems and the non-wearable systems. The following sections include reviews about major wireless wearable and non-wearable techniques for monitoring different vital parameters that have been developed during recent years.

4.3.1 Wireless Wearable Solutions

Wearable solutions for vital parameters monitoring consist of various sensors, signal processing techniques and communication technologies, seen in **Table 4.4**. There are different kinds of wearable in-home monitoring solutions under development. A few examples of these solutions are smart vests, hand-held devices and wristbands. All of the mentioned examples extract information about vital parameters in a non-invasive manner. Smart vests are e-textiles which monitor physiological parameters such as ECG, heart rate, blood pressure and body temperature, while hand-held devices are capable of measuring ECG, respiration rate and heart rate [77].

Heart Rate	Body Temperature	Blood Pressure	Respiratory Rate	Blood Oxygen Saturation
ECG	Temperature sensor	Pressure cuffs with a stethoscope	Acoustic	PPG
PPG		PPG	Airflow	
		Pressure sensor	Chest and abdominal movements,	
			Transcutaneous CO_2 monitoring,	
			PPG	

Table 4.4: Wireless wearable technologies to extract vital parameters.

Continuous **heart rate** monitoring in wearable tracking devices is usually based on ECG or Photoplethysmography (PPG). The heart rate information gained through both methods are very similar, even though it origins from different physiological sources. PPG can also be used to measure the peripheral oxygen saturation. Since PPG does not include any additional electrodes, this method is counted as one the most comfortable and effective methods to measure heart rate [78].
Skin temperature can usually be measured by temperature sensors [79]. Temperature sensors are mostly implemented in wrist-wearable devices to measure skin temperature [80]. However, according to different studies the skin temperature differs from the core temperature by a few °C and oscillates depending on ambient

factors throughout the day [81] [82]. *Malhi et al.* suggest to estimate the core temperature by measuring the skin temperature with an added temperature sensor on the wrist [83]. **Body temperature** can roughly be estimated since the core body temperature is around 5°C higher than skin temperature. *Looney et al.* present an algorithm to measure body temperature based on heart rate and skin temperature [84].

Blood pressure is traditionally measured by using pressure cuffs with a stethoscope on user's arm. However, a continuous usage of this device causes skin irritation and sleep disruption [74]. An introduced method to estimate blood pressure is to use PPG, to avoid the mentioned side effects. New technologies propose estimating blood pressure based on the pulse wave through PPG or ECG by measurements done on the chest or the wrist [74]. A different article proposes blood pressure measurement by introducing a prototype where a pressure sensor is placed close to a radial artery. This article claims to give an accurate measurement of blood pressure on a personal smartphone [85]. On the other hand, another article concludes that there is still a lot to be done considering the reliability of the introduced methods to measure blood pressure [82].

Respiratory rate can be measured by using different wearable methods based on acoustic, airflow, chest and abdominal movements, transcutaneous CO_2 monitoring and extracting volume of the lungs from plethysmograms [86]. *Hoilett et al.* introduce a method to monitor respiratory rate by using PPG in a smartwatch, although it has been pointed out that the validity of this device needs approval by conducting further real-life experiments [87].

PPG combined with pulse oximetry principles is an effective and widely used method which makes it possible to estimate **blood oxygen saturation**. PPG for blood oxygen saturation measurement is based on detecting the blood vessel wavelength by using two different wavelengths since the absorptivity of hemoglobin in the blood changes when it bonds with oxygen [74].

4.3.2 Non-wearable Solutions

Non-wearable solutions, with patient monitoring purposes, have been a major breakthrough in healthcare applications. The technologies utilized in these solutions vary. However, the introduced non-wearable solutions make the monitoring of a number of vital parameters possible when the patient presents a few meters from the sensors. Currently, the two main technologies used in non-wearable solutions are radar-based methods and image-based methods, as presented in **Table 4.5**. The major advantage with the these technologies is the possibility to capture vital parameters without any attachment to the person's body.

Heart Rate	Respiratory Rate	Blood Oxygen Saturation
Radar-based Image-based	Radar-based Image-based	Image-based

Table 4.5: Non-wearable technologies to monitor vital parameters.

Wenda et al. introduce a radar-based solution to measure respiratory rate [88]. The

solution is evaluated by conducting experiments for distances up to 1 meter in a controlled environment. The obtained results are promising and indicate the potential of the designed solution in healthcare applications [88]. In a newly released article, *Zeng et al.* investigate possibilities of using low-cost ultra wide-band noise sensor in monitoring vital parameters in pre-hospital setting [89]. The main objective in this article is to capture heart rate and respiratory rate to provide quick assessments in emergency cases which in turn facilitate medical decision making. According to this article, sixteen out of seventeen performed tests for a distance within 50 cm in the lab captured respiratory rate successfully. On the other hand, the technique needs to be improved further to capture heart rate accurately in the future [89].
During recent years, researchers have introduced other techniques to capture vital parameters without any contacts to the body. These techniques are based on low-cost digital cameras as well as various image processing methods. A number of reviewed articles, about image-based vital parameters monitoring, presented measurements through PPG imaging where the reflected light from the body, usually from face or hand, captures blood volume changes in the vessels [90]. *Tarassenkoet et al.* have investigated application of PPG imaging by conducting tests on patients undergoing haemodialysis during a four hour dialysis session in a controlled environment. The study managed to estimate heart rate, respiratory rate as well as variation in blood oxygen saturation when the camera was installed at a distance around 1 m from the patients [91].

5

Proposed Digital Health Solution

This chapter presents a proposal of a Digital Health solution for supporting a pre-hospital care chain in case of fall incidents. Additionally, this chapter includes a number of simulations to evaluate the proposed solution from a fall incident to the arrival of an ambulance.

5.1 Targeted Users - Authorities and Individuals

Stakeholders in the Pre-hospital Care Chain

Although automated systems are expected to work autonomously, they still require human involvement. An appropriate reaction of each stakeholder involved would aid in an effective flow of information. A stakeholder can be defined in many ways. One of the most popular definitions is given by *Freeman and Reed* which states, “an individual or group who can affect the achievement of an organization’s objectives or who is affected by the achievement of an organization’s objectives [92]”. According to this definition, stakeholders in the pre-hospital care chain are presented in **Figure 5.1**.

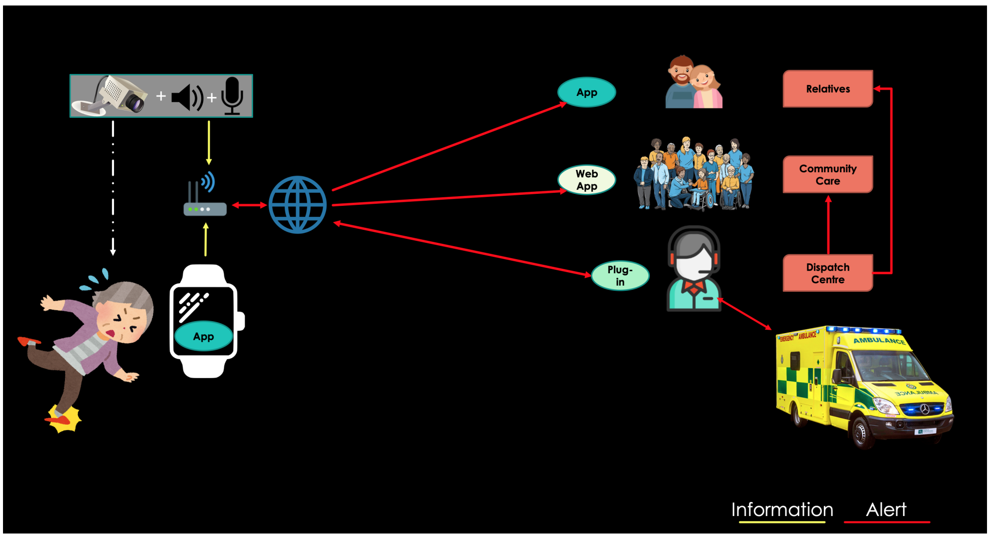


Figure 5.1: Stakeholders involved the pre-hospital care chain.

5.1.1 User

The average age of retirement is 64.5 in Sweden, but most of the Swedish elderly keep an active life even after retirement [93]. The healthcare system in Sweden aids in the independent living of elderly for as long as possible. The elderly have the opportunity to seek assistance from the municipality home-help services in case they are not able to independently handle their everyday life due to aging. This would support the elderly to remain at their own homes for a longer time, with the help of municipality home-help services [93]. Elderly care in Sweden has two main approaches, home-help services and nursing homes [94]. Based on the interview with *Johan Rindeborg*, the elderly can be split into three different groups:

1. People older than 65 years of age who remain at their own homes and live independently without receiving any external assistance to lead their everyday life.

2. People older than age 65 who remain at their own homes with assistance from municipality home-help services.

3. People older than 65 years of age who need extensive assistance and live in nursing homes.

The third group of the elderly has not been considered in the design of the Digital Health solution. The first and second group are our target groups in this project. The solution designed in this project will be based on the needs of people who remain in their homes and take care of their everyday tasks and activities either on their own, or by receiving assistance from home-help services. These two groups are the most vulnerable ones to fall incidents and their consequences. The third group is excluded due to their living situation in nursing homes and the extensive assistance they receive from the staff. The risk of a fall not being notices within a reasonable time is limited.

5.1.2 Relative

The relative of the user can react both actively and passively without causing any disruption in the chain. Active reactions to the alerts include calling the user as soon as the alert is received or checking on them physically in their home. The relative can also call the dispatch center to update information about the user. Transmission of information between all the stakeholders in the chain, for every action taken by each stakeholder could make it possible for the relative to be a passive audience. However, issues relating to privacy and data security need to be carefully considered when involving this stakeholder category in the information sharing.

5.1.3 Community Care and Services

The community care and services is mainly administered by municipalities. The community care plays an important role in the provision of the pre-hospital fall care services to the elderly. This includes taking responsibility of the service being provided to the elderly, handling alerts, and after alert, update the information about the user in the shared stakeholder information source. An alert shall quickly be evaluated for appropriate actions which may include trying to establish voice communication with the caller, potentially notifying the dispatch center, and sending a team to the home of the elderly to support before an ambulance eventually arrives. New information shared by the community care professionals from the site of the incident can also be helpful to the dispatch center in their decision making .

5.1.4 Alarm Handling and Dispatch Center

The dispatch center has a decisive role in this care chain. The judgment of this stakeholder directly impacts the pre-hospital process for the fall victim. A news article from 2012 stated that the decision made by a nurse at a dispatch center to not send an ambulance after talking to a 77 year old female patient who had a fall resulted in the death of the patient the next day [95]. This illustrates the necessity for the dispatch center to have as much relevant information as possible at hand when making dispatch decisions. Additional information received from other stakeholders in the chain may, therefore, play an important role. At present, the organization of alarm handling is setup in one of the two different ways depending on the region:

1. The call/alert is received and processed by the alarm center.

2. The call/alert is received by the alarm center. Preliminary information is gathered here. Thereafter, the healthcare dispatch center is added to the call to gather more medically relevant information and make a decision on dispatch of an ambulance.

