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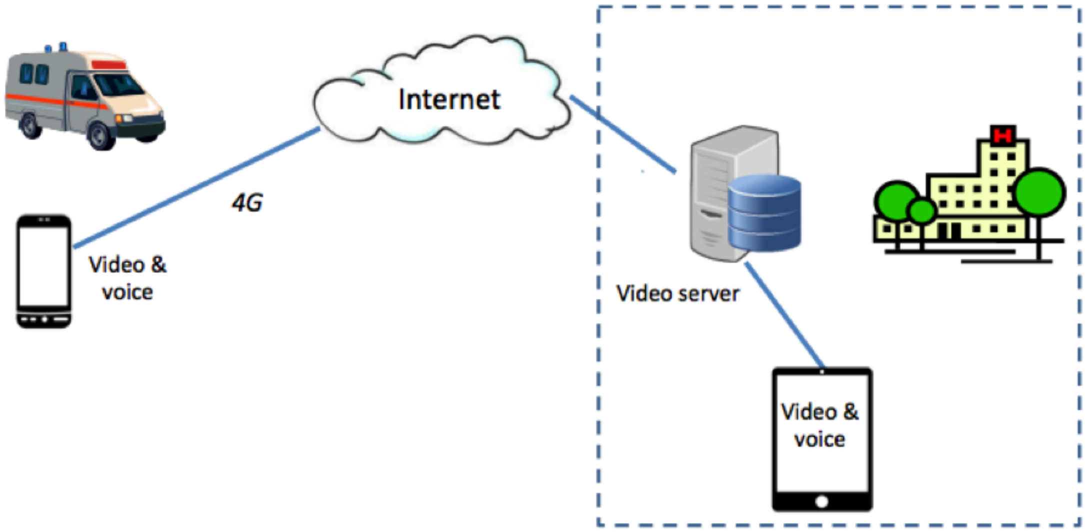

ViPHS mobile – a mobile video tool for decision support for transportation decisions in acute stroke cases

Master's thesis in Biomedical Engineering

SIGRÚN HRAFNSDÓTTIR

Department of Electrical Engineering
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2018

MASTER'S THESIS 2018

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Supervisor: Stefan Candefjord, Assistant Professor in the Biomedical electromagnetics research group, Chalmers University of Tecnhology.

Supervisor: Hanna Maurin Söderholm, Senior lecturer, University of Borås.

Examiner: Bengt-Arne Sjöqvist, Researcher and Professor of Practice in the Biomedical signals and systems research group, Chalmers University of Technology.

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Department of Electrical Engineering
Chalmers University of Technology
SE-412 96 Gothenburg
Telephone +46 31 772 1000

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Abstract

Stroke is considered as a very time sensitive medical emergency that, each year, causes millions of deaths worldwide. In Sweden only approximately 30 000 cases occur each year, out of which around 20% dies and 30% suffers lifelong disability. Societies cost for stroke in Sweden is estimated to be 19 BSEK a year – the most costly disease. Initiating treatment of stroke early is crucial in decreasing the mortality rate and improving patient overall outcome after treatment. Incorporating assistance from neurological experts in the prehospital setting can help to improve accuracy in decisions and therefore decrease the time from onset of symptoms to beginning of optimal treatment. Telemedicine systems, using real-time video, have been proposed to be a helpful tool in evaluating the severity of stroke as well as making more accurate decisions as to where the patient should be transported. As part of the PrehospIT stroke project lead by Prehospital ICT Arena (PICTA) at Lindholmen Science Park, a "best of breed" video support solution has been proposed including an ambulance as well as a mobile implementation. This master's thesis focus is on the mobile implementation.

Through an iterative design process and users involvement, a mobile telemedicine video tool was designed for paramedics to use in potential stroke patients location, e.g. an apartment, before being moved to the ambulance. Two views of the patient are required for the neurologist to assess the patient when using the National Institutes of Health Stroke Scale (NIHSS) as assessment tool for determining the patients neurological status. In first iteration, low fidelity prototypes of two design alternatives were tested and evaluated in a workshop. The data from the workshop was analyzed and the design solutions were revised for the making of a high fidelity prototype. This high fidelity prototype was tested and evaluated in a simulation environment. Results indicate this system to be beneficial for paramedics to use for support whenever there is a potential stroke. It seemed to work well overall, although more iterations are needed for a final solution. Recommendations for an effective system are presented based on results from workshop and simulations.

Keywords: stroke, prehospital, ViPHS, telemedicine, telestroke.

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I would also like to thank Magnus Hagiwara and Andreas Dehre for participating in the workshop and simulations. Both provided a very useful input for the optimization of the designed solution. During the simulation we worked with an application developed by Professor Boris Magnusson and colleagues from Lund University. I would like to thank them for providing us with their application. Finally I thank MedTech West for providing me with an office to work on my thesis and allowing me to use their facilities.

Sigrún Hrafnsdóttir, Gothenburg, March 2018

Contents

List of Figures

List of Tables

1 Introduction

In 2010 the number of deaths caused by stroke was 5.9 million, making it the second leading cause of death worldwide. Along with ischemic heart disease, stroke has been in the top two places for causes of death globally for the last 15 years [1]. In Sweden alone, reported cases (both first-ever and recurring cases) are around 30 000 per year and in 2011, 8000 people died from the disease. Not only is the mortality rate high, also many of the survivors are left with both mental and physical disabilities that affect their daily life [2]. In fact one in three people who survive remain disabled for the rest of their lives [3]. Because of the high disability rate, the cost of stroke is also very high. Assuming 19 200 first-ever cases per year, the excess cost in health care and social services would be SEK 9.9 billion a year [4].

The treatments offered for stroke require initiation within a specific time frame, usually 4-5 hours, from onset of symptoms to the beginning of treatment. This time frame is very limited and therefore, any delay in the prehospital setting can lead to acute stroke patients not receiving the treatment they need in time. Providing acute care to stroke patients in the prehospital phase could help reduce mortality rate as well as both medical and financial burden of stroke [5].

One of the factors in improving the accuracy in patient evaluation and transportation decisions, and therefore decrease delays, is to incorporate neurological assistance in the prehospital setting. Today, consultation between paramedics and physician when there is a potential stroke, is made verbally through telephone. This can often be problematic and from research, teleconsultation using real-time video has proven to be effective in improving patient outcome and appear to work better than using telephone consultation only [3]. In the past years, projects including development of video teleconsultation systems to be used in the prehospital environment have been established in several countries [5].

A project aiming to improve the stroke support in the prehospital setting, in Sweden, is ViPHS (Video support in the Prehospital Stroke chain). It is a part of the PrehospIT-stroke project in the Prehospital ICT Arena at Lindholmen Science Park. The ViPHS project is divided into 3 parts, ambulance, mobile and BOST. This thesis is a part of the mobile ViPHS solution which means that this solution offers a mobile video support between paramedics located in the patients' home and a stroke expert at a distance [6].

1.1 Aim

The aim of this Master's thesis is to propose and evaluate a design for a mobile video tool for paramedics to use in the prehospital setting in acute stroke cases, as well as to give a final recommendation of an effective system.

1.2 Objectives

To achieve this, the literature is thoroughly studied in order to learn about stroke and how time is crucial in order to get the best outcome after treatment. Current state-of-art and promising work of similar projects are identified such as prehospital applications, both ambulance fixed and mobile solutions. In order to get a further input how the system should be designed for it to be effective, observations of potential users in their natural work environment are made. Evaluations of the proposed design are conducted through workshop and simulations, where potential users use the system as they would in real life.

2
Background

The work of this project is performed in the Västra Götaland Region (VGR), in Sweden. Västra Götaland Region is a 24 000 km^2 county that lies on the west coast of Sweden. It has roughly 1.6 million inhabitants and therefore accounts for 17% of the total population [7]. In order to better visualize the region, a map is shown in figure 2.1. Next to the map, a few fact points regarding the region are shown.

Size:
24 000 km^2.

Inhabitants:
1 600 000.

Largest city:
Göteborg (500 000 inhabitants).

Largest hospital:
Sahlgrenska University Hospital.

Figure 2.1: Region Västra Götaland [7, 8].

The hospitals and the health care centers in the region can be divided into 4 groups: Sahlgrenska University Hospital, NU-health care, Skaraborgs Hospital and Södra Älvsborgs Hospital. There are 13 hospitals that fall under one of those groups and 4 hospitals that do not fall under any group [9]. The division of the hospitals is seen in figure 2.2.

Figure 2.2: Map of hospitals in VGR [9].

2.1 Stroke

2.1.1 Definition

The brain needs oxygen and nutrients for it to function properly. A stroke occurs when the blood vessels leading to and within the brain are blocked or rupture causing the blood flow through them to be limited or totally restricted. When this occurs the part of the brain affected will not receive the oxygen it needs and as a result brain cells will die [10].

Stroke can be of two main types, ischemic and hemorrhagic. Ischemic stroke is when the blood flow is somehow restricted in the blood vessel, this is most often caused by blood clots. It is called a hemorrhagic stroke when the blood vessel ruptures causing blood to leak from it. This limits the blood flow to the brain. Hemorrhagic stroke is often caused by high blood pressure or aneurysms [10]. The ischemic type is more common as it accounts for about 88% of all cases and the hemorrhagic type consequently accounts for the rest [11].

In addition to ischemic and hemorrhagic stroke there is another type which is transient ischemic attack (TIA). Getting a TIA can be an indicator that the same person is at an increased risk of suffering from stroke in the future. As many as 17% that get TIA will have stroke within 90 days after the TIA. The highest risk of stroke after TIA is within the first week [12].

2.1.2 Symptoms

The symptoms of stroke include but are not limited to abrupt numbness in one leg, arm or one side of the face, sudden loss of vision, dizziness that cannot be explained as well as severe headache [13]. The patient can also be experiencing speech difficulties such as loss of it or slurring. Difficulties understanding when talked to can also be present [13, 14].

2.1.3 Treatment

When it comes to the treatment of stroke the options are very different for the two types mentioned before, ischemic and hemorrhagic stroke. In case of ischemic stroke there are two treatment options that are being used today [15]. The one that is most frequently used is intravenous thrombolysis with tissue plasminogen activator (tPA), a drug that dissolves the blood clot in order to regain blood flow through the vein [15, 16]. Until recently tPA was the only treatment for acute ischemic stroke that proved to reduce disability. Thrombolysis is effective only if it is administered within 4.5 hours after onset of symptoms [15]. Hence the outcome depends on the time from symptoms onset and until the start of treatment and due to the time constraint, only a small percentage of patients suffering from acute ischemic stroke actually receive the intravenous tPA [17]. Also a limitation to the treatment is increased risk of fatal intrachranial hemorrhage in the days following the treatment [15]. Although the thrombolysis treatment is often very effective when given within the time frame it usually cannot be used alone when dealing with occlusion in the larger arteries in the brain [15, 17].

A more recent treatment option that only recently was approved as a standard procedure at Sahlgrenska University Hospital in Gothenburg is mechanical thrombectomy [17]. This procedure involves using a stent retriever, a wired caged device, which is deployed into the site of the blocked vessel. A catheter is threaded through an artery in the groin and up to the blocked artery, the stent retriever opens to grab the clot and is then pulled out together with the clot [17, 18].

Different types of stent retrievers are available on the market and one type that is used in the mechanical thrombectomy procedure is the Solitaire™ FR Revascularization Device from Covidien. This stent is self-expanding and has been linked with regaining blood flow faster and more frequently, reduced intracranial hemorrhage, and improved disability outcome in comparison with earlier generation mechanical thrombectomy devices [19].

The thrombolysis treatment has for many years been used at all acute hospitals in VGR, whereas thrombectomy has until recently not been a routine procedure and within this region it can only be performed at Sahlgrenska University Hospital. When dealing with occlusion in the larger vessels of the brain, thrombectomy following a thrombolysis has proven to more than double the effectiveness as compared to only giving thrombolysis treatment [17]. A study by Jeffrey L. Saver et al. showed this difference in using only thrombolysis versus using thrombolysis and thrombectomy together. It was performed on 196 patients at 39 different centers both in the United States and Europe. Using both intravenous t-PA along with the stent retriever within 6 hours after onset of symptoms in the treatment of acute ischemic stroke improved functional outcomes at 90 days. Improved disability outcome was observed in 1 further patient for every 2.6 patients given this treatment. One additional patient for every 4.0 patients treated was at 90 day follow up, functionally independent [19].

Mechanical thrombectomy is time sensitive, like the thrombolysis treatment where the recommended time between symptom onset and start of treatment is 6 hours, but can in certain cases be more [17]. In cases when patients arrive at a hospital within 4.5 hours, it is recommended that an intravenous thrombolysis is initiated before the thrombectomy. If performed by qualified professional, the risk of complication during a thrombectomy is not high. However, it is not free of risk as it can damage the vessels resulting in rupture and intracranial bleeding, the clot can also be split into pieces and occlude other vessels [15].