5.1.5 Ambulance

The intention with present day ambulance services is to provide emergency care to patients at pick-up site and during transit to hospital [96]. Usually regarded as the "Golden Hour" in emergency care services, the preparedness and the response of this final stakeholder within 60 minutes of the fall incident makes a remarkable difference [97]. Additionally, providing real-time information to the ambulance could enhance the quality of care provided to the user. Hence, the ambulance en-route in the proposed solution is continuously provided with all relevant information gathered by the involved stakeholders. This information may include vital parameters, when available. This will help the ambulance personnel to prepare for the up-coming actions at site.

5.2 Proposed Fall Detection Solution

Sensor Fusion: Smartwatch and Vision-based Sensor for Fall Detection

The fundamental goal in this project is to propose a reliable Digital Health solution that improves the pre-hospital care chain when a fall incident has occurred. A large number of individuals in the target group suffer from multiple diseases. Thus, it is very crucial to introduce reliable technologies in the solution and dispatch proper help as soon as the fall incident occurs. Another important aspect in this solution is to reduce the number of false alarms. False alarms can cause confusion and lead to loss of trust among users and the other stakeholders involved.

One possible approach to minimize false alarms and maximize accuracy in the fall detection system is to collect as much data as possible by reliance on sensor fusion technology. According to the literature study, a sensor fusion technology can be used in this solution by combining wearable and non-wearable devices. The utilized sensor fusion technology can be based on a smartwatch similar to Apple Watch in **Section 4.1.1** and the vision-based sensor developed by *De Miguel et al.* [67]. These solutions, the smartwatch and the vision-based sensor, extract various type of data in different ways. On one hand, the smartwatch is attached to the user's wrist and extracts information about the velocity and orientation of the user during fall incident based on the gathered information throughout the integrated accelerometer and gyroscope. This would aid in the understanding the kind of fall the user has experienced. The user is also able to manually activate an alert by pressing the integrated button or interface in the smartwatch. On the other hand, the vision-based sensor monitors the user and their daily activities continuously and detects any unexpected changes and addresses fall incidents with the aid of AI algorithms. The vision-based sensor presents information about the position of the user. Additionally, the stakeholders are able to receive visual information of the user's location in the house.

Sensor fusion technology is a growing trend that has been discussed when proposing fall detection systems in various studies [10]. As a technology, sensor fusion integrates multiple unrelated data sources to increase the performance, accuracy and reliability in fall detection systems [11]. Therefore it might be beneficial to merge the smartwatch and the vision-based sensor technologies in the solution to extract unique information from two different sources. This in turn might lead to an increased accuracy in detecting fall incidents. Furthermore, the user can be discriminated in case of co-residence by pairing the vision-based sensor along with the worn smartwatch. The drawback of such a design would be the reliability of the system on two different components to generate sufficient information for the stakeholders in the chain. The loss of information from the smartwatch would mean that the stakeholders, mainly the ambulance dispatch center, will not have information on the force of the fall the user has experienced.

5.3 Proposed Sensors for Measurement of Essential Vital Parameters

Looking at the need expressed by the representative from the healthcare dispatch center in the region of *Västra Götaland*, extracting accurate information about vital parameters would ease and speed up the decision-making process in the pre-hospital care chain. Hence, the proposed solution monitors important vital parameters such as heart rate, body temperature, blood pressure, respiratory rate and blood oxygen saturation through the smartwatch mentioned in **Section 5.2**. The selected method to monitor a majority of the these vital parameters is based on the implemented PPG technology in the smartwatch. In reliance on reviewed technologies, PPG is capable of monitoring heart rate, blood pressure, respiratory rate, blood oxygen saturation by including adequate algorithms. *Mouradian et al.* have developed a wearable prototype using PPG technology to monitor blood pressure, heart rate, oxygen saturation and respiratory rate which can be processed and transmitted to a customized application [98]. Body temperature can be estimated by integrating a temperature sensor in the same smartwatch.
A possible approach to extract information about level of consciousness of the patient is through establishing verbal contact with the patient. The dispatcher has the opportunity to speak with the patient through the implemented microphones and speakers in the installed vision-based sensor in the user's house. The dispatcher can determine the level of consciousness of the patient by asking the patient to respond to verbal stimuli e.g. asking questions about the time and place or asking them to wave their arm [99].

5.4 Application Interfaces for Stakeholders

An interface requirement for different stakeholders in the chain arises, since the stakeholders view and utilize information in different manners. There is an obligation to protect certain information from specific stakeholders in the chain. This gives rise to the need for designing specific interfaces considering the requirements of the different stakeholders.

5.4.1 Proposed User Application

An elderly-friendly mobile application, presented in **Figure 5.2** is proposed, to provide and obtain general information about the user. Some general parameters in the application designed for the solution should be stored in the application, and include the following:

- **Name**
- **Age**
- **Address**
- **Phone Number**
- **Contact Information of the Relative**

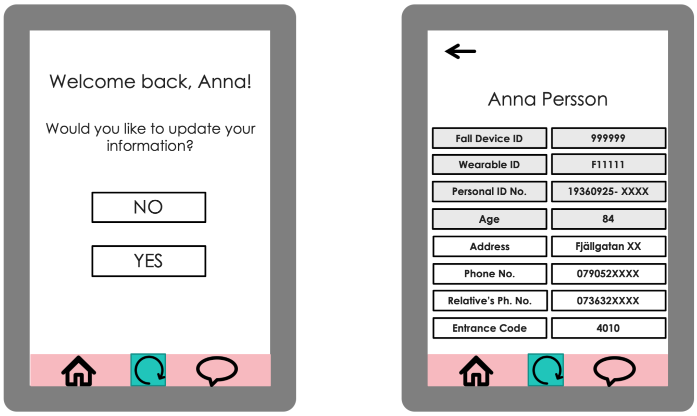


Figure 5.2: A representative design of the user Application.

Other parameters involving the use of the application for communication and information transfer in the chain are as follows:

- **Identification Number**: The identification number of the fall detection devices would be assigned by the community care providing the service. This number would then directly be mapped to the personal number of the person seeking the service. The identification number would help the community care to keep track of the devices, also helping identify the device from which the information is being transmitted. The user will not have the option to make changes to the identification numbers of both, the vision-based sensor as well as the smartwatch.

- **Gender**: Gender plays an important role in identifying the seriousness of a fall incident. As mentioned earlier, women are more vulnerable to the consequences of fall incidents than men. Therefore, it necessitates the need to reveal the gender.

- **Global Positioning System (GPS)**: GPS information taken from the application will help the ambulance personnel reach the patient's home with ease. The application could also additionally be integrated with features such as live tracking. This would help in relaying the location of the user to the arriving ambulance.

- **Entrance Code**: Entrance to buildings in Sweden almost always require a code or a Radio Frequency Identification (RFID) tag for access, causing delays to the ambulance personnel to assist the patient. In order to reduce this delay, the idea is to continually remind the user to update the information about their entrance code at regular intervals.

- **Vital Parameters**: One of the most essential information in the chain is the vital parameters obtained from the smartwatch. The application in the smartwatch would store the information about vital parameters for a certain period of time until it has been transferred to a common information cloud, described in **Section 5.5.3**. This information would get deleted automatically later on, helping save storage space on the device. The information could still be made available to the user for any future reference by retrieving it from the information cloud.

5.4.2 Proposed Application For Other Stakeholders in the Chain

5.4.2.1 Relative

The alert intended to be sent to the relative, in case of their elderly experiencing a fall, would be through a similar application to the user's, as seen in **Figure 5.3**. The only difference would be that the relative's interface would not have the option to change any of the elderly's privacy settings. However, the relative will be able to make changes to the general information, for example, the address, phone number, contact information of the relative and other information such as the entrance code to the building, specified in **Section 5.4.1**.

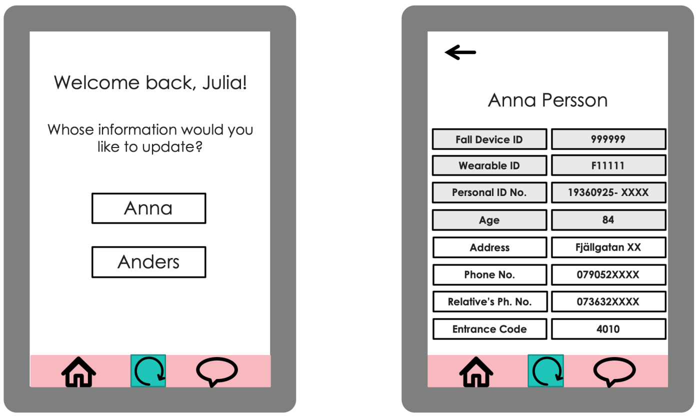


Figure 5.3: A representative design of the relative's application.

5.4.2.2 Community Care and services

The web application designed for the community care and services would directly be connected to the information cloud. This application would enable the community care to make changes to the general information of the user. The application would also facilitate the community care to maintain the database of information about the users subscribed to the service. A pop-up window would appear on receiving an alert. On receiving more than one alert at the same time, the pop-up window would be divided into two. The smaller part of the window would display different active cases, helping the operator at the community care to navigate between the various active cases. The larger part of the window would have an interaction panel to take actions, whilst also displaying several general information about the user.

5.4.2.3 Dispatch Center

All dispatch centers throughout Sweden currently use a tool called **CoordCom** in their daily operations. A plug-in connected to the information cloud could be integrated with this tool, facilitating the dispatcher to view the information received. Additionally, the dispatcher can make annotations on the case being handled. In case an ambulance is assigned, the annotated information along with the ambulance ID would be directed into the information cloud through the plug-in. This would aid in the transmission of information to the right ambulance.

5.4.2.4 Ambulance

It is very important that the information is transmitted to the ambulance personnel in an efficient manner. The essential vital parameters from the information cloud would be transferred in real-time into an interactive interface on a mobile tablet in the ambulance, on being assigned to a case. This would aid the personnel to prepare themselves before reaching the spot of the incident to administer an appropriate first aid. Additionally, general user information along with the GPS location, will be available for the ambulance personnel.

5.5 IT Infrastructure

5.5.1 The Internet Network

It is essential to keep an updated interaction between the healthcare providers and the elderly who has experienced a fall. This could be made possible by including a reliable and secure connectivity in the proposed solution. Today, internet is a common service that most households see as an essential part of life. Therefore, it can act as a platform to receive and transmit information from one stakeholder to another in the chain. However, the use of internet motivates the requirement for a secure gateway.

5.5.2 Gateway

Adaptable communication and intelligence between medical devices is increasingly used in supervision, prevention and treatment purposes through gateways such as WiFi and Bluetooth. WiFi technology is included as a gateway in the proposed solution. WiFi as a gateway enables a connected Digital Health solution. The use of WiFi technology in this solution would aid in achieving a convenient communication between devices. Additionally, it is seen as a key component used to establish a stable communication between the vision-based sensor and the smartwatch. It also helps to transfer both, the alert and all the necessary information of the user, to the consequent components and stakeholders in the chain in a secure manner.