In case of hemorrhagic stroke, the treatment options differ from the ones in ischemic stroke. Because hemorrhagic stroke is often the result of high blood pressure, one of the treatments given to patients suffering from this type of stroke is to lower the blood pressure [20]. Depending on what is causing the hemorrhage there are many different treatment options, such as surgical and endovascular treatments [20].

2.2 The National Institutes of Health Stroke Scale (NIHSS)

Stroke related neurological deficit can be quantitatively measured using the National Institutes of Health Stroke scale, an assessment tool used by health care professionals with relevant training. It's purpose is to predict patient outcome, evaluate stroke severity along with contributing to the treatment decision for patients suffering from stroke [21, 22]. Although alternative stroke scales are available, the NIHSS is particularly beneficial for initial assessment of potential stroke patients. This initial evaluation is conducted in the emergency departments, hospitals and also in the pre-hospital setting [23].

The scale consists of 15 items that covers patient assessment at the level of consciousness, gaze, visual field, facial palsy, motor functions in arms and legs, ataxia, sensation, language, dysarthria and extinction/inattention [23]. These items are shown in tables 2.1 and 2.2, along with descriptions on how each item is measured on the patient. In addition, the response is shown where different scores are given depending on which applies in each incident.

Table 2.1: The NIHSS: Items 1-8 [23, 24].

Name and description	Response
1a. Level of consciousness	0=Alert 1=Not alert, arousable 2=Not alert, obtunded 3=Unresponsive
1b. Questions Ask about month and age.	0=Answers both correctly 1=Answers one correctly 2=Answers neither correctly
1c. Commands Give a command. Tell patient to close their eyes.	0=Performs both tasks correctly 1=Performs one task correctly 2=Performs neither task
2. Gaze The eye positions are observed and then the eye movements are tested on both right and left side.	0=Normal 1=Partial gaze palsy 2=Total gaze palsy
3. Visual fields Confrontation test. Counting fingers or move hand in a threatening way towards patient.	0=No visual loss 1=Partial hemianopsia 2=Complete hemianopsia 3=Bilateral hemianopsia
4. Facial palsy Ask patient to smile and lift eyebrows If patient has decreased consciousness test with painful stimuli.	0=Normal 1=Minor paralysis 2=Partial paralysis 3=Complete paralysis
5a. Left motor arm Lift the patients left arm, if he/she is lying down then lift 45°. The patient is asked to hold the arms up for 10 seconds while observing any drift of the arms.	0=No drift 1=Drift before 10 seconds 2=Falls before 10 seconds 3=No effort against gravity 4=No movement
5b. Right motor arm Lift the patients right arm, if he/she is lying down then lift 45°. The patient is asked to hold the arms up for 10 seconds while observing any drift of the arms.	0=No drift 1=Drift before 10 seconds 2=Falls before 10 seconds 3=No effort against gravity 4=No movement

Table 2.2: The NIHSS: Items 9-15 [23, 24].

Name and description	Response
6a. Left motor leg Test the patient lying. Lift left leg straight to 30° and ask the patient to hold the leg for 5 seconds while observing any drift of the leg.	0=No drift 1=Drift before 5 seconds 2=Falls before 5 seconds 3=No effort against gravity 4=No movement
6b. Right motor leg Test the patient lying. Lift right leg straight to 30° and ask the patient to hold the leg for 5 seconds while observing any drift of the leg.	0=No drift 1=Drift before 5 seconds 2=Falls before 5 seconds 3=No effort against gravity 4=No movement
7. Ataxia Tested with knee-heel and finger-nose test.	0=Absent 1=One limb 2=Two limbs
8. Sensory Tested with a needle and only sensory loss attributed to stroke is scored as abnormal. Patients with decreased consciousness or aphasic should be tested with painful stimuli.	0=Normal 1=Mild loss 2=Severe loss
9. Language	0=Normal 1=Mild aphasia 2=Severe aphasia 3=Mute or global aphasia
10. Dysarthria	0=Normal 1=Mild 2=Severe
11. Extinction/inattention	0=Normal 1=Mild 2=Severe

In VGR, the ambulance teams use a modified version of the NIHSS (mNIHSS), containing only a part of those 15 items. Since some items on the NIHSS have insufficient reliability, redundancy and are complex they are excluded to form the mNIHSS. The items that have repeatedly shown a lack of reliability and/or redundancy are level of consciousness, facial palsy, ataxia and dysarthria. When containing fewer items the scale is simpler and easier to administer [25]. This shortened form is used at the scene, to assess the patient and to provide the physician with the scores obtained. In conclusion, the mNIHSS contains items 1b through to 3 and 5, 6, 8 and 9 in tables 2.1 and 2.2.

2.3 Telemedicine

Telemedicine refers to using telecommunication technology to provide remote delivery of health care and health information [26, 27]. It can be used for treatment, consultation and diagnosis of any medical related issues, in addition it is also used for teaching [26]. Although telecommunication technologies have been used in medicine since the invention of the telephone and radio, the first prototype of an interactive telemedicine system was established in 1967. This system linked together the medical station at Boston's Logan International Airport and the Massachusetts General hospital where it provided a complete range of primary care and emergency services. The medical staff working with the system were the nurses at the medical station at the airport and consulting physicians located at the hospital [26, 27].

With constant evolution in technology, telemedicine systems are always becoming more advanced and therefore more effective. In past decades they have become an increasingly cost-effective alternative to conventional care where the physician is physically present. There is also always an increase in the use of these systems and today they are an integrated technology used in many settings, such as hospitals, physicians' offices and patients' homes [28].

Many different applications of telemedicine systems are present, for example live interactive videos and the transfer of electronic information for professionals to consult, diagnose or determine treatment plans [28]. In more detail these applications include home care, where health care professionals can monitor patients remotely from their own home. As well as so called store-and-forward application, where medical related data is collected and transmitted between health care providers such as doctors and other specialists. Real-time interactive applications such as teleconsulting and videoconferencing are also an important area of telemedicine and this thesis relates to [29].

Telemedicine systems in the prehospital setting have become prominent in situations where minimizing treatment delays is very important to clinical outcome. In medical emergencies such as stroke, myocardial infarction and trauma, paramedics have been using telemedicine in order to consult with specialists [30].

2.3.1 Telestroke

The term 'telestroke' refers to the application of telemedicine in stroke care and was first coined in 1999 by Levine and Gorman. Since then it has become routine in many settings in the US and Europe with the main focus of increasing the use of intravenous tPA in patients with acute ischemic stroke [31, 32]. However telestroke systems today have moved beyond only utilizing the use of tPA to also identifying candidates for intra-arterial intervention, such as thrombectomy [32].

The initial use of telemedicine for stroke namely the first generation telestroke systems (Telestroke 1.0) provided high quality two-way audio-video (AV) conferencing. They were however, point-to-point models that required consultants to travel to specific fixed workstations in order to perform the consultations. This was very impractical since consultations had to be either only performed during working hours, the consultant had to be always close to the workstation or travel to the workstation after hours. In addition, video conferencing was the only thing provided by many of these systems meaning that they lack many of the features that are present today, such as decision support, integration with medical records and more [31].

The second generation telestroke systems (Telestroke 2.0) now include those parts frequently missing in the first generation and don't have to rely on consultations from a fixed workstation. They incorporate features that implemented across the World Wide Web along with providing high quality, real-time, AV of point-to-point teleconferencing. Through using the internet, the consultations are now mobile and can be used on laptops, tablets and hand-held devices. In fact they can be done from anywhere where there is internet access [31, 32].

Incorporating telestroke in the prehospital phase is the basis of the third generation of telestroke systems (Telestroke 3.0). These systems can aid to early stroke diagnosis, help in the assessment of stroke severity as well as identifying patients for specific stroke treatments. For this reason the ASA (American Stroke Association) recommends research on third generation telestroke systems [5].

Although limited experience in using telestroke in the prehospital setting, several projects have been showing promising work in evaluation of these systems. They incorporate biderectional audio-video (AV) communications for the evaluation of patients on-site or during emergency transport in real-time [5]. Results demonstrate that using video consultations in the prehospital phase provide more accurate decision making compared to using telephone consultation [5, 33]. Limitations to the telestroke systems include data security, privacy, medical device regulations, liability on product failure and reimbursement [5].

2.4 Prehospital care

The treatment and care provided on scene or during emergency transportation is the definition of prehospital care. It refers to the time between an emergency call and when handing over the patient to the relevant medical center. Although in the past, ambulance service in Sweden was considered as a only transporting patients to the hospital, prehospital care is now an important first link in the chain of care as well as in the patients' total care. This is due to advantages in techniques, resuscitation and pharmacology [34].

Today in prehospital stroke care, consultation from the physician is made by telephone only. This has it's advantages since it is simple, accessible, it doesn't take long and is easily transported. The advantages of using telemedicine systems for consultation are that they are accurate, efficient, reliable and effective. Also they are more technologically sophisticated and have high grade of recommendation [33].

2.4.1 Video support in the PreHospital Stroke chain (ViPHS)

ViPHS is a part of the PrehospIT-stroke project which is lead by Prehospital ICT Arena (PICTA) at Lindholmen Science Park. Aimed to improve utilization and development of IT and eHealth for it to be used to their fullest, the arena works with the entire chain of healthcare. This means the chain from when first a person is in need of help all the way until this person has received the appropriate treatment.

ViPHS is divided into three parts where the first part is ViPHS ambulance which supports a video consultation between ambulance and a stroke expert through a fixed video camera in the ambulance. The second part, where this thesis is a part of, is ViPHS mobile. This mobile solution offers video support between for example the patient home and the stroke expert. The third part is ViPHS BOST and is a smartphone solution that supports video conferencing between for example a relative and the alarm central. The aim is to have these three parts work seamlessly together. Figure 2.3 shows where each part of the ViPHS project fits into the prehospital phase. A schematic view of the ViPHS mobile solution is shown in figure 2.4.

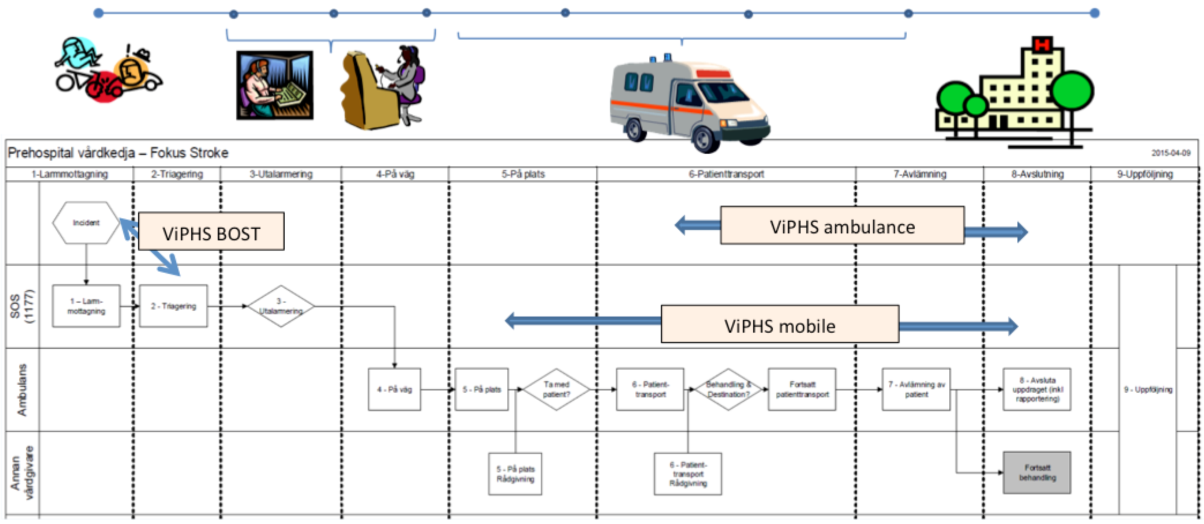

Figure 2.3: The three parts of the ViPHS project, visualized in the prehospital phase.