5.5.3 Information Cloud

Centralization of information along with acquiring real-time information from different stakeholders is one of the primary concerns in the proposed solution. This would enable intermediate processing and transfer of information to other stakeholders involved in the care chain, thereby being updated in the decentralized registries. Therefore, an information cloud connected to the different components, common to all the stakeholders is being proposed for integration into the care chain. Format of the information being transferred and shared plays an important role in centralization of information. Thus, interoperability is a concern for the overall integration of individual systems.

5.5.4 Protocols for Interoperability

The rapid growth in ICT has largely been possible due to the ease in digital partnership. Interoperability is a characteristic feature which makes it possible for different systems to interact with each other [100]. Interoperability functions primarily at four different levels, where each level confines the succeeding one to a certain boundary [101]. The various levels according to their rank in the ascending order are, **Legal, Organizational, Semantic** and **Technical Interoperability** [102].
The designed solution is proposed to operate with the guidelines, laws and regulations set by the government and the regulatory authorities in Sweden. This therefore would address legal interoperability. Setting a common method of operation and communication to relay information or requirements between various organizations involved in the care chain could enhance organizational Interoperability. The information being transferred in the chain involves various medical terminologies. Use of Systematized Nomenclature of Medicine Clinical Terms (SNOMED CT) could help in setting a common structure of reporting and communication of medical terminologies among the different stakeholders involved. This would aid in the understanding of the various medical terms the same way among the stakeholders in the care chain, thereby improving semantic interoperability.
Technical interoperability is the last of the four levels, having a high need to be considerate of all the aforementioned levels of interoperability. The use of standards from Health Level 7 (HL7) and Fast Healthcare Interoperability Resources (FHIR) would address the exchange of information from EHR and resources such as Application Program Interfaces (API) needed for EHR exchange, respectively [103] [104]. The proposed adoption of standards from Continua, an international organization that outlines standards based on already existing HL7, and standards from Institute of Electrical and Electronics Engineers (IEEE), would set guidelines for components in the proposed solution to communicate with each other through wired connection, or over internet networks along with sensors, gateways, and EHRs [105].

5.6 Electronic Health Records

An important component in the automated fall detection and pre-hospital care chain would be the availability of the EHR through the process of decision making and pre-hospital care. Due to a rapid development in ICT-based health services, there is a belief that EHRs could reduce medical risks [106].
Currently, EHRs in Sweden are being managed by the respective regions. Each region has a authority to choose the providers of EHR services to the citizens in the respective regions to be able to cater to the population by considering the local conditions while designing the healthcare system[107]. This gives a wide room to implement the integration of EHR into the proposed solution in multiple ways, each suited to the need and structure of data collection, storage and transfer in the different regions.
The idea to integrate EHR into the proposed solution is to automate, wherever possible, the addition of crucial health information about the users. This would be more advantageous for the elderly in case they would not remember incidents prior to, during, or after a fall incident. This could also help healthcare professionals infer on the underlying cause to a fall, if any, along with being able to provide the users, information about the fall incident.
In the care chain, EHR can be used to determine the previous health condition of the user enabling the decision makers, i.e. dispatch center and ambulance, to make accurate decisions helping them handle patients in a better manner. In light of the fact that the dispatch center does not require as much data from the EHR to make decisions, an intelligent CDSS has also been proposed further. This would additionally enable an expedited dispatch of ambulance. In the context of information storage, medically relevant information from different entities in the care chain, such as the sensors measuring fall and vital parameters and annotations sent into the information cloud by dispatchers could provide a new dimension to the kind of information that goes into the EHR, aiding in better healthcare in the future.

5.7 Intelligent Clinical Decision Support System and Data Fusion

Integration of patient and clinical data into Healthcare Information Systems (HIS) to provide support in decision making for patient care forms the basis of CDSS [108]. CDSS can be built in two ways:

- **Knowledge-based** DSS is built by segregating the system into three parts, knowledge base, decision engine and interface for communication. The knowledge base consists of an IF-ELSE structure with multiple rules to determine the association of various data with each other [109].

- The advent of AI and ML techniques have given birth to a novel **non-knowledge-based** DSS [110]. These systems rely on finding patterns or learn from previous experiences, thereby eliminating the need for requirement of a knowledge base for their operation [111].

An interesting example in the deployment of AI-based CDSS into mainstream healthcare is that of Corti's AI integration into the ED of Danish healthcare system, to identify cardiac failures using speech recognition. When tested, it was found that this AI-based CDSS system outperformed human dispatchers in identifying cardiac arrests, 93% to 73%. [112]
In the proposed solution, there is a need to analyze the medical information which comes in from different sources, such as the smartwatch or the EHR. This would provide meaningful information aiding human stakeholders in the chain to make appropriate decisions. According to *Marta Fernandes et al.*, "*the first point where the patient acuity state is evaluated, takes place at the triage stage in the ED* [113]". Prioritizing the requirement of assistance based on the urgency of treatment is a defining factor in pre-hospital care [113]. Triage systems used by healthcare professionals can therefore be used to prioritize cases based on this need. A combination of knowledge-based and non-knowledge-based systems to analyze clinical data could therefore be a potent player in the pre-hospital care for fall incidents. The role of knowledge-based system would be to provide recommendation to the dispatch center based on the user's need for an ambulance by analyzing information from various sources. The non-knowledge-based CDSS could aid in provision of better recommendations to the dispatch centers by learning from previous decisions made by them.

5.8 Dispatch of Ambulances

A quintessential part of the pre-hospital care is to optimize the utilization of ambulances to those in immediate need of assistance. Further, with reference to the interview with *Åsa Högstedt*, ambulance dispatch in Sweden today has been observed to be made based on priority of requirement of immediate assistance.

5.8.1 Pre-dispatch

The proposed solution allows for priority-based ambulance dispatch for assistance to victims of fall. Assorted information obtained from different components in the chain along with the recommendation from CDSS are sent to the interface which is used by the dispatch center. Based on the recommendation received from CDSS and analysis of various related information, the dispatcher can either choose to call the user back, or proactively make a decision on dispatching the ambulance. As a side note, the knowledge and the intellect of a dispatcher handling the case would always precede the recommendation from CDSS.

5.8.2 Post-dispatch

Once the ambulance has been dispatched, the dispatch center and ambulance have a joint responsibility of the case. As it exists in present day, a continuous contact between the two are maintained until the ambulance reaches the scene. Information from the information cloud, along with the recommendation from CDSS, are curated to the need of the paramedics and is streamed into the ambulance. Information about vital parameters would be streamed in real-time into the ambulance. This would ensure that the paramedics have information about the patient's health condition prior to reaching the scene of the incident, thus helping them to prepare themselves to handle the situation better.

5.9 Proposed Concept of a Digital Health Solution for Complete Pre-hospital Care Chain in Case of Fall

An imperative outcome of this thesis is to propose a concept of a Digital Health solution that would automate fall detection and help the elderly to receive faster pre-hospital care. Examination of preexisting IT infrastructure that exists for Digital Health in Sweden preceded the designing of the proposed solution. This allowed for the design to be able to incorporate all possible stakeholders in the care chain. Enabling therefore, to integrate the proposed solution well with an already existent superior welfare system in the country.

The proposed solution includes information about the parameters considered decisive for the care chain, that would aid the stakeholders to determine their next course of action inclined towards patient centered care. The design of the proposed solution also focuses on implementing the prime characteristics and properties found in the systems that exist today, while trying to mitigate the disadvantages, such as rigidity, found in the various system designs for other Digital Health solutions.

The architecture of the proposed solution is as seen in the schematic **Figure 5.5**. This solution focuses on automatic indoor fall detection for elderly who live independently, with or without the help of home-help services.

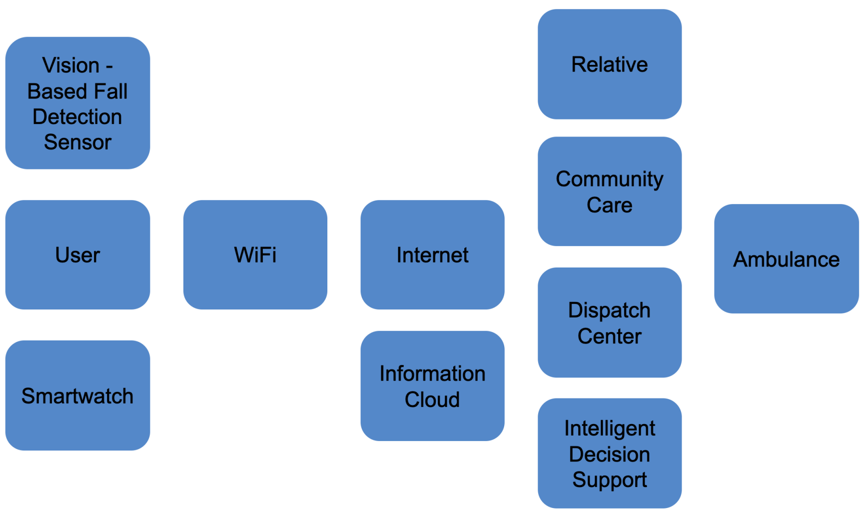


Figure 5.4: Components and stakeholders involved in the pre-hospital care chain in case of fall.

Each stakeholder in the chain has an independent as well as a shared responsibility, with one or more stakeholders, who influence the actions of stakeholders that succeed. In order for the chain to be automated and to present additional information that would determine a case, various block of components have been integrated into the solution to aid stakeholders. The different component blocks and stakeholders involved in the chain are represented in **Figure 5.4**, and are described in **Section 5.1**.

5.9.1 The Proposed Digital Health Solution

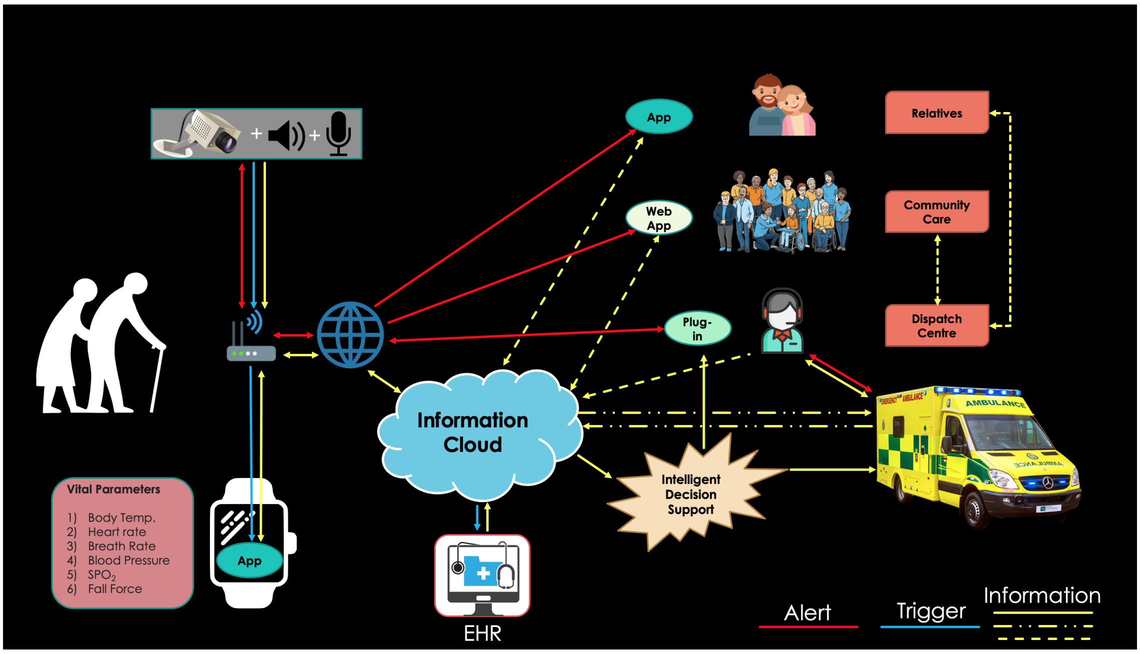


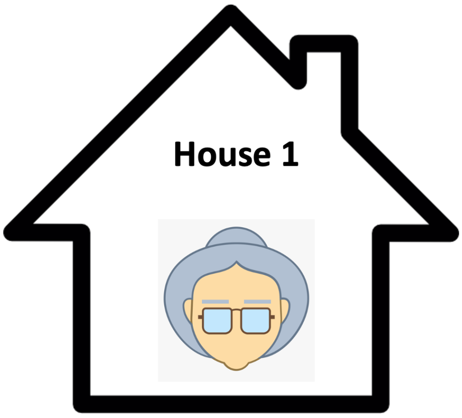
Figure 5.5: The proposed Digital Health solution.

A prerequisite for the ideal functioning of the solution is that the smartwatch is worn by the user, to be able to extract all the information necessary to provide a good care. The primary fall detection sensor, which is a vision-based sensor, senses the fall experienced by the user. On sensing a fall, the vision-based sensor triggers a communication with the smartwatch through a gateway, which in our case is WiFi, to verify with the built-in fall detection sensor in the smartwatch through an application designed for the user. The application acts as a middleman to process the information sent in from the primary fall detection sensor and the parameters of fall obtained from the smartwatch through predefined algorithms. The primary fall detection sensor would work even without a verification with fall parameters from the smartwatch. However, the verification with fall parameters from the smartwatch would increase the dispatcher's confidence in the system to detect a true fall incident. Additionally, it would help in recognizing the identity of the user involved in the fall incident in case of an environment of co-habitation. The parameters from the smartwatch could also give the dispatcher at the end of the chain enough information about the severity of the fall, i.e. hard fall or soft fall. This could form the base for the intelligent CDSS to output better recommendations.
On verification of fall, information about the vital parameters, from the smartwatch, and the masked images of the fall incident, from the vision-based sensor, 3 minutes prior to and after the fall incident is extracted and sent in to the information cloud.

The information cloud acts as a repository for the information, i.e. general user information, information on the vital parameters, images from the vision-based sensor and the EHR, needed to be sent to the different stakeholders in the chain. Simultaneously, an alert is sent out to the relative and community care through the internet on the applications intended to be used by them. An intelligent CDSS is proposed to be set in chain, for the dispatch center to have all the necessary information and to aid them make a faster decision. The information from the information cloud is processed using a set of intelligent algorithms, conclusively recommending an action plan for the personnel handling the case in the dispatch center.

A marginally delayed alert, similar to the one sent to the relative and community care, is sent to the dispatch center. This alert contains all the necessary information in the information cloud along with the recommendation from CDSS. The dispatcher then would make a decision on whether to send an ambulance or not. The dispatcher can either use the information at hand or connect with the person in need through the integrated speaker and microphones in the vision-based sensor setup by making a call. An alert about the dispatcher's decision on the case would be sent to the user, relative and community care. All the information from the information cloud and CDSS would directly be transmitted into the interface integrated in the ambulance.

5.10 Testing the Proposed Solution – Typical Use Cases, Pros and Cons of Using Various Sensor Setups



Name	Lina Andersson
Age	82 years
Gender	Female
Living Condition	Lives alone in her 1 BHK Apartment. Does not have a subscription to home – help services.
Health Condition	Visual impairment, Neuropathy, Osteoporosis
Medication	Analgesics
Tendency to Fall	High

Figure 5.6: Persona of an old woman living alone.

5.10.1 House Number 1

5.10.1.1 About

Lina Andersson is a retired nurse living in her 1 Bedroom-Hall-Kitchen (BHK) apartment in Gothenburg, spending time mostly reading on her 'Kindle'. At 82 years of age, Lina does most of her daily activities herself, and is not reliant on the home-help services provided by the municipality in spite of suffering from a visual impairment, neuropathy and osteoporosis. Her rationale behind not seeking help from home-help services, although she needs it sometimes, is that she wants to be self-reliant, and is not willing to be a burden on the state's resources. She has been on Analgesics and Bisphosphonates for a long time, given her medical condition. The medications, along with her medical condition have a high impact on her tendency to fall. She has been experiencing soft falls at least twice a month for the last 6 months, and was not in a position to call for help when she needed it. Lina believes that the Digital Health solution that has been newly integrated into the healthcare services for elderly could help her seek assistance whenever she is need, as well as live her life independently. Her relatives have been very supportive of her in this regard.

5.10.1.2 Scenario 1: Lina and her new Digital Health Solution

The simulation performed in Scenario 1 considers Lina wearing the smartwatch that is connected to her smartphone, which contains the mobile application designed for the Digital Health solution. The vision-based sensor have also been installed, to make sure that there are no blind spots. A chronological description on Lina's fall incident are as below:

Time	Activity
18:30 HRS	Lina trips, and experiences a hard fall.
18:30 HRS	Vision-based sensor in the kitchen detects a fall.
18:31 HRS	Vision-based sensor confirms a fall.
18:31 HRS	Vision-based sensor triggers communication with the smartwatch through the mobile application.
18:31 HRS	Through data and sensor fusion algorithms, the information obtained from the smartwatch and the vision-based sensor are analysed to verify that a fall incident has occurred.
18:33 HRS	Information on vital parameters and the masked images from **[18:27HRS] to [18:33 HRS]** are transferred into the information cloud.
18:33 HRS	An alert is sent to the relatives, the community care and the dispatch center on their respective applications. The information sent to the relatives could look like this:

ALERT!! Your relative living in Linnégatan XX has experienced a hard fall at 18:30 HRS. An alert has been sent to the dispatch center who will take further action on this case. Please respond with a 'Yes' if you will be able to visit the patient in the next 15 minutes, else respond 'No'.

The information sent to the community care could look like the one below:

ALERT!! Your patient with device ID-number XXXX, living in Linnégatan XX has experienced a fall at 18:30 HRS. An alert has been sent to the dispatch center who will take further action on this case. Please respond with a 'Yes' if you will be able to visit the patient in the next 15 minutes, else respond 'No'.

The information sent to the dispatch center, could look like the one below:

ALERT!! A patient living in Linnégatan XX has experienced a hard fall at 18:30 HRS. Please remain on standby for more information.

Time	Activity
18:33 HRS	EHR information is retrieved from the master EHR storage into the information cloud.
18:34 HRS	Information present in the information cloud is then fed into CDSS.
18:34 HRS	An output from CDSS is given on the designed plug-in to the already existing CoordCom tool of a registered nurse assigned to handle the case, which reads as below:

*Lina Andersson, an elderly woman aged **82 years** has experienced a hard fall in her residence at Linnégatan XX. She seems to be alone in the house with no movement for 3 minutes after the fall incident. The fall incident has been triggered by the sensor in the kitchen.*

*The fall preceded with a decrease in **oxygen saturation of 95%** irregular heart rate, maybe atrial fibrillation. Heart rate, body temperature, blood pressure, respiratory rate are normal, while blood oxygen saturation is still maintaining only at 95%.*

She has a medical history of increased risk of fall because of her visual impairment. She suffers from dizziness and numb feet now and then, osteoporosis and has had a mild hip injury previously, caused by fall.

***Conclusion**: A high priority needs to be given to the case. An ambulance would need to be sent at the earliest.*

Time	Activity
18:36 HRS	A decision to send an ambulance is made by the registered nurse without the need to have other information.
18:36 HRS	Annotations made by the registered nurse is added into the EHR.
18:36 HRS	An alert about this decision is sent to the community care and the relatives.
18:37 HRS	Real-time vital parameters and other general information about the patient is transferred from the information cloud into the integrated application in the ambulance.
18:50 HRS	Ambulance reaches the destination with the help of the provided information. The ambulance personnel gain entry into the building and are able to locate the patient easily inside the residence, providing the required assistance.

5.10.1.3 Scenario 2: Lina and her 8 months old Digital Health Solution

The simulation performed here represents Scenario 2 where Lina becomes forgetful about wearing the smartwatch. The vision-based sensor have been working well since installation. A chronological description on Lina's fall incident are as below:

A few weeks earlier

Lina's relative updates some general information about Lina through their version of the mobile application designed for the Digital Health solution.

Today

Time	Activity
18:30 HRS	Lina experiences a soft fall while getting off her couch.
18:30 HRS	Vision-based sensor in the living room detects a fall.
18:31 HRS	Vision-based sensor confirms a fall.
18:31 HRS	Vision-based sensor triggers communication with the smartwatch through the mobile application.
18:31 HRS	No data is obtained from the smartwatch since Lina has not worn her smartwatch, therefore providing no verification to the vision-based sensor using data and sensor fusion algorithms for a fall incident. The vision-based sensor nevertheless records a decent enough confidence on its detection of the fall to send an alert without verification.
18:33 HRS	Masked images from **[18:27 HRS] to [18:33 HRS]** are transferred into the information cloud.
18:33 HRS	An alert is sent to the relatives, the community care and the dispatch center on their respective applications. The information sent to the relatives could look like this :

ALERT!! Your relative living in Linnégatan XX has experienced a fall at 18:30 HRS. An alert has been sent to the dispatch center who will take further action on this case. Please respond with a 'Yes' if you will be able to visit the patient in the next 15 minutes, else respond 'No'.

The information sent to the community care could look like the one below:

ALERT!! Your patient with device ID-number XXXX, living in Linnégatan XX has experienced a fall at 18:30 HRS. An alert has been sent to the dispatch center who will take further action on this case. Please respond with a 'Yes' if you will be able to visit the patient in the next 15 minutes, else respond 'No'.

The information sent to the dispatch center, could look like the one below:

ALERT!! A patient living in Linnégatan XX has experienced a fall at 18:30 HRS. Please remain on standby for more information.

Time	Activity
18:33 HRS	EHR information is retrieved from the master EHR storage into the information cloud.
18:34 HRS	Information present in the information cloud is then fed into CDSS.
18:34 HRS	An output from CDSS is given on the designed plug-in to the already existing CoordCom tool of a registered nurse assigned to handle the case, which reads as below:

*Lina Andersson, an elderly woman aged **82 years** has experienced a fall in her residence at Linnégatan XX. She seems to be alone in the house with some movement for 3 minutes after fall. The fall incident has been triggered by the sensor in the living room.*

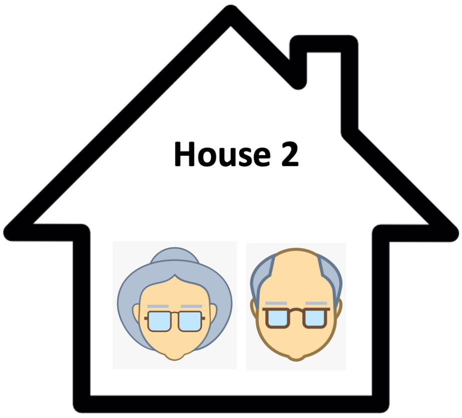
Reason for the fall is unknown.