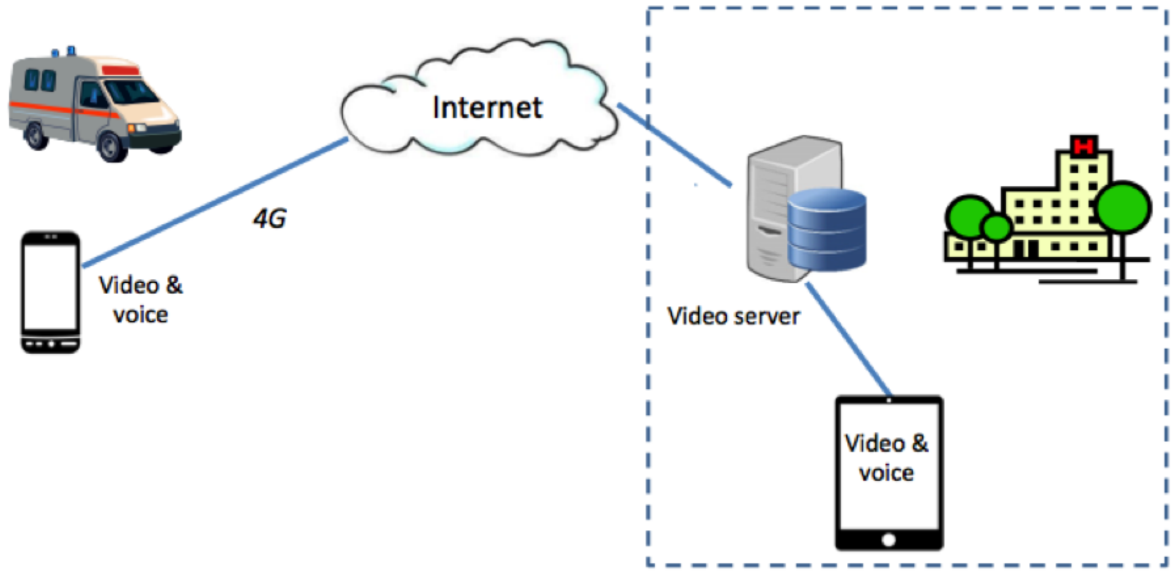

Figure 2.4: Schematic view of the ViPHS mobile solution.

3

Previous work

This chapter will cover the current and previous work of projects, considered as being related to the ViPHS mobile solution. The solutions used in these projects are evaluated and research results are observed. Individual sections cover one project where all projects are also divided into hospital-based solutions and ambulance-based solutions.

3.1 Hospital-based solutions

A qualified stroke expert is needed for the management and treatment decisions of an acute stroke patient. Often these experts are located in stroke centers but many of the stroke patients are located in the general hospitals. In the general hospitals, stroke expertise is limited along with few diagnostic possibilities. To offer the expertise to the stroke patients, they are moved from general hospital to the stroke centers. This transport is both expensive and time consuming, which can be problematic for patients in urgent need of care. To address this problem, telemedicine can be used to link together hospitals and stroke centers where stroke expertise is more often available [35].

3.1.1 Remote video examination compared to bedside testing

A system designed with the function to link together hospitals in order to reduce the need of transferring patients between hospitals, is the EVITA system. The use of electronic communications infrastructure for high-speed transfer of different kinds of data such as voice, video and imaging data, a component based architecture was implemented. To provide data security that has to be present in such a system a special Internet protocol-based communication protocol with a strong data security concept was utilized. In addition, other communication methods like DICOM, file transfer protocol (FTP), or hypertext transfer (HTTP) can be integrated in the system [35].

In a study, conducted in 2002, in Germany, the EVITA system was used for a real time video and audio transmission that was made possible between an emergency room and a stroke unit at a different site in the same hospital. For the first time they tested if remote examination was feasible and reliable when applied in emergency stroke care shortly after onset of symptoms, using the NIHSS. The aim was to evaluate if a remote video examination was possible for hyperacute stroke patients within the first hours after onset of symptoms ad if such an examination would produce the same results as a bedside testing [35].

In the study the EVITA system was adapted to be used in stroke care, whereas originally it was designed to integrate the requirements of healthcare professionals into one telemedicine device. One of the changes that were made was the optimization of the compression factor in the video stream for diagnosis of movements in the face, such as eye movements. In addition the viewing size was also optimized to 384×288 pixels. Figure 3.1 shows the view of the system at a desktop PC used in the study. The video was shown in a browser and the camera can be manipulated to fit each individual case. The arrows control the movement of the camera and the numbers demonstrate the different angle views of the camera [35].

Figure 3.1: The view of the desktop PC. Reprinted from Stroke, Vol 34, René Handschu et al., Telemedicine in Emergency Evaluation of Acute Stroke, p. 2844, Copyright (2003), with permission from Wolters Kluwer Health INC.

The system used consisted of many structural components. Most important components were were a pan, tilt and zoom camera with video-inside interactive control, also a multimedia server unit was used along with a personal computer as part of a client-server system. The camera could be controlled by a mouse click within the overview image. For audio connection, a microphone and speaker were located at patients' bedside and the examiner used a headset. The examiner directed the whole process by giving instructions to the patient and assistant who was a trained medical student. The NIHSS assessment was then repeated at bedside by another examiner not in any way involved in the video examination. Both examiners were stroke neurologists experienced in using the NIHSS [35].

All patients (41) included in the study were assessed with the NIHSS within 36 hours of onset of symptoms. In all cases the full scoring of the NIHSS was possible, even though in two cases the NIHSS had to be repeated. All examinations were finished completely in a short time without any major problems. No major difference was observed between the bedside and remote examinations. It was concluded that it seemed possible as though a reliable examination could be conducted by an experienced experts in stroke centers [35].

3.1.2 Teleconsultation from patient bedside to hub hospital using Google Glass

Using Google Glass to establish real-time two-way audio and one way video connection between a physician at bedside and a neurologist at a hub hospital was the purpose of this study. A group in China conducted the study in 2015 in order to report results of using teleconsultation to guide intravenous thrombolysis. Two components were used in the study, a Google Glass device that the physician at bedside was wearing and a smartphone handheld by the neurologist at the hub hospital. The neurologist guided the physician on whether or not to initiate an intravenous thrombolysis [36]. Figure 3.2 shows two separate images from the study. In the left image, the physician examines the patient while wearing the Google Glass. The right image shows the neurologist watching the examination on the other end.

Figure 3.2: The figure to the left shows the physician at bedside wearing the Google Glass. The right figure shows the neurologist guiding the physician. Reprinted from CNS neuroscience and therapeutics, Vol 21, Zi-Wen Yuan et al., Mobile Stroke: An Experience of Intravenous Thrombolysis Guided by Teleconsultation Based on Google Glass, p. 608, Copyright (2015), with permission from John Wiley and Sons.

A limitation that the group tried to solve was that local physician did not feel that holding a device while evaluating patient was efficient enough. Therefore wearable device such as Google Glass was used for the teleconsultation. This allowed the physician to remain hands-free in the patient evaluation. They however found that the time of the teleconsultation was too long since the physician were not familiar with the teleconsulation system. A lack of a stable internet connection also resulted in delays in the consultation [36].

3.2 Ambulance-based solutions

The use of mobile telemedicine solutions in order to deliver medical services using communication technology has become a very fast growing area with constant development in the field of wireless communication networks [37]. Nonetheless, experience in using telemedicine in the assessment of stroke severity in the prehospital setting is limited. Even if the projects involved in using real-time bidirectional AV communication in ambulance or on-site are not frequent, systems that use video consultation have indicated more reliable decision making than using telephone for consultation [5].

When dealing with mobile telemedicine systems in moving vehicles like ambulances, they have some limitations since current wireless communication technologies are not efficient enough. With 3G networks, that included higher bandwidth it was possible for the in-ambulance staff to establish AV conferencing real time. The needs of the moving ambulance, when referring to seamless communications with high data rate, was, however not fully supported by 3G networks. Deployment of the 3G connection, mostly in rural areas, was limited and coverage gaps occurred. With more advanced communication technology, e.g. 4G, higher bit rates and more coverage is established and therefore giving more support to mobile telemedicine applications [37].

3.2.1 First project evaluating video transmission from ambulance

The very first project involving the evaluation of video transmission from an ambulance based telemedicine system was a project conducted by the Brain Attack Team (BAT) [38]. It was carried out in the United States, namely in Baltimore, Maryland. The BAT used a prototype of a mobile telecommunication system (MTS) where communication between a moving ambulances and a physician at a distance was made possible [39].

The MTS consisted of two major components, an ambulance transmitting unit and a receiving base station for hospital intranet connection. In the ambulance there was a television, microphone, digital camera and a video cassette recorder. In addition there was an equipment to monitor patients' vital signs, handheld blood laboratory device and video and communication system that integrates camera inputs while managing a parallel array of 4 digital cellular phones. The system transmitted video data from the ambulance and to the desktop computer using cellular technologies where the video images were captured over time in sequence and stored in an individual file [39, 40].

Shown in figure 3.3 is the desktop interface that the physician observed and participated in the assessment of the patient.

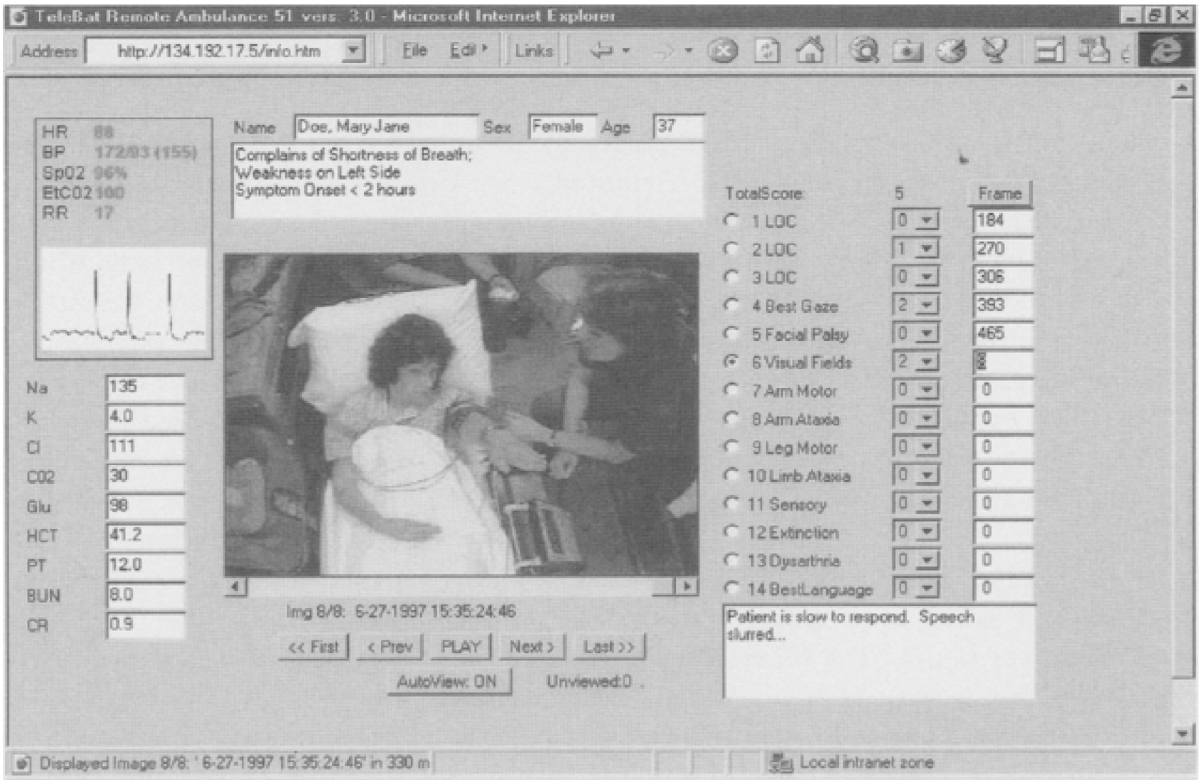

Figure 3.3: The interface of which the physician was able to see. Reprinted from Journal of Stroke and Cerebrovascular Diseases, Vol 9, Marian P LaMonte et al., TeleBAT: mobile telemedicine for the Brain Attack Team, p. 132, Copyright (2000), with permission from Elsevier.

From 1997 to 1999 the BAT, from the University of Maryland Medical Center, performed a study using a prototype of a MTS that delivered video and audio signals as well as patient information, such as vital signs, from a moving ambulance to a internet connected desktop computer of a receiving physician. Their aim was to check the feasibility in decreasing the time in the two phases of three in the treatment of ischemic stroke where delays are most likely to occur. They also tested the feasibility of combining these two phases [39].

They found that one persistent issue was cellular network connectivity. Three situations cause imbalance in transmission, when moving through gaps in the cellular network coverage, when moving between network cells and when reconnecting with the new cell. However the bandwidth was evaluated as being adequate for the stroke assessments. The paramedics and stroke experts included in the study were afterwards provided with a survey with questions in 4 areas. In all areas the outcome of the survey was in great extent in favour for the MTS TeleBAT [39].