She has a medical history of increased risk of fall because of her visual impairment. She suffers from dizziness, numb feet now and then, osteoporosis and has had a mild hip injury previously, caused by fall.

***Conclusion**: The severity of the fall incident is inconclusive. A call to the patient is necessary.*

Time	*Activity*
18:36 HRS	A call is made by the registered nurse to Lina, on her vision-based sensor with the integrated speakers and microphones, through the plug-in tool to CoordCom. After a brief interview and assessing her consciousness and pain levels, a decision to not dispatch an ambulance is made by the registered nurse.
18:36 HRS	Annotations made by the registered nurse is added into the EHR.
18:36 HRS	An alert about this decision is sent to the community care and the relatives.

5.10.2 House number 2



Name	Anna Persson
Age	84 years
Gender	Female
Living Condition	Lives with her husband in their 3BHK Apartment. Has a subscription to home – help services.
Health Condition	Visual impairment, Cardiovascular Disease
Medication	Antihypertensives
Tendency to Fall	High

Name	Anders Persson
Age	86 years
Gender	Male
Living Condition	Lives with his wife in their 3BHK Apartment. Has a subscription to home – help services.
Health Condition	Visual impairment, Parkinson's Disease
Medication	Benzodiazepines
Tendency to Fall	High

Figure 5.7: Persona of an old couple living together.

5.10.2.1 About

Anna and Anders Persson are a retired couple living in their 3 BHK apartment in Gothenburg, spending time mostly watching television and playing 'Tetris' on their iPad. Both Anna and Anders require some sort of assistance in their daily living, due to their health conditions, and are reliant on the home-help services provided by the municipality. Anna and Anders have been on Antihypertensives and Benzodiazepines, respectively, given their medical condition. The medications, along with their medical condition have a high impact on their tendency to fall. One of these days when Anna was out running some errands, Anders had experienced a fall and was not in a position to call for help until Anna returned home. They believe that the Digital Health solution that has been newly integrated into the healthcare services for elderly could help them seek assistance during hours of need, as well as live their life as secure as possible. Along with having both of them support each other, their daughter has been very supportive of them in this regard.

5.10.2.2 Scenario 3: Getting Familiar with the Digital Health Solution

The simulation performed in Scenario 3 shows a possibility where Anders forgets to wear the smartwatch. The vision-based sensor have been working well since installation. A chronological description on Anders' fall incident are as below:

A few weeks earlier

Anna and Anders update their general information through their version of the mobile application designed for the Digital Health solution.

Today

Time	Activity
18:30 HRS	Anders experiences a fall while on his way to plug in his dead phone to the charger.
18:30 HRS	Vision-based sensor in the bedroom 1 detects a fall.
18:31 HRS	Vision-based sensor confirms a fall.
18:31 HRS	Vision-based sensor triggers communication with the smartwatch through the mobile application on Anna's phone.
18:31 HRS	Fall data obtained from the smartwatch does not correspond to the measurements from the accelerometers and the gyroscope on Anna's smartwatch, therefore providing a verification to the vision-based sensor using Data and Sensor fusion algorithms that Anna has not taken a fall. The vision-based sensor records a decent enough confidence on its detection of the fall, to send an alert.
18:33 HRS	Masked images from **[18:27 HRS] to [18:33 HRS]** are transferred into the information cloud.
18:33 HRS	By the method of elimination, the vision-based sensor decides that Anders has experienced a fall. An alert is sent to the relatives, the community care and the dispatch center on their respective applications. The information sent to the relatives could look like this :

ALERT!! Your relative living in Fjällgatan XX has experienced a fall at 18:30 HRS. An alert has been sent to the dispatch center who will take further action on this case. Please respond with a 'Yes' if you will be able to visit the patient in the next 15 minutes, else respond 'No'.

The information sent to the community care could look like the one below:

ALERT!! Your patient with device ID-number XXXX living in Fjällgatan XX has experienced a fall at 18:30 HRS. An alert has been sent to the dispatch center who will take further action on this case. Please respond with a 'Yes' if you will be able to visit the patient in the next 15 minutes, else respond 'No'.

The information sent to the dispatch center, could look like the one below:

ALERT!! A patient living in Fjällgatan XX has experienced a soft fall at 18:30 HRS. Please remain on standby for more information.

Time	Activity
18:33 HRS	EHR information is retrieved from the master EHR storage into the information cloud.
18:34 HRS	Information present in the information cloud is then fed into CDSS.
18:34 HRS	An output from CDSS is given on the designed plug-in to the already existing CoordCom tool of a registered nurse assigned to handle the case, which reads as below:

*Anders Persson, an elderly man aged **86 years** has experienced a soft fall in his residence at Fjällgatan XX. He seems to be have company in the house. The fall incident has been triggered by the sensor in bedroom 1.*

Reason for the fall is unknown.

He has a medical history of increased risk of fall because of his visual impairment. He suffers from shaky limbs, and has impaired posture and balance. No previous recorded cases of fall.

***Conclusion**: A medium priority can to be given to the case.*

Time	Activity
18:36 HRS	A call is made by the registered nurse to Anders, on his vision-based sensor with integrated speakers and microphones, through the plug-in tool to CoordCom. After a brief interview with Anders and Anna about Anders' consciousness and pain levels, a decision to not dispatch an ambulance is made by the registered nurse.
18:36 HRS	Annotations made by the registered nurse is added into the EHR.
18:36 HRS	An alert about this decision is sent to the community care and the relatives.

5.10.2.3 Scenario 4: Seasoned Users of the Digital Health Solution

The simulation performed in Scenario 4 shows a possibility where both Anna and Anders wear the smartwatch. The vision-based sensor have been working well since installation. A chronological description on Anna's fall incident are as below:

A few days earlier

Anna and Anders update their general information through their version of the mobile application designed for the Digital Health solution.

Today

Time	Activity
18:30 HRS	Anna experiences a hard fall outside the bathroom.
18:30 HRS	Vision-based sensor in the bedroom 2 detects a fall.
18:31 HRS	Vision-based sensor confirms a fall.
18:31 HRS	Vision-based sensor triggers communication with the smartwatch through the mobile application on Anna and Anders' phone.
18:31 HRS	On verification with both Anna's and Anders' data obtained from their smartwatches, the data obtained from Anna's smartwatch corresponds to a hard fall, therefore providing a verification to the vision-based sensor using Data and Sensor fusion algorithms that Anna has experienced a fall.
18:33 HRS	Masked images from **[18:27 HRS] to [18:33 HRS]** are transferred into the information cloud.
18:33 HRS	Simultaneously, the vision-based sensor decides that Anna has experienced a fall. An alert is sent to the relatives, the community care and the dispatch center on their respective applications. The information sent to the relatives could look like this :

ALERT!! Your relative living in Fjällgatan XX has experienced a hard fall at 18:30 HRS. An alert has been sent to the dispatch center who will take further action on this case. Please respond with a 'Yes' if you will be able to visit the patient in the next 15 minutes, else respond 'No'.

The information sent to the community care could look like the one below:

ALERT!! Your patient with device ID-number XXXX living in Fjällgatan XX has experienced a hard fall at 18:30 HRS. An alert has been sent to the dispatch center who will take further action on this case. Please respond with a 'Yes' if you will be able to visit the patient in the next 15 minutes, else respond 'No'.

The information sent to the dispatch center, could look like the one below:

ALERT!! A patient living in Fjällgatan XX has experienced a hard fall at 18:30 HRS. Please remain on standby for more information.

Time	Activity
18:33 HRS	EHR information is retrieved from the master EHR storage into the information cloud.
18:34 HRS	Information present in the information cloud is then fed into CDSS.
18:34 HRS	An output from CDSS is given on the designed plug-in to the already existing CoordCom tool of a registered nurse assigned to handle the case, which reads as below:

*Anna Persson, an elderly woman aged **84 years** has experienced a hard fall in her residence at Fjällgatan XX. She seems to be have company in the house. The fall* *incident has been triggered by the sensor in bedroom 2.*

The fall preceded with elevated, irregular heart rate between 115 - 125 BPM with a decrease in ***blood oxygen saturation of 94%****. Increase in blood pressure and respiratory rate is seen throughout the recording.*

She has a medical history of increased risk of fall because of her visual impairment. She suffers from coronary heart disease. One previous recorded case of fall.

Conclusion*: A high priority needs to be given to the case. An ambulance would need to be sent at the earliest.*

Time	Activity
18:36 HRS	A decision to send an ambulance is made by the registered nurse without the need to have other information.
18:36 HRS	Annotations made by the registered nurse is added into the EHR.
18:36 HRS	An alert about this decision is sent to the community care and the relatives.
18:37 HRS	Real-time vital parameters and other general information about the patient is transferred from the information cloud into the integrated application in the ambulance.
18:50HRS	Ambulance reaches the destination with the help of the provided information, the ambulance personnel gain entry into the building and are able to locate the patient easily inside the residence, providing the required assistance.

Although there are certain mandatory requirements for the solution to perform efficiently, it can be said that the proposed Digital Health solution would be a helpful tool for the elderly to be able to live securely and independently. The proposed solution manages to solve the problem of directly alerting the dispatch center when a fall is detected. The use of data and sensor fusion algorithms aid in the mitigation of false alarms. It additionally alerts the other stakeholders in the chain, such as the relatives and the community care, thus enabling the availability of information about a fall incident. Solving problems related to discrimination of the user in scenarios of co-residence is also addressed well in the proposed solution, as seen during the evaluation in **Section 5.10.2.2**. Challenges such as forgetfulness of the user to wear the smartwatch, or a breakdown in the WiFi would lead to an eventual failure of the solution. Robustness, therefore depends on the normal functioning of the various components and stakeholders involved in the proposed Digital Health solution for fall detection and pre-hospital care.

6
Discussion

Statistics for the year 2019 received from *Åsa Högstedt* at SvLc revealed that about 20753 cases of injuries to extremities were seen in total. Priorities 1 and 2 were assigned to about 2874 cases of injuries to extremities involving suspicious hip fractures, caused possibly due to fall incidents. The implementation of an ideal Digital Health solution integrated into the pre-hospital care chain for fall incidents could significantly improve the quality of healthcare services provided to the elderly. This would also reduce the stress faced by ambulance dispatchers. However, one of the major challenges in the detection of fall, and implementation of Digital Health solutions were seen to be in alignment with how technology is being used today. Although there currently exist potent independent solutions, these today are not put together to provide a sturdy all-in-one solution. Robust models for detecting fall incidents automatically and providing sufficient quality of pre-hospital care, especially for the elderly in need of assistance, can be made possible by making a combination of these solutions. An implementation of care chains for fall today need significant human intervention, causing delays in providing the kind of assistance that is necessary, due to the fact that there is insufficient information about the incident with the stakeholder responsible for providing the service. In countries like the USA and Netherlands, private insurance and healthcare providers have a major role in providing assistance to the elderly, at a cost. Although private services can be effective players in providing efficient healthcare services, they pose a greater challenge to the implementation of new healthcare solutions to the population as a whole.