3.2.2 Ambulance to stroke center & Stroke center to hospital

There have been many advances in technology since the MTS prototype was made in 1999 but this project involving an ambulance based telemedicine system was conducted in 2012, in Germany. The project, called StrokeNET, used a prototype of VIMED® CAR. This mobile telemedicine prototype was developed in concurrence with the StrokeNET project where its purpose was to be used in ambulances. It enabled an AV link using third generation mobile network from a commercial network provider. Every ambulance had two cameras, one for the head and one for the body of the patient. The head camera had a 10x optical zoom function [38]. Shown in figure 3.4 is the view from inside one of the ambulance used in the study.

Figure 3.4: An image from the inside of an ambulance used in the study. Reprinted from Stroke, Vol 43, Thomas G Liman et al., Telestroke ambulances in prehospital stroke management, p. 2087, Copyright (2012), with permission from Wolters Kluwer Health INC.

Conducted in Berlin, three ambulances were equipped with this wireless cellular communication technology. The approach to the implementation of a telemedical stroke network in Berlin was twofold, one was to provide an AV connection between telestroke ambulances in Berlin and Charité University Hospitals certified stroke centers. The other was to carry out telestroke networks for linking the stroke centers and local hospitals [38].

Hoping to improve pre- and early intrahospital stroke care and reduce the time to beginning of treatment in hospitals they began testing with a pilot study. Along with overall feasibility of the telestroke ambulance prototype and accuracy of stroke severity assessment the AV quality was tested. This study was conducted by driving an ambulance from a suburb of Berlin to the city center through various surfaced streets [38].

Using the NIHSS, 30 stroke assessments were conducted in the Berlin city region. In 18 cases the NIHSS was not completed due to low quality or lack of the AV signal. This resulted in that the feasibility was only marked in 40% of all cases where the AV connection stability was not sufficient for clinical use. They reported that this kind of telestroke ambulance in the use for patient assessment was not ready for the clinical environment [38].

3.2.3 Rating of network using AV transmission from ambulance

In 2013, the development of a mobile telemedicince platform was started in order to perform prehospital stroke assessments. Using low-cost, off the shelf technology and high-speed wireless connectivity, it was developed in coordination with a clinical research protocol called the Improving Treatment with Rapid Evaluation of Acute stroke via mobile Telemedicine (iTREAT) study. This mobile telemedicine platform was design to be used in ambulances and using videoconferencing to connect to a neurologist at distance [41].

The components of this system are as mentioned before, equipment that was already available such as iPad 2 with retina display, which means that the naked eye cannot distinguish between each pixel in the display [41, 42]. A Health Insurance Portability and Accountability Act-secure videoconferencing application was used for AV transmission. A 128-bit advanced encryption standard was used through the University of Virginia Health System firewall in order to provide protected health information across video streaming. For the high speed mobile connectivity in the ambulance, they designed a portable Wi-Fi system using a wireless modem/router with a Verizon Wireless network SIM card and two magnetic, external multiple-input - multiple-output antenna.
The main focus of this study was the quality rating of the network. It didn't include any patient examination [41]. For the first two months of development a connectivity testing was conducted. Test runs were made within the primary transport routes to the University of Virginia Medical Center [41].

Overall, thirty test runs were conducted. They did, in 93% of the test runs, achieve at least 9 minutes of high-quality, continuous videoconferencing. This is, from their investigations, enough time to complete a screening neurological assessment. They found that using low-cost commercially available components and data networks, mobile prehospital assessment of acute stroke patients via ambulance-based videoconferencing was feasible [41].

3.2.4 Feasibility and reliability using telemedicine in the field and in ambulance

The Prehospital Utility of Rapid Stroke evaluation Using In-ambulance Telemedicine (PURSUIT) study was conducted in Houston, Texas in 2014. Like in the iTreat study, it did not involve any real patient examinations but instead trained actors were involved. Ten predefined scenarios were acted out in the study where each scenario was conducted four times. The actors were picked up and transported to the stroke center by Houston Fire Department emergency medical technicians (EMT). NIHSS certified vascular neurologists with experience in doing teleneurology consultations in the emergency room environment where trained in using the telemedicine software and how to remotely control the telemedicine device prior to the study [43].

The devices that were used in the study were portable telemedicine units from In Touch Health called the RP-Xpress System. Two way AV communication through the internet was made possible by the system, which was mobile and robotic. A fisheye camera with a 175° field of view and up to 6x zoom was integrated into the device as well as a high quality speaker and microphone [43].

Since the RP-Xpress system was fully mobile it was mounted on the stretcher and therefore brought to the patient location by the EMT's. Full body view of the patient was provided by the device as well as a close up for examining eye and face movements with the zoom function. The attachment of the device to the stretcher was a controllable C-arm which allowed the EMT personnel to position the device for the evaluation. A 4G-hotspot was used for internet connection where it was able to provide good connection in and around the ambulance as well as to follow to the patient loaction [43].

Figure 3.5 shows four images during the PURSUIT study. In A the neurologist evaluates the patient from a remote location, the RP-Xpress system is mounted on the stretcher in the ambulance in B. In C the remote examination is being conducted in the ambulance and D show the remote examination being conducted at the scene of the patient [43].

Figure 3.5: Still images from the PURSUIT study. Reprinted from Stroke, Vol 45, Tzu-Ching Wu et al., Prehospital Utility of Rapid Stroke Evaluation Using In-Ambulance Telemedicine, p. 2344, Copyright (2014), with permission from Wolters Kluwer Health INC.

The results from the PURSUIT study were overall promising where in 85% of all scenarios no extensive technical problems were experienced. For the scenarios where technical problems were experienced, half of them were likely due to a poor WIFI connection of the 4G-hotspot [43].

4
Methods

In [44], interaction design is defined as ”designing interactive products to support the way people communicate and interact in their everyday and working lives”. It is a user-centered design, which is the involvement of the users throughout development. To get the perspective from someone that will use the intended product on a regular basis provides useful information for the design. Early focus on users and their tasks increases the possibility of designing a useful and easy to use system. The user involvement requires the understanding of who the users will be by observing the users in their natural environment, doing their normal tasks. Additionally studying the nature of the users normal tasks and in the end involve them throughout the design process [44]. Consequently, in this project, users were included throughout the process, from early design and requirements gathering to evaluation and testing.

The user experience, how a product performs and is used by people in real life situations, is fundamental in interaction design. Therefore the first step in the design process is to identify needs and establishing requirements for the user experience. The second step is to develop alternative designs that meet the earlier requirements established in the first step. Building interactive versions of the designs so that they can be communicated and assessed is the third step in the process. Finally, the fourth step is to evaluate what is being built throughout the process and the user experience it offers. These steps are iterated in the sense that after testing and evaluation, a feedback is given and from that changes must be made to the design and the process is repeated. The interactive design process is repeated until the product meets the requirements and needs of the intended user [44]. This iterative method is described in figure 4.1.

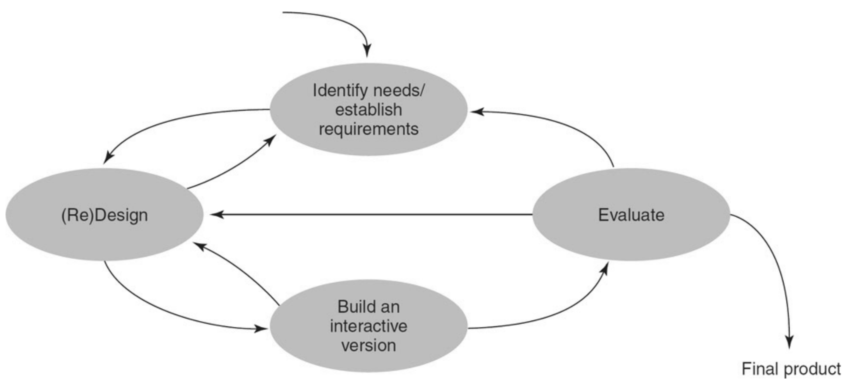

Figure 4.1: Schematic view of the interaction design lifecycle. Reprinted from Wiley, Helen Sharp et al., Interaction Design: Beyond Human-Computer Interaction, Second Edition, Copyright (2007), with permission from John Wiley and Sons.

The first task is to identify who the intended users are and where to find them. In this project, the system involves users on two ends. On one end are the ambulance personnel and on the other, the doctors or physicians.

4.1 Study design

In this thesis, two iterations of the interaction design process were carried out. The first iteration included the development and analysis of low fidelity prototypes. First by reviewing the literature related to this thesis as well as looking at previous work of similar projects. Along with observations in the field of ambulance nurses, the literature review helped with identifying needs and establishing the design requirements. When the requirements became clear the ideation began relative to these requirements. This lead to the design of 10 alternative solutions. From these alternatives, mock ups prototypes were made from each. From pros and cons weighing, two alternative solutions were selected for the low fidelity prototypes. These two prototypes were tested and evaluated in a workshop.

A chart of process factors in iteration 1 is shown in figure 4.2. To the right, the users feedback is pointed out as to where in the process the users experience was taken into account. While observing the ambulance nurses at their work, a lot of feedback was provided from the nurses. The feedback was in the form of conversation and speculation as to how the system should perform.

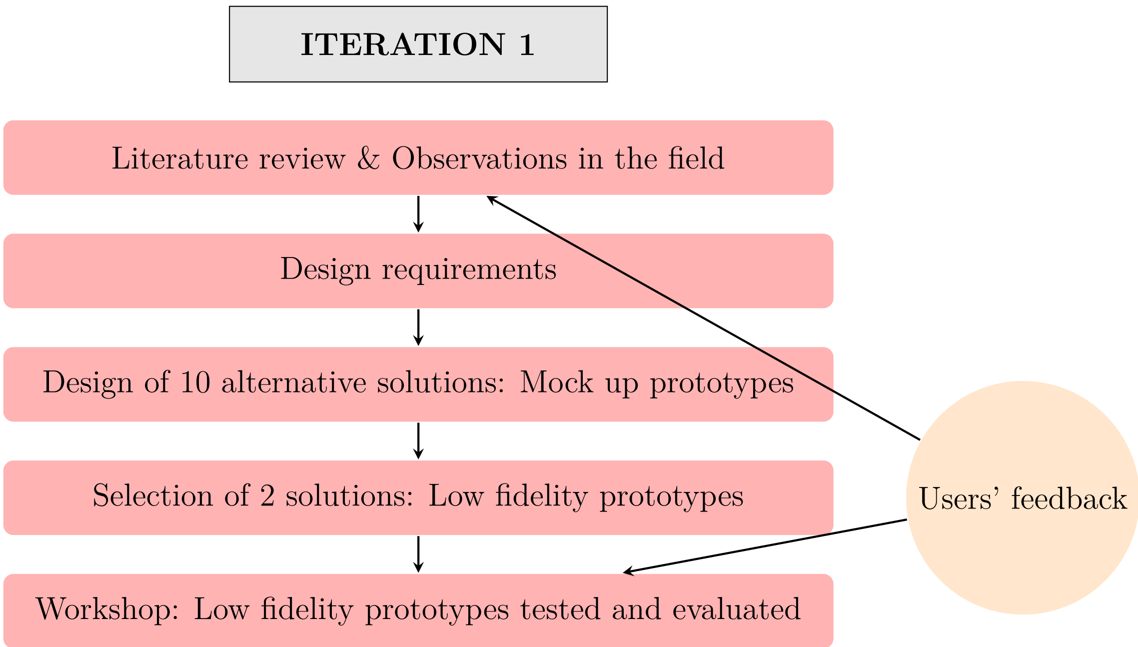

Figure 4.2: Iteration 1.

In the second iteration, the interaction design process was repeated. From the workshop in iteration 1, where the low fidelity prototypes were tested, the results were analyzed. The feedback that was made during the workshop was taken into consideration and new requirements were established. The prototype was then revised according to this feedback and a design for the high fidelity prototype was proposed.

In figure 4.3, the process for iteration 2 is visualized. The users feedback is again presented at the right hand side and comes into play in the workshop and simulations. The feedback from the workshop was gathered through a discussion with the individuals participating in the workshop. The second users feedback is during the simulations and testing of using the high fidelity prototype.