Organizational interoperability between the public services and among the private players can be seen as a major hurdle in the implementation and integration of new healthcare services. For instance, usage of EHRs in the healthcare system in the USA have been around for a long time. Yet, there is a significant hindrance in sharing of medical records with each other. This is due to the use of various government-approved EHR management solutions. Each of these have a different format of specifying technical information, phrasing clinical reports and functionality. A difference can be seen in this regard when compared to welfare states, such as Sweden, where healthcare is provided to all the citizens by the state. The public healthcare model eases the effort that needs to be put into implementing solutions on a large scale, throughout the country for instance. The reason for this is that the legal obligations formed by the government provide guidelines to different public healthcare organizations and the 21 administrative regions in Sweden. Several interaction models exist between healthcare organizations and the administrative enterprises in these regions. Considering these legal regulations and clauses would make it easier to implement healthcare services more effectively on a large scale.

Public healthcare system can be looked at as an ideal model to implement new healthcare services on a massive scale. However, a number of organizational factors, among security of information, play an extensive role in efficient implementation. This cascades down to the level of technical interoperability for which considerations need to be made. Implementation of a new healthcare services would need to be considerate of different organizations' operational structures to be able to design a robust service. According to the discussion with *Ulrika Björner*, for a newly introduced healthcare service, provisions would need to be made for necessary training to already existing employees and healthcare workers. This would aid in an efficient interaction cross-organizationally in the care process. Thereby, making them skillful enough to provide a seamless and competent service to the citizens.

6.1 General Reflection on the Proposed Solution

Focus Groups : Who and Why?

The project and the proposed solution is mainly directed towards two specific elderly groups, people older than 65 years of age living independently in their ordinary homes and people older than 65 years of age remaining in their homes with provided home-help services by municipalities. Based on the interviews conducted during this project, these mentioned groups would benefit from using modern technologies in their home environment. The major issue raised during interviews was lack of security and safety that these groups experienced in their everyday life. Implementing such solutions in their homes would reduce the number of required supervisions done by their relatives or the healthcare providers. This would result in the primary advantage of bringing peace of mind and enhancing safety. At the same time, having modern technologies installed in elderly's house would assure quick and suitable medical help in the case of incidents.

Elderly who live in nursing homes were excluded in this project. The main reason to this was the special requirements that had to be accounted, including several chronic deceases and uncertainties in handling such technologies, while proposing the Digital Health solution. In addition, the group living in nursing homes are offered nurse supervision round the clock which increases the possibility to receive assistance in case of an incident. The proposed solution, however, can be modified to be appropriate to these challenging cases as well. Adjustments such as, the type of implemented sensors and the devices used to interact with the users, can be made to the proposed solution to appropriate the need of use.

Although the aim of this project was to propose a Digital Health solution primarily towards the two focus groups, other elements in the population, such as people with chronic injuries and other disabilities were mentioned by medical professionals. These 'other elements' in the population might have the possibility of being benefited from the implementation of the thought that goes into designing such solutions. As explained by the professionals during the interviews, the need of implementing modern technology in elderly people's lives exist. In Gothenburg, it has been observed that individuals purchase digital solutions privately, e.g. GPS trackers, to guarantee the safety of their older family members. However, the family of the elderly are primarily responsible to handle these digital solutions without any intervention from the public healthcare services since it has been provided privately. For instance, the GPS tracker is not supported by the government and if any incident happens, the situation must be handled by the family or relatives. The interview with *Ulrika Björner* revealed that digital, automated healthcare services would significantly impact the elderly living independently. This could significantly help the elderly who have no relatives or family members to assist them in times of need, also making them feel more secure.

Stakeholders and Their Involvement

Different stakeholders have been brought together in the proposed solution such as, the family members and relatives, the community care, the dispatch center and the ambulance services.The main purpose of gathering several stakeholders in the proposed solution is to decrease the impact of the potential injuries caused by fall incidents as well as to avoid mortality. An existing example is Safety Alarm, where the relatives of the elderly and the community care are always involved in one way or another when any incidents occur. Their engagement plays an important role, taking into account both physical and psychological aspects. In the proposed solution, the relatives and the community care have the choice of acting actively as well as passively in case of incidents e.g. by calling or visiting the elderly in the time of incident. Additionally, the involvement of the relatives or community care can be a reliable source of information for the dispatch center and the ambulance personnel.

Has the Proposed Fall Detection Solution Been Able to Mitigate False Alarms?

To tackle the fall detection issue, the fused data comes from the vision-based sensor and the smartwatch, in the proposed solution. Implementing a sensor fusion technology in the proposed solution could have several advantages, including increased accuracy and reliability while reducing uncertainty and confusion. Nevertheless, the data fused from different sources can prove to be a challenging task, raising several major issues particularly in data imperfection as well as conflict and alignment in the fused data. Collecting data through multiple sensors adds to the diversity of measured data, which in turn affects the quality of provided information. Conflicts in the fused data is a common problem in sensor fusion solutions, for instance when a fall is detected by the vision-based sensor and not by the smartwatch in the proposed solution. The data logged from the two separate sources must be processed and obtained in a common time frame. Hence, it is essential to implement accurate data fusion algorithms and calibration methods to effectively reduce the mentioned impacts in practice.

The reason for the use of a vision-based sensor as a primary sensor for detecting fall is to be able to extract masked visual information about the incident before, during and after the fall in order to make an accurate analysis of the situation at hand. Rapid advancements in the field of computer vision could aid in better detection of soft falls and sliding falls.

Have the Expectations of Healthcare Providers on Extracting Essential Vital Parameters Been Met?

The desired vital parameters when receiving medical emergency calls, mentioned during the interview with *Åsa Högstedt* were namely, respiratory rate, heart rate, blood pressure, signs on skin, possible head and hip injuries and level of consciousness. Respiration rate and heart rate were considered to be essential vital parameters, since even small variations in these parameters can affect the priority given to a case. For instance, a respiratory rate higher than 30 breaths per minute could indicate large amounts of blood loss, which therefore can be an indicator of a critical situation. Additionally, it was desired to extract information about any changes on the skin, possible head and hip injuries as well as level of consciousness. Extracting information about these parameters was found to be a challenging task after reviewing available sensors to extract essential vital parameters. Usage of a monitoring camera might be a possible approach to extract information about changes on the skin. A hindrance, however, to extract these information could be caused due to a degradation in the quality of the image, or the posture of the person lying on the floor, or if the specific part of interest on the body is not visible. On the other hand, this would raise discussions on privacy and ethical issues when using a camera to monitor individuals.

The essential vital parameters which are possible to extract in the proposed solution are heart rate, body temperature, blood pressure, respiratory rate, blood oxygen saturation and level of consciousness. The extraction of heart rate, body temperature, blood pressure, respiratory rate and blood oxygen saturation in the smartwatch is taken care of by using PPG technology with the implementation of appropriate algorithms to extract the different vital parameters. However, uncertainties in measuring blood pressure by this method need to be considered. A possible way to gain information about the level of consciousness could be trough the built-in microphones and speakers in the installed vision-based fall detection solution. In this case, the dispatcher can communicate with the person in need by asking them to respond to their voice, for instance by moving the arm or waving.

Rationalizing the Development of Multiple Applications for Different Stakeholders

With reference to the user application, the necessity of designing an application and therefore an interface, being considerate of the elderly makes a astounding impact to the purpose for which it was designed. In the proposed solution, the general information about the user subscribed to the service makes an impact on the service provided to the person in need. Empowerment of relatives and the community care to actively take part in updating the general information of the user through their respective mobile and web applications gives a sense of security to the elderly using the service.

Since maintaining a database is considered as an important part of information systems, a requirement in the web application of the community care arises, to be enabled with a two-way communication into the information cloud, where the community care can update relevant information.

The extensive use of **CoordCom** in the dispatch centers across Sweden has restrained the development of a standalone application for the Digital Health solution. A plug-in designed to be integrated with **CoordCom** is therefore proposed in the solution. This would help in keeping the current system of triage followed by the dispatch center as well as provide additional information to the dispatcher aiding in a possibly faster response to a case of fall incident.

Relaying all the necessary information as discussed in **Section 4.2** to the ambulance personnel to help in the preparation of assisting the elderly could impact the quality of care provided on reaching the site of the fall incident. Relevant and timely help can be given to the person in need, in the possibility of the information being available beforehand. The application proposed to be used by the ambulance personnel on a tablet would enable mobility of the device, thereby allowing the device to be carried along.

Whose Responsibility is it to Update the Medical Information That Goes Into the EHR?

Since EHR is handled locally by each region today, the municipalities have to guarantee that EHR is updated by healthcare providers in real-time. EHRs in Sweden are updated with changes in the health condition or medications by healthcare personnel after each appointment with a doctor, on the doctor having investigated the cases thoroughly. EHR is considered as an essential item in the proposed solution, since it is one of the most important sources which builds the foundation to the decision made by the intelligent CDSS. The information retrieved from EHR can also significantly impact the final decision made by the ambulance dispatcher. On the other hand, the dispatch center and the ambulance staff have at least as high responsibility, if not higher than the hospital and primary care personnel in updating the EHR.

Mapping Device IDs: With Each Other, With a User ID, and to the Information in the Information Cloud

Identification of devices being used to detect fall and other vital parameters becomes essential, since multiple devices are being used in the solution. This would ease the storage of incoming information into the information cloud. Assigning device IDs to the proposed devices for fall detection and measurement of vital parameters, and mapping the personal number of the elderly as a user ID to these devices would aid in easing the retrieval, storage, import and export of various types of information. Importing and exporting of EHRs, to and from the information cloud, can be made possible by using personal numbers as identifiers to access most healthcare information in public healthcare databases. Using personal number as a common entity for identification would help streamlining the process, also aiding in the integration of other auxiliary services into the proposed solution. An interesting perspective to using IDs to map devices and users together is also to be able to discriminate between elderly living in environments of co-habitation. Difficulty for the vision-based sensor to discriminate between people during a fall incident in a household would be high. This would cause problems in routing the information to the right destination in the information cloud. The smartwatch in the proposed solution alleviates this difficultly. The information can be routed to the right destination in the information cloud, by mapping the device ID with the user's personal number.

Why Address Issues Related to Information Security and Encryption of Information?

Security of information in an ICT-based healthcare service demands, in order to be structured and organized throughout the communication process among different stakeholders with active tasks in the chain [114]. Close interactions between different stakeholders in a care chain bring them together to communicate and share information with each other. However, accessibility to information should be made available only to the intended stakeholders, restricting unauthorized access of information [114]. The advancement and prevalence of the use of connected systems has posed a challenge in maintaining confidentiality of information. Multitude of information is transferred trough the proposed Digital Health solution between various stakeholders. This intermittent transfer of information over the internet exposes the vulnerability of the solution to cyber attacks. Information stored in the information cloud is also vulnerable to getting stolen. A need for discussion consequently has arisen, to secure data in motion, data at rest and data in use, also called the three data states. [115] Encryption of information plays a vital role in securing information. Adoption of modern infrastructure for data encryption when data is at rest, in motion or in use in the proposed solution could increase the security of information throughout the operation. Additionally, this would increase the trust of the elderly citizens to use such services, when implemented.