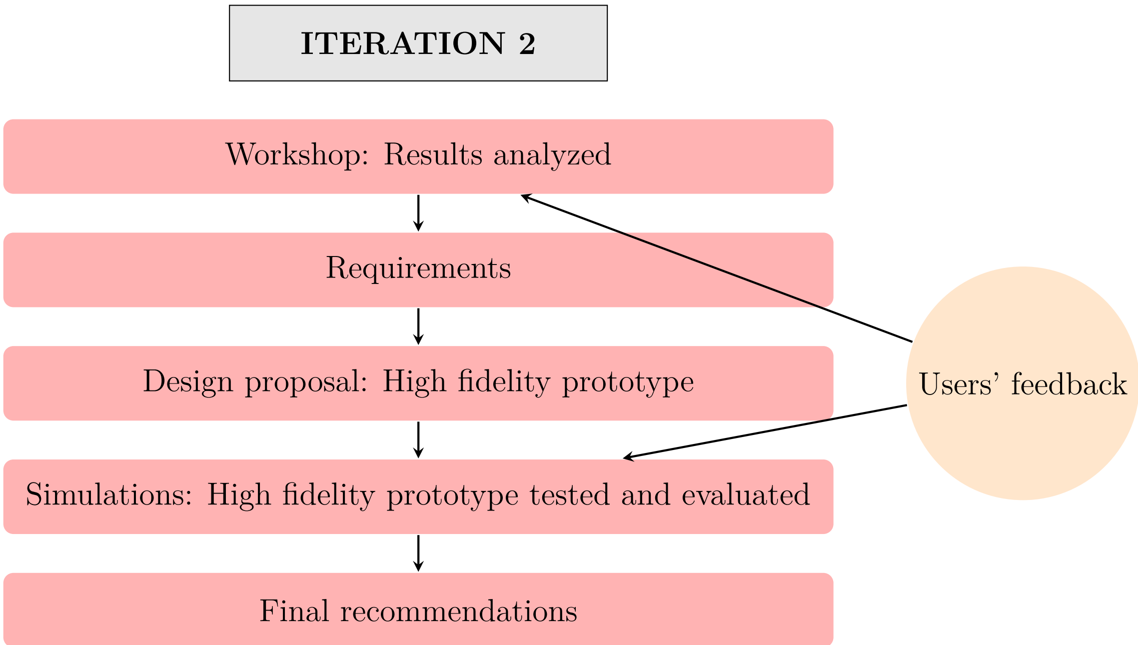

Figure 4.3: Iteration 2.

4.2 Observations in the field

Observing the work of intended users is one form of data gathering for establishing requirements. Since it is very important to understand the potential users and how they would be using the system, the work of ambulance nurses and paramedics was observed. The observation of space in the ambulance as well as how much equipment the paramedics need to use in each case was made. What work needs to be done in the patient home is also a factor that needed to be considered.

The work process was observed on a ride-along in an ambulance in Göteborg, Borås and Ulricehamn. The reason for observing ambulances in different areas is to look at the time the transporting takes and how the work plan for dealing with stroke differs between areas. Since Ulricehamn is for example a more rural area it is assumed that the transporting could take longer time than in Göteborg. Ulricehamn and Borås fall under an area where Södra Älvsborg sjukhus (SÄS), located in Borås, is the largest hospital.

4.3 Ideation

After reviewing the outcome of the literature review, presented in chapter 3, where the work of previous or current projects were recognized as well as observing ambulance staff at work, the ideation began. Ideas were based on the design requirements and written down on paper. All ideas were written down and sketched to get a better overall view.

4.4 Prototypes

Interacting with a product being developed can help potential users and other stakeholders to experience how it might feel like to use the product in a real setting. This is why prototypes are used, where various types can be created for different requirements and scenarios. Countless types of prototypes can be made, all from a sketch on a paper to a high fidelity prototype, even a whole workstation can be built [44].

Prototypes can be convenient for designers to test an idea and choosing between alternatives. This in return leads to testing technical and user feasibility and if the product meets all design requirements [44].

In this project 8 mock up prototypes were made. They were then used to select 2 alternative solutions for the making of low fidelity prototypes. By testing and evaluating the low fidelity prototype, a final high fidelity prototype was made. The low fidelity prototypes were revised according to evaluation to make the final prototype.

4.5 Assessing alternatives: Selection of 2 solutions

Not all solutions could be tested in a workshop so they had to be narrowed to only two solutions. In order to assess all alternatives, they were placed together side by side and different functions of each were written down. The functions were camera views, components, fixation of camera(s), physician view(s), easy to carry, audio and number of handheld components. From this information the pros and cons of each solution were weighted to come to a final conclusion on which solutions should be tested. The two solutions were tested in a workshop with the supervisors of this thesis as well as intended users.

4.6 Workshop: Low fidelity prototype evaluation

In order to get a feeling how the low fidelity prototypes would work, they were tested in a workshop. The aim of the workshop was to test the basic functionality of the prototype that had been developed from the mock up sketches. This was therefore the first prototype of the solution to be evaluated. The tests included the technical aspects of the components used in the solution and how they would perform once being used in stroke related situations. How the camera performed, in terms of field of view and video quality, and if it was acceptable in order to conduct the NIHSS assessment was also of interest. It was also observed what was most sufficient setup to use for connecting the physician and paramedics. Different cases were proposed for the tested solutions in terms of patient status and environment, along with recommended work process.

4.6.1 Environment and participants

This workshop was held with the supervisors of this thesis, Bengt Arne Sjöqvist, Stefan Candefjord and Hanna Maurin Söderholm. In addition to them, ambulance nurse Magnus Hagiwara was also present. The workshop took place in two simulation rooms at the University of Borås.

Participants had different roles during the workshop. Paramedic number 1, who assessed the patient using the NIHSS, was played by Magnus, and paramedic number 2 was played by Stefan. Hanna acted as the patient and Bengt Arne as the physician. The roles and participants are show in table 4.1.

Table 4.1: Actors and roles during workshop.

Actor	Role
Magnus Hagiwara	Paramedic 1
Stefan Candefjord	Paramedic 2
Hanna Maurin Söderholm	Patient
Bengt Arne Sjöqvist	Physician
Sigrún Hrafnsdóttir	Observer

Actors used the solutions like they would in a real life scenario and meanwhile the physician in the other room observed and participated in the assessment of the patient. The mNIHSS was used as the stroke assessment tool as it is used in ambulances in Sweden.

The environment of the patient was established as well as the setup for the physician. Two simulation rooms at the University of Borås were used, one to resemble the patients environment and one to resemble the location of the physician. The room used for the patient environment is shown in figure 4.4.

Figure 4.4: The simulation room for the patient environment.

In the second room used for the physician environment, a screen showed a real-time audio and video streaming from the patient environment room. This allows the observer to watch without disturbing. Figure 4.5 shows the screen when one of the case was being conducted.

Figure 4.5: The screen from where it can be seen into the other room.

4.6.2 Data gathering and analysis

Postworkshop, a discussion between participants was opened so that everyone could add their input on how the systems worked. The feedback was gathered for the revision of the low fidelity prototype. The data from the workshop was collected by recording the screen on the tablets and smartphones while the test cases were being conducted.

4.7 Simulations: High fidelity prototype evaluation

In the user centered design process described in the beginning of this chapter, usability evaluation is a crucial factor. It is a way of confirming that the system is appropriate and works well with the intended users and their tasks [45]. The goal of the simulations was to test the usability of the proposed design using a high fidelity prototype. In addition the goal of a usability testing is to determine if the performance of the system meet the tasks it was designed for, as well as establish how much time, effort and other resources are required for using the system. A no less important goal of the usability testing is to get feedback from the intended users [45].

The low fidelity prototype was evaluated in a workshop with the basic functionality of the components in mind. Simulations were conducted after the low fidelity prototype had been revised based on the results obtained during the workshop. The simulations involved a more detailed testing than the workshop. The ambulance team (two paramedics) were instructed to use the product as they would in a real life situation, all from when arriving to the patients' location to when it was time to transport the patient to appropriate medical center. They were however not instructed on how to use the prototype rather they were to use it how they felt was most comfortable. The prototype was tested where the actors involved played different roles in order to best simulate a real stroke incident.

4.7.1 Environment and participants

The simulations were conducted in the same location as the workshop, at the University of Borås. Same simulation room was also used and is shown in Figure 4.6. Actors involved were the three supervisors in this thesis, Bengt Arne sjöqvist, Stefan Candefjord and Hanna Maurin Söderholm. In addition, Magnus Hagiwara and Andreas Dehre participated in the simulations. They both are ambulance nurses with over 15 years experience working in the ambulance. Actors and roles are displayed in table 4.2.

Figure 4.6: Scenario 2 being conducted, one paramedic is attending to the patient while the other starts the setup of the system.

Table 4.2: Actors and roles during simulations.

Actor	Role
Magnus Hagiwara	Paramedic 1
Andreas Dehre	Paramedic 2
Hanna Maurin Söderholm	Patient
Bengt Arne Sjöqvist	Physician
Stefan Candefjord	Observer
Sigrún Hrafnsdóttir	Observer

4.7.2 Data gathering and analysis

The whole simulations were recorded on a GoPro camera mounted on a tripod that overlooked the whole room in which the simulations took place. This data was reviewed and analyzed afterwards and results established.

4.7.3 Postsimulation questionnaire

A questionnaire was handed to the two paramedics involved, who are the intended users of the system, after the simulations. It's purpose was to shed light on what was functioning well and what could be improved. This questionnaire, shown in Appendix 1, included 10 questions related to the solution being tested. The questions were derived from previous work on technology acceptance in prehospital care [46, 47].

5

Results 1: Low Fidelity Prototype and Evaluation

5.1 Requirements: Iteration 1

Understanding the requirements is an important part of any design. From the interviews and the ride-along, design requirements became easier to understand. For the ViPHS solution the most important requirement is that it should provide at least one way video support from the patient home to a physician located at a distance. Two way video support would be more beneficial as it would provide a more realistic sense of the physician actually being in the room. Two visual fields should be supported by this system, one for the face of the patient and one for the whole body. This could be that the camera has to be moved from one view to the other or it could be that the system contains two cameras, one for each view. The reason for this two view requirement is that in order to be be able to assess the patient correctly by using the NIHSS, the physician must be able to see the facial movements of the patient. In the same way the physician must be able to see the whole body for assessment, arm/leg drift and etc. In order to follow the NIHSS these two visual field views are extremely important.

Two way audio support is required between ambulance personnel and the physician sitting at a distance. The solution should be portable and very easy to carry and the setup should be simple. It should be light but also durable to withstand all sorts of treatment such as a fall and bad handling. Last but not least it should take as little space as possible since it will be fitted in to an ambulance for transport and not have too many components. These requirements are listed in Table 5.1.

Table 5.1: Requirements: Iteration 1.

	Requirements
System	1. Easy to carry.
	2. Easy and quick setup.
	3. Not too many components.
	4. Durability.
Video	5. At least one way video support.
	6. Two visual fields.
	7. Good field of view.
Audio	8. Two way audio support.

5.1.1 Literature study/Previous work

While reviewing the literature, it was noticed just how crucial it is for stroke patient to receive relevant treatment in time, in order to have more probability of a good outcome. Research show that there is a need for decreasing delays in the prehospital settings where decision support for transportation decisions is the main priority. Most previous projects observed showed promising results in the evaluation of using video communications in the assessment of acute stroke. A common challenge was the quality of the internet connectivity.

5.1.2 Observations in the field

When the ambulance personnel get an emergency call they get notified on the radio, where they can see basic facts about the particular case and its priority. On an additional screen located in the front in the ambulance a more specific facts about the case and its priority. The same screen also contains GPS to guide the driver to the site. The priorities range from 1 to 4, where stroke is considered a priority 1. When the ambulance is on its way to the patient location they notify the "station" by pressing a button on the screen. The same is done when they arrive on the scene and when they have transported the patient to the hospital, or if it's not necessary to go to the hospital, leave them at the scene.

The observations in the field of ambulance nurses involved three shifts in ambulances, in three different locations in Sweden. Overall a total of 28 hours were spent with the ambulance and during this time, 13 cases were observed. Out of all cases there were two potential stroke cases. In one case it was difficult to use the NIHSS since the patient did not comprehend the questions asked. This resulted in a high score on the NIHSS and therefore the patient was considered to be in a very urgent need of medical care. Both patients were lying down, one on the floor and the other in a bed, this made it difficult for the paramedics to assess them in a good way. In both cases the time from onset of symptoms was not specifically known because the patients had been alone for quite a while.

It was observed that the potential stroke patients are assessed from first observing the vital signs, such as blood pressure, ECG, blood oxygen levels etc. When the vital signs have been established the NIHSS is used to assess the stroke severity. In continuation, a contact is made with a neurologist in order to get information on where to transport the patient. This contact is made through a mobile phone where the patients condition is described as thoroughly as possible. The patient is finally transported to a relevant medical center.

During the ride-alongs it was noted that there are always two ambulance nurses or one ambulance nurse and one paramedic in each ambulance. Advantage could be taken of this since one of them could potentially be holding any kind of device during the stay in the patient home. A few photos were taken to show how little space there actually is in the ambulance, these are shown in Figure 5.1. The first photo, Figure 5.1a shows the storage in the back end of the ambulance. Figure 5.1b and 5.1c show what can be seen when the side door is opened.