CDSS: Knowledge-based, or Non-knowledge-based, or Both?

The increased use of automated information has seen an overwhelming growth in the healthcare sector in providing novel services. CDSS being one such, has also made a mark to rooting itself as a common entity in several healthcare services. An issue, however, is that the usage of a poorly developed and deployed CDSS could lead to more harm than the good it does [116]. The use of a combination of a knowledge-based and a non-knowledge-based CDSS could help the dispatcher make decision on a case faster. The knowledge-based part of the CDSS can help understand the clinical basis on which cases need to be prioritized by analyzing the measurements of the vital parameters sent in, along with the health history of the patient retrieved from the EHR. Learning, using prevailing techniques in the field of AI, from the previous actions taken on different cases by the dispatchers could aid in building a more robust solution. This could provide an output with increased accuracy for decision support. Output from the knowledge-based CDSS can be fed as an input into the non-knowledge-based CDSS based on mathematical and statistical models. Thereby, yielding an output that provides a sturdier decision support to the dispatcher.

6.2 Performance of the Proposed Digital Health Solution

The smartwatch proposed in the Digital Health solution was intended to be similar to Apple Watch. However, according to the conducted experiments with Apple Watch described in the **Appendix A**, the watch does not seem to be the best fall detection solution and health monitoring device for the elderly. Apple Watch might not be able to detect the common types of fall incidents experienced by elderly, since the watch is based on a high preselected threshold level. Additionally, Apple Watch is designed in a way that might be complicated to be used by the elderly. The battery consumption in Apple Watch is high, possibly due to the large number of offered features in Apple Watch, and the watch is required to be recharged often. This means that the watch has to be detached from the elderly more often. The concept of proposing a smartwatch similar to Apple Watch for automatic fall detection and health monitoring is good. However, a number of improvements need to be included in the proposed smartwatch. The fall detection feature should be made more sensitive, for example by selecting a lower threshold level. In addition, the user-friendliness of the smartwatch should be assured to enable an effortless use by the elderly for instance, by offering a bigger screen, more visible icons or buttons and elimination of unnecessary features. The battery consumption is another challenge that possibly could be improved by removing unessential features such as an always-on display.

A noteworthy mention to the ideal functioning of the proposed Digital Health solution is the prerequisite of having to wear the smartwatch. The problem of detecting fall has been handled by proposing a solution based on sensor fusion technology. Considering cases when the user does not wear the smartwatch, which is an important source of information, the force experienced by the user during a fall incident and the information about the vital parameters are lost. Additionally, the recognition of the targeted user by the smartwatch is not possible anymore. However, the dispatcher is sill able to communicate with the user through the built-in microphones and speakers along with the vision-based sensor to extract additional information about the state of the user. Losing a source of data in the proposed solution results in the CDSS making decisions relying on only the user's EHR, which in turn might end up in a ambiguous decision.

A Reflection on The Simulated Tests

Although the four scenarios mentioned in **Section 5.10** might not be as comprehensive, the simulated tests contemplate with different scenarios that could occur in real-life.

Scenario 1 describes an ideal situation where the user wears the smartwatch which is able to provide all the necessary information to the dispatch center, to be able to react to the alert quickly. The availability of all the necessary information, such as the measurement of vital parameters, nature of fall, medical history from the EHR and the general information is received by the information cloud. Further processing of the information in the CDSS takes place before having the output sent in to the dispatch center. The probability of an ideal case scenario in the real world is low, therefore another scenario is considered to simulate the stability of the proposed solution.

Scenario 2 considers a situation where the user does not wear the smartwatch. On the user experiencing a soft fall, the vision-based sensor detects the incident with a mediocre confidence. Thereafter, the vision-based sensor tries to establish a communication with the smartwatch to verify the measurements from the accelerometer and gyroscopes in the smartwatch. Since the vision-based sensor was not able to verify a fall incident with the measurements from the smartwatch, the vision-based sensor, based on its confidence of having detected a fall, sends an alert to the different stakeholders in the chain. The masked images are simultaneously transferred into the information cloud. The only source of information now is the medical history from the EHR, which gets processed in the CDSS. The output from the CDSS gives a suggestion to the dispatcher that a call to the user is necessary, thereby possibly taking more time for the dispatcher to make a decision. This also demands the already stressed dispatcher to take additional efforts into resolving a case.

On comparing **Scenario 1** and **Scenario 2**, it can be seen that the missing information from the smartwatch could be of greater use to know the current condition of the user before, during and post fall. Although some major information to make a decision on the case was missing, the positive outcome of the solution is that a fall was detected, and an alert was sent to the dispatch center. This does not seem to be possible automatically for any fall detection solution available today.

Referring to **House 2** in **Section 5.10**, **Scenario 3** describes an environment of cohabitation. An ideal example of a problem in case of an environment of cohabitation is that of user discrimination. One of the users here does not wear the smartwatch intended to couple, not only as a vital parameter measurement and fall verification device, but also as a device intended to identify which user has taken a fall. The verification of fall in this case does not happen directly since the vision-based sensor only gets a negative verification from the device that is switched on. Based on the method of elimination and on the confidence of detection of fall, the vision-based sensor sends an alert. The vision-based sensor maps it to the right person that has taken the fall and transfers the masked images into the information cloud. Thereafter, similar steps as discussed about in **Scenario 2** would continue.

Scenario 4 describes the same environment of cohabitation, where both the habitants wear the smartwatch. On one person experiencing a fall, the vision-based sensor detects the fall and triggers the smartwatch of both the habitants through the application to verify a fall. On analysis of data measured from both the smartwatches, the data from the correct measurements of a fall is verified with the vision-based sensor. Having the smartwatches mapped to specific users beforehand makes it easier to discriminate the person experiencing a fall. All the recorded information is then transferred into the information cloud, thereafter following the process mentioned in **Scenario 1**.

On comparing **Scenario 3** and **Scenario 4**, we can infer that the discrimination of the user experiencing a fall in an environment of cohabitation is possible, either directly or using the method of elimination. The drawback of the method of elimination is that it will only succeed if the confidence of the vision-based sensor in detecting a fall is high or medium. A major limitation in the proposed solution in an environment of cohabitation could be that the devices worn by the habitants could be interchanged, subsequently transferring the information mapped to the incorrect user.

Existing Fall Detection Solutions and The Proposed Solution: A Comparison

Improvements in the quality of care given to the elderly has seen significant changes in the last decade. A number of solutions, ongoing research and several scientific papers which focus on fall detection have been examined through this thesis. A significant disclosure was that a majority of the solutions available on the market today cater only up to a certain point, such as detection of fall. While some solutions like the **Philips Lifeline**, **Bellpal**, **Fearless**, **Walabot Home**, **CareEye**, **Medical Guardian** and **MobileHelp** automatically detect fall and send alerts either to a preselected contact or to a private response center operated by the device provider, the entire chain of pre-hospital care is not addressed in an effective manner, while losing out a lot of information in the process. The solutions available today incorporate state of the art for fall detection technology, but are not integrated with one another. Doing so would help in providing an efficient fall care chain. The solution proposed in the project can be viewed as a concept to address issues relating to automated fall detection, while taking into consideration several aspects of implementation of the solution into the existing Swedish healthcare system. A fully connected solution has been designed, which automatically identifies fall incidents using a combination of several state of the art technologies and transfers information considered necessary by healthcare professionals. The information is curated for the involved stakeholders to provide quality pre-hospital care to the elderly in need.

6.3 Who Should Provide the Solution?

Since the beginning of our initial discussions on this question, the opinion was to have a shared model to provide the Digital Health solution to the target groups. The rationale behind this was to make sure that neither the state nor the seeker of this solution would take a substantial hit on their treasury or savings, respectively. The solution proposed would be to ensure that the state pays for a larger part of the product cost that would need to be installed or given to the elderly in need of this service. A financing model similar to that of the existing healthcare services could be replicated to this automated fall detection and pre-hospital care service. Additionally, this automated fall detection and pre-hospital care service could also be integrated into the home-help services provided by the municipalities to elderly people in need. The home-help services are financed by the government, with the government funding a majority portion by direct payments to the service providers, both public and private.

Questions that further arise here can be as follows:

Does this not prove to be an additional cost to the government?

Who would be eligible to seek this service?

The answer to the first question lies in the answer to the following, *"How much money is spent into unnecessary dispatch of ambulances?"*. The proposed Digital Health solution could help save a significant amount of money for the government, in terms of fuel and manpower, and save time to make decisions on if an ambulance dispatch is necessary for fall incidents. This also would depend on how reliable the solution is, to help the dispatchers make quick decisions from the parameters that have been received through the fall detection solution.

In Sweden, many elderly seek home-help services to go about their day to day activities. The need for this assistance is fulfilled by each municipality for their respective citizens. A similar model, as mentioned in **Section1.2.5** could be replicated with the proposed Digital Health solution, whereby a doctor would firstly assess the health condition of the person seeking this service. Based on the assessment of the doctor, if the application progresses further, the application would move to the municipality officer handling welfare of the elderly. The municipality officer would then decide on the aid depending on the recommendation by the doctor and the other socioeconomic situations similar to the one for home-help services.

6.4 Ethical and Privacy Challenges

The main intention of introducing assistive technologies is to enhance safety and protection of elderly population as well as assist them in maintaining an independent lifestyle. However, the nature of such technologies in healthcare raises concerns in ethical issues associated with surveillance, tracking and privacy. As mentioned earlier, fall incidents can be detected by using several types of solutions either wearable or non-wearable. It is essential that the sensors utilized in a fall detection solution reduce the invasion of the elderly's privacy as much as possible. In addition, when proposing automatic fall detection solutions, it is very important to have clear answers to questions such as, *Who are the stakeholders that are informed that a fall incident has occurred?*, *How the received alert is responded to by the stakeholders?*, *How the service is provided?*, *How the transmitted data about the elderly is handled?* and *Who has access to this data?*.

Ganyo et al. describe the importance of four principles, autonomy, privacy, benefit and use of resources, when discussing ethical issues in use of fall detection solutions

[117]. Autonomy emphasizes the importance of the consent of the elderly when implementing fall detection solutions in their homes. To avoid violating the elderly's privacy, the type of implemented sensors in the solution should have as little invasion as possible. Furthermore, the logged personal information should be transmitted securely to the involved stakeholders. The main idea of implementing fall detection solutions in elderly's home is to bring benefits such as, safety, an increased quality of life, quick assistance in case of fall incidents and a more active social life. However, it should also be taken into account that implementing an automatic fall detection solution might lead to lesser supervisions and visits from family members and relatives, consequently, leading to a more isolated lifestyle. In order to deliver safety and reduce the number of false alarms, the fall detection solution should be based on reliable sensors with high accuracy in detecting fall. As a precursor to proposing a fall detection solution, detailed investigation should be made on the usage of the solution laying an unfair burden on stakeholders involved in the care chain. Lastly, proper utilization of resources such as time and money should be considered during the design and implementation phases of an automated fall detection solution for pre-hospital care.

7 Conclusion and Recommendation

7.1 Conclusion

Enhancements to already existing healthcare solutions can be a possible reason to cause paradigm shifts to how healthcare is provided to the citizens. Integration of a Digital Health solution for automatic fall detection into the mainstream healthcare services could be one such, given that a significant proportion of the elderly experience a fall.

The existence of various fall detection solutions has made it a compelling need to be aware of the advancements in the field of fall detection, in order to be able to build an automated solution for detecting fall, and providing necessary pre-hospital care. Based on the literature study in this project, a majority of solutions on the market do not offer a fully connected care service when a fall incident occurs. The unavailability of solutions based on sensor fusion technology, to aid in the automatic detection of fall leading to a faster pre-hospital care, has made it possible for connected collection of several standalone technologies to be seen as a potent solution in providing effective care to the elderly. At the same time, the availability of critical information such as vital parameters could aid in a faster response in the assistance provided to the elderly. The use of an intelligent CDSS to provide an enhanced overview and suggestion on a particular case could additionally ease the pressure on the dispatcher. This would also lead to boosting the confidence of the decision made by the dispatcher.

Outcomes from the evaluation of the proposed solution showed promising results with respect to how the solution performs in different scenarios. However, the proposed solution and the evaluation of it was based merely on a literature study. Going in depth with further research into each part of the proposed solution with respect to the technical, social and economic aspects could aid in a better evaluation of it. This would help to build a solution based on the needs of the elderly in the society.

Powerful ICT infrastructure for Digital Health in Sweden enables the proposal of a solution being considerate of the above aspects. At the same time, the implementation of these technologies into the healthcare system faces several challenges. These challenges include interoperability on a technical and semantic level, security of information being transferred through the chain and the accuracy of the sensors deployed.

In conclusion, it can be said that integrated Digital Health solutions for automatic fall detection and provision of pre-hospital care are the need of the hour. However, it is necessary to carry out further extensive research within each part of the proposed solution in order to effectively implement it. The *Vision for eHealth 2025* provides great opportunities for research to building Digital Health solutions, and must be exploited.

7.2 Future Work

Although, the outcome of the project dealt with proposing a Digital Health solution for automatic fall detection and providing pre-hospital care, considerations should also be made to design the solution by being inclusive of various social and economic factors. The literature study disclosed that the current fall detection solutions, although many in number, do not offer extensive pre-hospital care in case of fall. The proposed solution, however, was an abstract prototype in entirety. Designing a working model, based on further research, would aid in a better evaluation of the solution that could have possibilities of being implemented into the mainstream healthcare service for the elderly.

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A

Appendix 1

This appendix includes a review of latest developments in Apple Watch Series 4 and 5. Additionally, a description of experiments carried out with an Apple Watch Series 5 along with results.

A.1 Apple Watch

Smartphones today offer plenty of smart features, and have become an essential tool for daily living. The bulkiness of smartphones, however, curtails the ease of use. Apple Watch was developed therefore, to be easily carried by users since people are extremely dependent on the advanced features offered by smartphones. Another important goal was to reduce the gap between users and healthcare providers by helping people record their own health data. [118] The latest series of Apple Watch, Series 4 and 5, can be paired with an iPhone and make calls, send text messages and receive notifications and several other smart feature such as automatic fall detection. Apple Watch can be considered as one the recent updates among existing technologies in health monitoring and fitness tracking.

A.1.1 Apple Watch as a Fall Detector

Recent advances in Apple Watch Series 4 and 5 by Apple, introduce a feature whereby Apple Watch can work as an automated fall detector. This feature can be considered as an option to aid elderly experiencing fall incidents. In addition, the monitoring of health parameters makes it possible to track the health and well-being of the person carrying the device. The automated fall detection in Apple Watch is based on accelerometers and gyroscopes implemented in the smartwatch. In case of a fall, the user have the option to cancel an automated alert or to choose to send an alert to emergency services. An automatic call, including the location of the user, is in the latter case established to the local dispatch center if the user has been immobilized for a period of time more than 60 seconds. [50]

A.1.2 Apple Watch as a Healthcare Measurement Device

The integrated sensors and features in Apple Watch are not only limited to a watch, they rather offer a small mobile phone as well as a device for measurement of vital parameters, e.g. continuous measurement of heart rate by using PPG technology [119]. Additionally, the watch can monitor ECG in real time whereby any irregular-

Figure A.1: Apple Watch Series 5.

ity in the heart can be detected [119]. ECG is recorded during a time interval of up to 30 seconds by touching the watch with a finger on the opposite arm from where the watch is worn [120]. Monitored and recorded health data can be transmitted to caregivers. The watch is powered by a battery based on rechargeable lithium ion technology. According to Apple, the utilized battery technology in the watch is the best option, since it weighs less than older batteries, lasts longer and can be charged effectively. The battery used in Apple Watch lasts up to 18 hours after being fully charged. [121]

A.2 Trial and Evaluation of Apple Watch

As part of the project, a set of experiments to evaluate the fall detection were conducted by performing fake falls. Falls on different type of surfaces, a mattress, a trampoline, a floor covered with cushions and a hard floor covered with a thin carpet, were studied. Each experiment was repeated five times on each surface. Each test is described below.

Mattress

A medium firm mattress was used in the first experiment, **Figure A.2**. The test person fell on the mattress trying different position. The experiment was repeated five times without any fall alarm activation. The watch was also dropped two times on the mattress, resulting in no fall alarm activation.

Figure A.2: The utilized mattress in the experiment with Apple Watch.

Trampoline

In the second scenario, a trampoline was used, **Figure A.3**. The test person made fake falls using different fall poses. The experiment on the trampoline was carried out five times without leading to any fall detection alerts. In addition, the watch was dropped on the trampoline separately whereby the fall detection feature was not activated.

Figure A.3: The utilized trampoline in the experiment with Apple Watch.

Floor Covered with Cushions

In the third experiment, a hard floor was covered with cushions to protect the user from potential injuries, **Figure A.4**. The test person fell on the floor five times, trying different fall techniques. None of the experiments led to activation of the fall detection feature in the watch.

Figure A.4: The floor covered with cushions in the experiment with Apple Watch.

Hard Floor Covered with a Thin Carpet

In the final experiment a hard floor covered with a thin carpet was used, **Figure A.5**. The test person performed fake falls which were carried out five times. During the fourth try, the user experienced a hard fall leading to an activation of the automatic fall detection feature.

Figure A.5: The floor covered with a thin carpet in the experiment with Apple Watch.

In summary, in the three first scenarios, Apple Watch was not able to detect any falls. During the fourth experiment on the hard floor covered with a carpet, where the test person experienced a harder force, Apple Watch managed to detect the fall. This was indicated by first beeping and tapping on the wrist, followed by an automatic message asking if the user was fine. An automatic call would now be established to the local dispatch center if the test person had not canceled the alert within 60 seconds.

A.3 Discussion and Conclusion

According to Apple, the integrated accelerometer and gyroscope are only able to detect hard falls and thereby establish a beneficial automatic call to the local dispatch center [122]. Additionally, a number of health insights are continuously extracted by Apple Watch, e.g. ECG, heart rate using electrical heart sensors and PPG technology [119].

A possible explanation to the results the experiments could be a high predefined threshold for detecting a fall. A high threshold may be chosen be Apple in order to avoid mistaking various activities for fall incidents. Consequently, this causes less false alarms, but at the same time the chance for missing falls, especially in the targeted elderly group, increases. The type of fall incidents experienced by elderly are often quite different from hard falls, e.g. sliding, soft falls and falling during several steps. Therefore, Apple Watch might not be a sufficient or "good enough" fall detector in an elderly population.

Considering the watch's size, weight and design, the watch, to us, was comfortable to be worn for a longer period. However, this should be further investigated to understand the perspective of the elderly. Looking at usability aspects, the watch might not be the most user-friendly device for elderly. Since Apple Watch offers as many features as iPhone through a small screen, common sight impairments and trembling hands, could aggravate the uneasiness to handling Apple Watch. Apple Watch uses a rechargeable lithium battery which operates up to 18 hours between each full charge [122], thus requiring the watch to be recharged at least 9 times in a week. A constantly switched-on screen, various pop-up information updates, and other smart features running in the background is reflective of a high battery consumption, thereby serving as a possible limitation to using this as an efficient fall detection device.

In summary, Apple Watch might be a suitable health and activity tracker for younger population. However, Apple Watch does not seem to be the best option as a fall detector and health monitoring device for elderly. Looking at the experiences high preselected threshold level, Apple Watch might not be able to recognize many of the common types of fall experienced by elderly. Furthermore, taking the usability aspects mentioned above into account, the device is not designed in a way to be effortlessly used by an elderly. Additionally, the high battery consumption requires the watch to be recharged frequently, which adds even more demands on the elderly in order to guarantee safe and good functionality. This also implies that the device is removed from the elderly in long periods and the chance for being forgotten, and not used, increases.

In conclusion, the concept of a wearable device like the Apple Watch for automatic fall detection is good, but need to be designed with the elderly and the intended use in mind to a much higher degree.

B

Appendix 2

B.1 The VIPHS model for innovation and utilization

(The stepwise Verified Innovation Process for Healthcare Solutions)

1. Thorough care process analysis/process mapping, proposals for technology and system design and ”theoretical” testing and evaluation, etc. including ”personas”, realistic ”use cases”, etc.

   Result: ”Blueprint 1”. This blueprint consists of documentation describing proposals for a technical solution and a functioning care process. Provides basis for broader business anchoring and realistic full-scale simulations.

2. Realistic full-scale simulations, based on ”Blueprint 1”, between e.g. prehospital activities (e.g. ambulance) and expert consultant/specialist (e.g. neurologist) to suggest modifications and understand the impact on the actual care process, working model, etc. Evaluation of technology solution.

   Result: ”Blueprint 2”. This blueprint consists of documentation describing solution, experience and proposals for a functioning care process. It is, among other things, the basis for initial clinical testing in an operational environment.

3. Initial limited tests in operational environment, i.e. in the care process concerned. ”Blueprint 2” is of significant value at this stage when, among other things, seeking ethical approval. For example, many ”childhood diseases” are now already being investigated and taken care of due to step 2. This significantly reduces the risks when entering a clinical operative environment. This step verifies step 2 in practice.

   Result: ”Blueprint 3”. This blueprint consists of documentation describing solution, experience and proposals for a validated and verified working care process based on clinical pilot operation. Provides a basis for extended clinical trials and further test operation in an operational environment.

4. Extended clinical and operational trial based on ”Blueprint 3”. Here the solution in step 3 is updated and scaled up to a level where expected care effects in a full-scale implementation can be studied, calculated and documented.

   Result: ”Blueprint 4”. This blueprint consists of documentation describing solution, experiences, proposals for a functioning care process and expected clinical results and effects based on a clinical operation. Provides a basis for deciding, for example, on full-scale implementation and procurement model.