(a) Seen inside the back of an ambulance.

(b) Seen inside the ambulance from the side door.

(c) The storage when opening the side door.

Figure 5.1: Storage and space in an ambulance.

5.2 Technical proposal: 8 alternatives

As stated previously in this chapter, an essential requirement is to have two views of the patient in order to conduct the NIHSS. These views are an overall view of the patient and a close up facial view. Since this requirement is of a great importance, the first step in designing the solutions was to explore how the camera(s) could be mounted so that the requirements are met. Based on what was observed during literature review and by observing in the ambulance, several alternatives for a camera mount were established. These alternatives are described in the following sections as well as how the audio communication is established and the view for the physician. Finally, 8 alternative solution are described in terms of components, audio and physician view.

5.2.1 Suction cup

This suction cup camera mount contains suction cups on the back in order to stick to the wall or any smooth surface at the patient location. A camera attached to this mount can be fixed on smooth surfaces such as walls, cabinets, wardrobes etc. Since it is able to stick to a smooth surface, it can be mounted inside the ambulance so the physician is able to observe the patient all the way to the hospital.

Cameras that could be used for this smooth surface mount can contain functions such as pan-tilt-zoom where it can be controlled by the physician at a distance. This can also be a camera with a good field of view so that it can be mounted in various places. This setup should be preferably used for the overall view of the patient since it could be difficult finding an acceptable location so that the facial view is clear for the physician.

5.2.2 Tripod

A tripod is a component most people are familiar with, with it being used frequently for capturing stable photographs or videos. They are available in many shapes and sizes depending on their functionality. Much like the suction cup mount, the tripod can be fixed in various places. Depending on the scenery, it can be placed on a table, shelf, the floor etc. The paramedics can easily move the tripod around in order to capture the best view of the patient for the NIHSS assessment.

5.2.3 Head/body mount

The camera can be worn by one or both paramedics via a head or body mount. This means the view for the physician is somewhat similar to that of the paramedic wearing the camera. Depending on how the paramedics move, the view will change. This can however create an unstable image since the paramedics are constantly moving.

Body mounted cameras have proven to be been used by police officers to record what they see and hear when making arrests as well as evidence recordings from crime scenes. By this complaints against the police can be more easily resolved as well as increase police transparency and liability. The videos recorded can also be used by law enforcement agencies to assist with prosecuting crimes and more [48].

5.2.4 Clamp attached to flexible arm

The camera in this case is mounted on a flexible arm attached to a clamp. The flexible arm can be bent in different ways depending on each case and where it is mounted each time. This should be convenient if the arm were to be fixed on the stretcher, it can be bent in a way for the camera to have an appropriate view of the patient. In this situation the physician is able to follow the patient from when the paramedics arrive, all time through to when he is transported and finally dropped off to a suitable health care facility. This can be very beneficial for the patient to receive the best possible care.

5.2.5 Handheld device

The handheld device refers to a device with and integrated camera that is handheld by one paramedic. This can be a tablet or a smartphone which are both devices that people use in their everyday life. This can be beneficial as it wont surprise the patients and the paramedics might feel more comfortable using a device they are familiar with. A limitation to this is that there is an increased risk of shaking when holding the device, this can cause distorted image for the physician and cause problems in doing the NIHSS assessment.

5.2.6 Audio

The communication between the physician and paramedics is of great importance. This is why the audio has to be very reliable so that they are able to hear each other at all times. In the following solution descriptions, the audio depends on what components the solutions contain. Either it is provided by a headset worn by one paramedic or the integrated speaker and microphone in the handheld device. It is also possible to incorporate headsets in all solutions. This however eliminates the possibility of the physician being able to talk directly to the patient. However there might not be a need for this to be possible, the physician can direct the paramedics on what to ask the patient.

5.2.7 Physician view

The physician view varies between two simultaneous views or one view at a time, depending on how many cameras are included in the solutions. This means that if they contain two cameras the physician is able to observe both views, overall and facial at the same time. If one camera is used, one view is shown at the physician end each instance.

5.2.8 Solution descriptions

From the camera mounts described above, 8 solutions were designed. For this, few aspect were needed to be recognized in order to meet the requirements. All solutions are presented in the following sections where they are described as well as visualized through computer sketches, acquired using SketchUp. For each solution, a table is generated that shows what components described above are included in the solution.

5.2.8.1 Solution 1

As shown in table 5.2 the camera mounts chosen for this first solution are for the overall view, a suction cup mount and for the facial view of the patient, a handheld device was chosen. These should work well together since they provide two simultaneous views for the physician. The audio in this case is provided by the integrated speakers in the handheld device.

Table 5.2: Camera mount and physician view in solution 1.

	View of patient	
Camera mount	Overall	Facial
Suction cup	X	
Tripod		
Head/body		
Clamp attached to flexible arm		
Handheld device		X
	Simultaneous	One at a time
Physician view	X	

The use of the components is demonstrated in figure 5.2 where a stroke scenario is shown as the patient is being assessed with the NIHSS. The overall view camera is mounted on the wall in front of the patient and the paramedic is holding the handheld device, which in this case is a tablet, for the facial view.

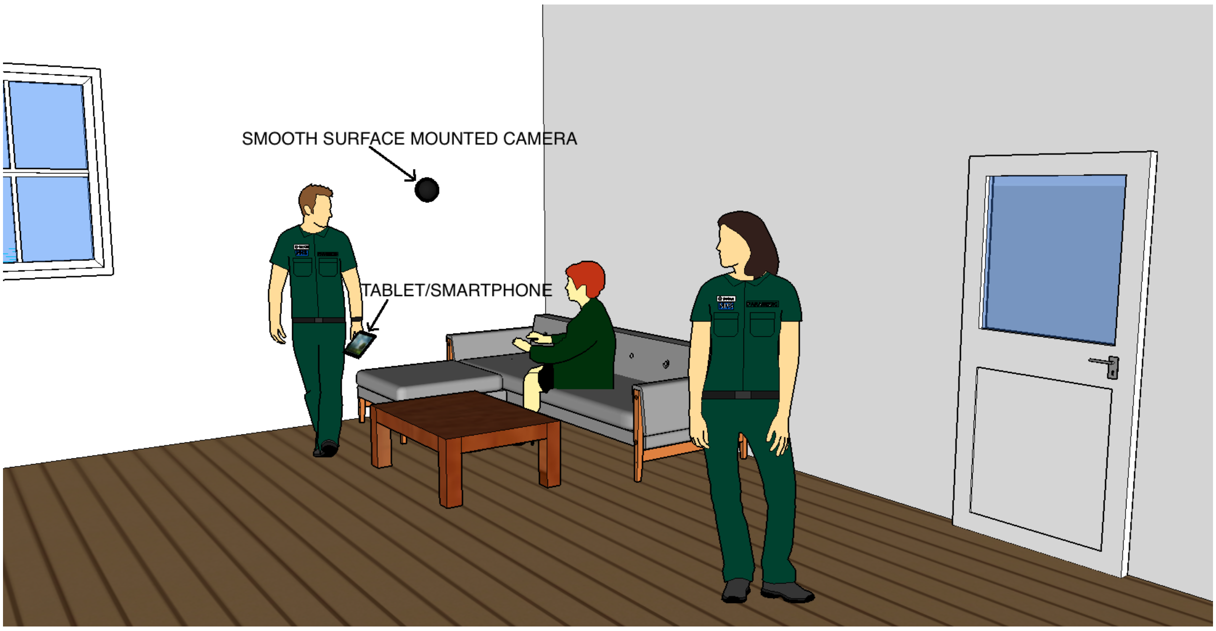

Figure 5.2: A smooth surface mounted camera and a handheld device.

5.2.8.2 Solution 2

A tripod was selected as camera mount for the overall view in this solution, whereas for the facial view a handheld device was chosen. This is shown in table 5.3 along with how the view for the physician is implemented, in this case the two views are simultaneously shown on the physicians' screen. The communication between the physician and the paramedics is provided by the integrated speaker and microphone in the handheld device.

Table 5.3: Camera mount and physician view in solution 2.

	View of patient	
Camera mount	Overall	Facial
Suction cup		
Tripod	X	
Head/body		
Clamp attached to flexible arm		
Handheld device		X
	Simultaneous	One at a time
Physician view	X	

Figure 5.3 shows how the setup of the system solution would look like, the tripod is placed where the overall view of the patient is acceptable and one paramedic is holding the handheld device for the close up of the patient.

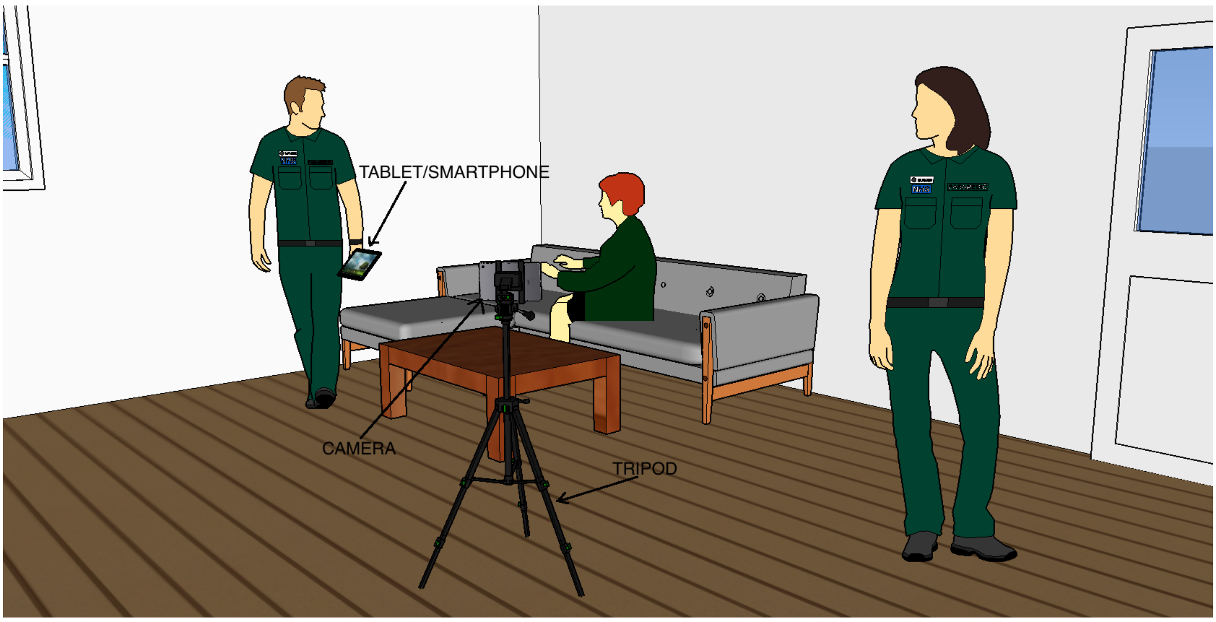

Figure 5.3: A camera mounted on a tripod and a tablet.

5.2.8.3 Solution 3

This solution also contains a camera mounted on a tripod, however the same camera is used for the overall and facial view of the patient. The tripod has to be moved in order to switch between the two views depending on what part of the NIHSS is being conducted. The camera mounted on the tripod can for example be the integrated camera in a tablet or smartphone, which is the case in this solution. Since only one camera is suggested in the system, the physician is able to observe one view at a time. The integrated speakers and microphone allow the physician and paramedics to interact.

Table 5.4: Camera mount and physician view in solution 3.

	View of patient	
Camera mount	Overall	Facial
Suction cup		
Tripod	X	X
Head/body		
Clamp attached to flexible arm		
Handheld device		
	Simultaneous	One at a time
Physician view		X

As mentioned before, the integrated camera in a tablet/smartphone is suggested to be used in this solution, where it is mounted on a movable tripod as shown in figure 5.4. The sketch shows the setup when the NIHSS is conducted where the overall view of the patient is needed. The tripod then has to be moved closer to the patient for the facial view.

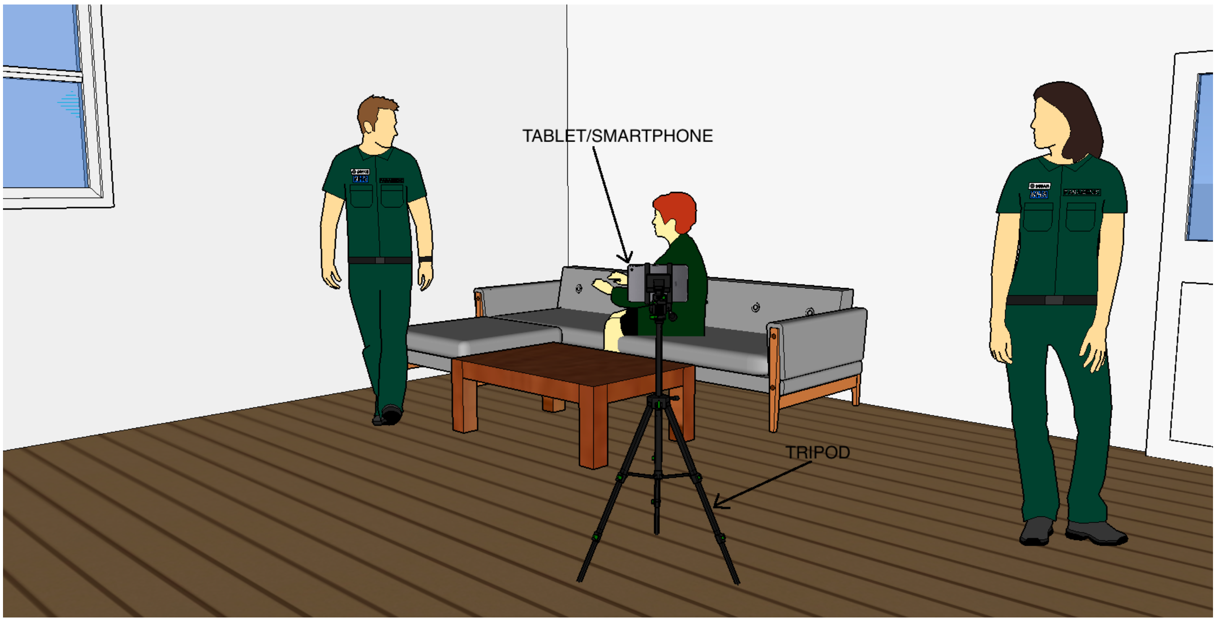

Figure 5.4: A tablet/smartphone mounted on a tripod.

5.2.8.4 Solution 4

In this solution the head/body mounted camera and the tripod are combined in a system. The head/body mounted camera is worn by one paramedic, the same as the one conducting the NIHSS, and provides the physician with the facial view of the patient. The overall view is established using a camera mounted on a tripod. Shown in table 5.5 are which camera mounts are used in this solution as well as how the view for the physician is provided.

Table 5.5: Camera mount and physician view in solution 5.

	View of patient	
Camera mount	Overall	Facial
Suction cup		
Tripod	X	
Head/body		X
Clamp attached to flexible arm		
Handheld device		
	Simultaneous	One at a time
Physician view	X	

Either a head or body mounted camera can be used for this solution. Figure 5.5 show how the system setup can look like. A head mounted camera is used as an example here and is worn by one paramedic. The integrated camera in the tablet/smartphone is used and is mounted on the tripod which offers the overall view of the patient.

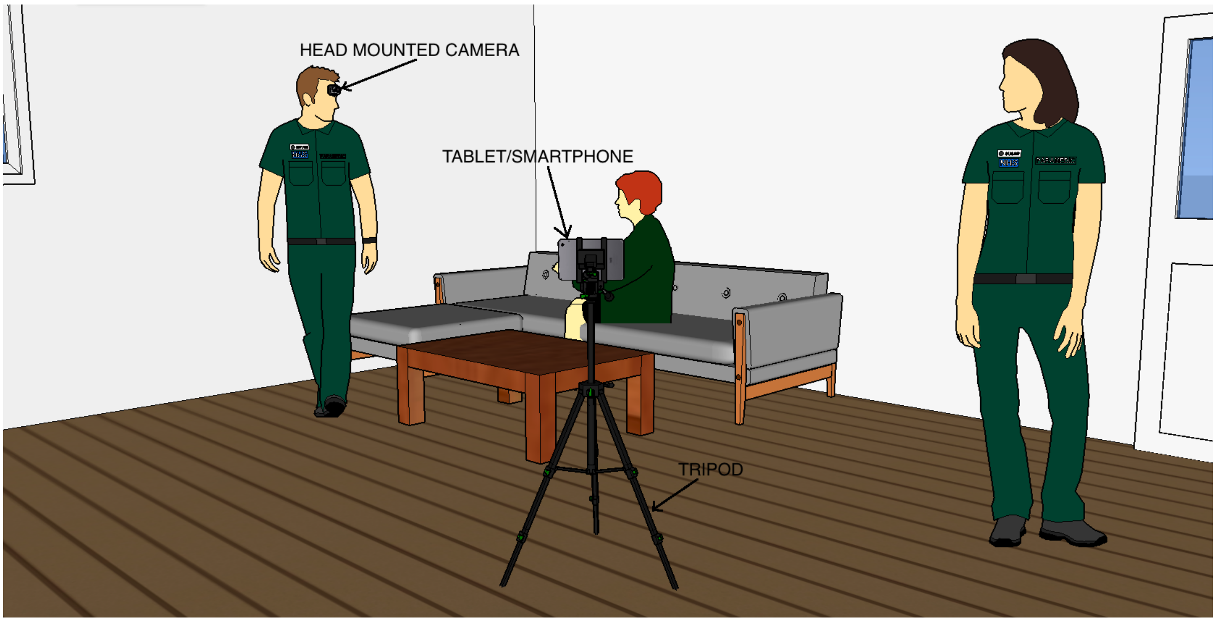

Figure 5.5: A head mounted camera and a tablet/smartphone on a tripod.

5.2.8.5 Solution 5

This solution contains very compact components, a head/body mounted camera and a headset. This means that the one paramedic is wearing both while interacting with the physician. The other paramedic is therefore not able to hear the physician but can instead attend to the patient and conduct the NIHSS. The paramedic wearing the camera and headset has to move as instructed by the physician, so the view of the patient is suitable for the NIHSS. Consequently the physician is able to see one view, overall or facial, at a time. Table 5.6 displays an overview of what camera mounts are used in this solution as well as the physician view. In addition the audio link is provided by the headset.

Table 5.6: Camera mount and physician view in solution 4.

	View of patient	
Camera mount	Overall	Facial
Suction cup		
Tripod		
Head/body	X	X
Clamp attached to flexible arm		
Handheld device		
	Simultaneous	One at a time
Physician view		X

The paramedic wearing the devices is the one standing to the far left in figure 5.6. In this case the camera is mounted on the chest of the paramedic, but this could also be a head mounted camera. The paramedic to the right is thus the one conducting the NIHSS and attending to the patient.

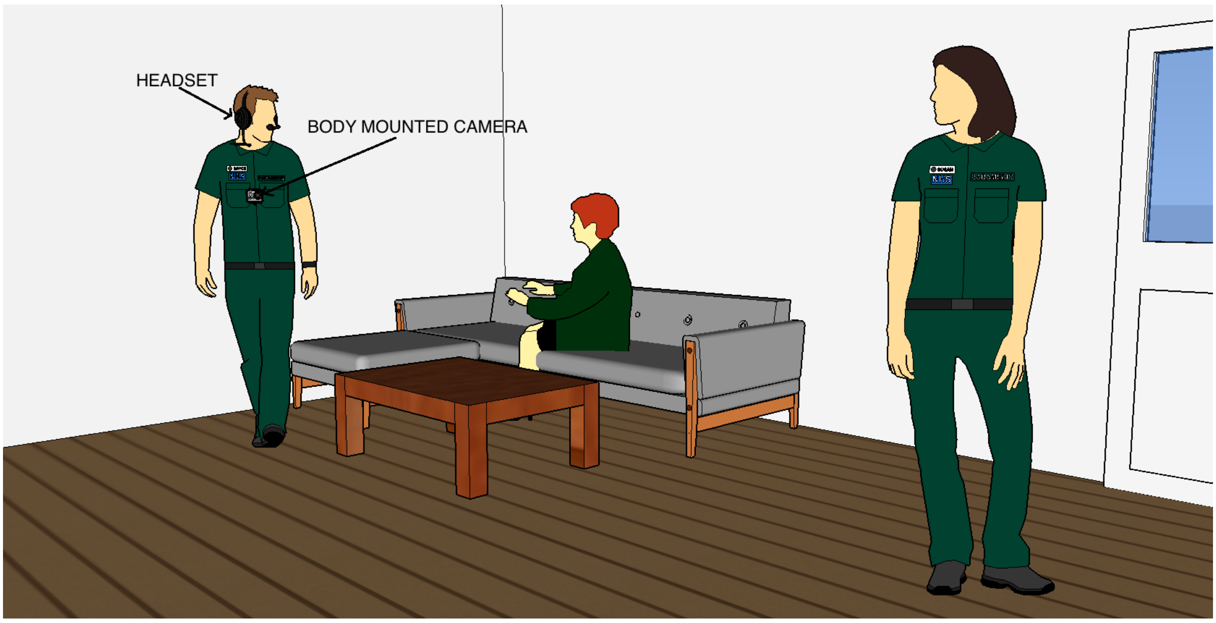

Figure 5.6: A body mounted camera and a headset.

5.2.8.6 Solution 6

A clamp attached to flexible arm is the camera mount for the overall view of the patient in this solution as shown in table 5.7. One paramedic has a handheld device in order to capture the facial view of the patient while the other paramedic assists in conducting the NIHSS. The audio is provided by the handheld device.

Table 5.7: Camera mount and physician view in solution 6.

	View of patient	
Camera mount	Overall	Facial
Suction cup		
Tripod		
Head/body		
Clamp attached to flexible arm	X	
Handheld device		X
	Simultaneous	One at a time
Physician view	X	

Figure 5.7 shows an example of how this system setup might look like. The clamp with the flexible arm is fixed on the sofa table and the arm is bent in a way so that the view of the patient is good.

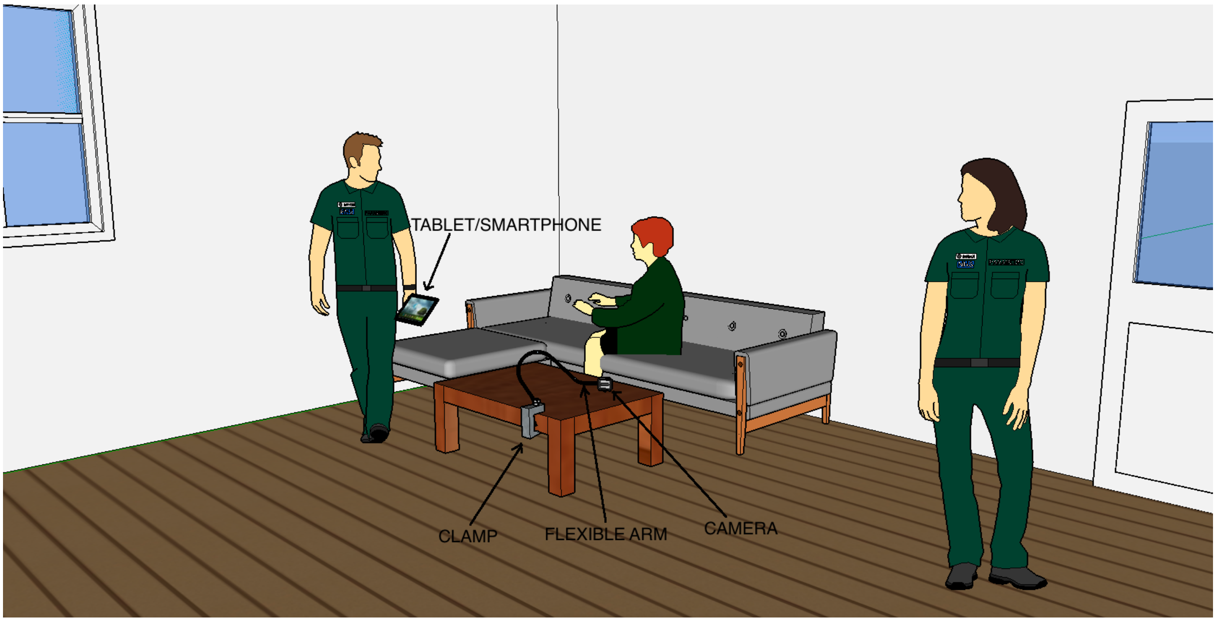

Figure 5.7: A camera mounted on a clamp and a tablet/smartphone.

5.2.8.7 Solution 7

In this solution the overall and facial view camera mount is a clamp attached to a flexible arm as shown in 5.8. Therefore the physician view is one view at a time, one for when conducting the NIHSS questions that require the overall view and one when the NIHSS requires the facial view. The audio communication is provided via headset worn by the paramedic conducting the NIHSS assessment.

Table 5.8: Camera mount and physician view in solution 7.

	View of patient	
Camera mount	Overall	Facial
Suction cup		
Tripod		
Head/body		
Clamp attached to flexible arm	X	X
Handheld device		
	Simultaneous	One at a time
Physician view		X

Shown in figure 5.8 is the setup of the system, where the paramedic on the left is wearing the headset and conducting the NIHSS. The clamp attached to a flexible arm is mounted on the table in front of the patient.

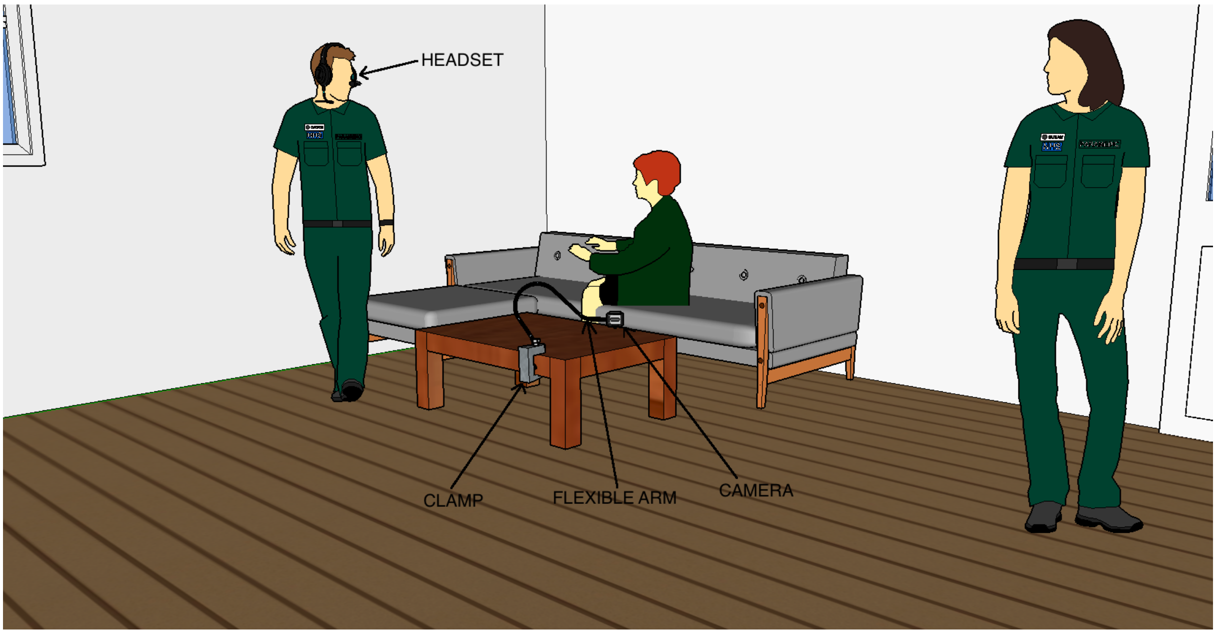

Figure 5.8: A camera mounted on a clamp and a headset.

5.2.8.8 Solution 8

This solution is the simplest, containing only one component, a handheld device, used for capturing both the overall and facial view. It will here be demonstrated using a tablet/smartphone, held by one paramedic. Table 5.9 shows the overview of this along with the physician view. The physician has one view to look at each time since the handheld device has to be moved away from the patient for the overall view and close to the patient for the facial view. The paramedic not holding the device is the one attending to and assessing the patient using the NIHSS. The job for the other paramedic is to capture the appropriate view of the patient depending on what is needed for the NIHSS. The integrated speakers and microphone in the handheld device provide the audio link needed.

Table 5.9: camera mount and physician view in solution 8.

	View of patient	
Camera mount	Overall	Facial
Suction cup		
Tripod		
Head/body		
Clamp attached to flexible arm		
Handheld device	X	X
	Simultaneous	One at a time
Physician view		X

Figure 5.9 shows one paramedic holding the device in front of the patient. The other paramedic should conduct the NIHSS evaluation.

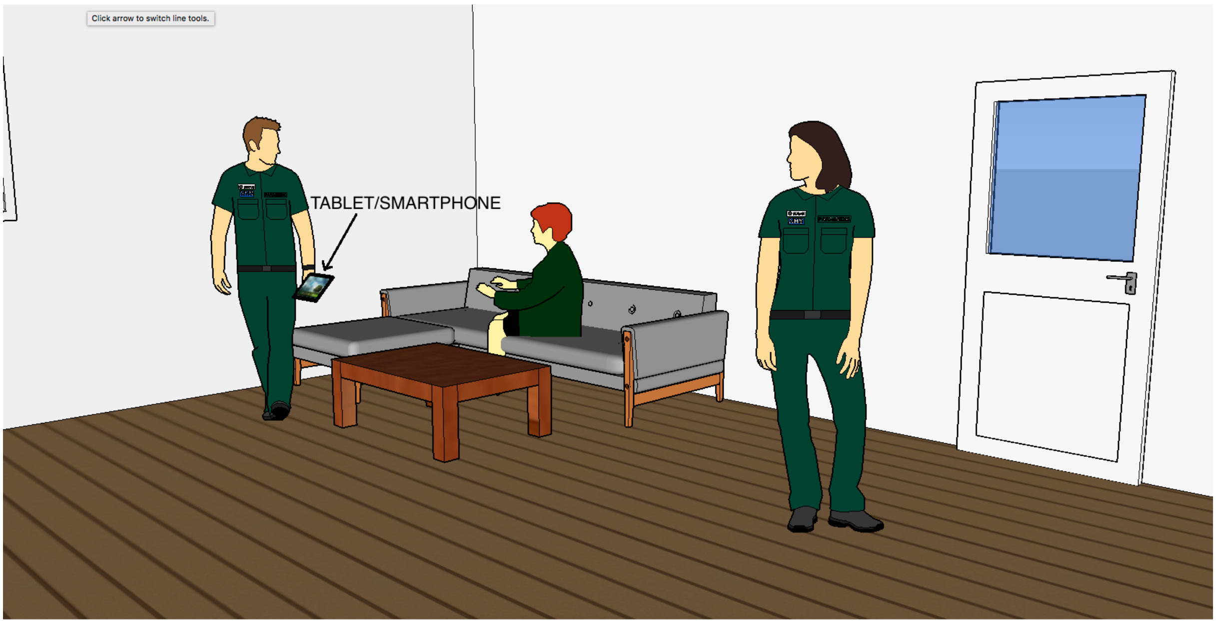

Figure 5.9: A tablet/smartphone.

5.3 Choosing between alternatives: Summary

Out of the 8 alternatives proposed, 2 solutions were chosen for the creation of the low fidelity prototypes. For a clearer perspective, the solutions were placed side by side in a table and evaluated in terms of the requirements along with weighing the pros and cons. This is shown in table 5.10 and 5.11.

Table 5.10: Overview of the alternatives: Part 1.

	SOLUTION 1	SOLUTION 2	SOLUTION 3	SOLUTION 4
Camera views *Better to have a simultaneous view of the face and full body of the patient rather than switching from one view to another.*	simultaneous view of both the close up and full body.	simultaneous view of both the close up and full body.	only one view at a time, just the close up or the full body view.	simultaneous view of both the close up and full body.
Components *More components can mean more complex. More complex setup while at the scene.*	two components: a pan-tilt-zoom camera and a tablet/smartphone.	three components: camera, tablet/smarpthone and, a tripod.	two components: a tablet/smartphone and a tripod.	three components: a head mounted camera, a tablet/smartphone and a tripod.
Fixation of camera(s) *More versatile the better. If it can be fixed in more places it can fit more versatile situations.*	wall fixed camera, versatile. Handheld camera on tablet/smartphone.	camera on a tripod, rather versatile. Handheld camera on tablet/smartphone.	tablet/smartphone on a tripod, rather versatile. Handheld camera on tablet/smartphone.	camera fixed on the head of one of the paramedic. View of camera is almost the same as the paramedics. Tablet/smartphone camera on a tripod, rather versatile.
Physician view(s) *Two views means that the physician is able to see more each time and that can offer better experience.*	two views, close up and full body at the same time. Controllable in terms of pan-tilt-zoom.	two views, close up and full body at the same time.	one view, either close-up or full body at each time.	two views at a time, close up and full body at the same time.
Easy to carry *The lighter and more easy to carry the better for the ambulance staff.*	non heavy components and can be fixed in a case.	a bit heavy components, could be voluminous.	non heavy components, could be voluminous.	a bit heavy components, could be voluminous.
Audio *Good audio quality is essential.*	two way audio provided by the tablet/smartphone.	two way audio provided by the tablet/smartphone.	two way audio provided by the tablet/smartphone.	two way audio provided by the tablet/smartphone.
Handheld components *If one or more component has to be handheld means that at least one of the ambulance nurse has his/her hands tied during the examination.*	one handheld component, during whole examination.	one handheld component, during whole examination.	one handheld component, only when doing close-up.	no handheld component.
PROS	1.Versatile fixation of camera. 2. Paramedics able to see the physician on the tablet/smartphone. 3. The physician views close up and full body simultaneously.	1. Versatile fixation of camera. 2. Paramedics able to see the physician on the tablet/smartphone. 3. The physician views close up and full body simultaneously.	1. Versatile fixation of camera. 2. Paramedics able to see the physician on the tablet/smartphone. 3. Easy setup.	1. Versatile fixation of the camera. 2. One camera follows the paramedic everywhere (could also be a downside). 3. The physician views close up and full body simultaneously.
CONS	1. Relies on a smooth surface like a wall. 2. One handheld component (one paramedic has his/her hands tied during examination). 3. Camera could fall of the smooth surface during examination if not properly fixed to it.	1. Possibly voluminous components (depending on the size of the tripod). 2. One handheld component (one paramedic has his/her hands tied during examination).	1. Possibly voluminous components (depending on the size of the tripod). 2. Paramedics might not be able to hear the physician well during the full body view since the audio is provided by the tablet/smartphone. 3. One handheld component (one paramedic has his/her hands tied during examination). 4. The camera has to be moved back and forth for different views.	1. Since one camera is located on one paramedics head, it is constantly moving. This might cause problems for the physician. 2. Paramedics might not be able to hear the physician well during the whole examination since the audio is provided by the tablet/smartphone.

Table 5.11: Overview of the alternatives: Part 2.

	SOLUTION 5	SOLUTION 6	SOLUTION 7	SOLUTION 8
Camera views *Better to have a simultaneous view of the face and full body of the patient rather than switching from one view to another.*	only one view at a time, just the close up or the full body view.	simultaneous view of both the close up and full body.	only one view at a time, just the close up or the full body view.	only one view at a time, just the close up or the full body view.
Components *More components can mean more complex. More complex setup while at the scene.*	two components: a body mounted camera and a headset.	three components: a camera, clamp and a tablet/smartphone.	three components: a camera, clamp and a headset.	one component: a tablet or a smartphone.
Fixation of camera(s) *More versatile the better. If it can be fixed in more places it can fit more versatile situations.*	camera fixed on the chest of one of the paramedic. Camera moves with the paramedic.	camera mounted on a clamp that can be fixed on shelves, tables, etc. Tablet/smartphone camera on a tripod, rather versatile.	camera mounted on a clamp that can be fixed on shelves, tables, etc. Rather versatile.	Tablet/smartphone camera handheld by one of the paramedics.
Physician view(s) *Two views means that the physician is able to see more each time and that can offer better experience.*	one view at, either close up or full body at each time.	two views at a time, close up and full body at the same time.	one view at, either close up or full body at each time.	one view at, either close up or full body at each time.
Easy to carry *The lighter and more easy to carry the better for the ambulance staff.*	light and non voluminous components.	a bit heavy components, could be voluminous.	non heavy components, not voluminous	very light and non voluminous component.
Audio *Good audio quality is essential.*	two way audio provided by the headset.	two way audio provided by the tablet/smartphone.	two way audio provided by the headset.	two way audio provided by the tablet/smartphone.
Nr. of handheld components *If one or more component has to be handheld means that at least one of the ambulance nurse has his/her hands tied during the examination.*	no handheld component.	one handheld component, during whole examination.	no handheld component.	one handheld component, during whole examination.
PROS	1. Light components(easy to carry). 2. Clear audio through headset. 3. No handheld component. 4. Easy setup.	1. Versatile fixation of camera. 2. Paramedics able to see the physician on the tablet/smartphone. 3. The physician views close up and full body simultaneously.	1. Versatile fixation of camera. 2. Clear audio through headset. 3. No handheld component.	1. Light components. 2. Easy setup. 3. Paramedics able to see the physician.
CONS	1. Since the camera is located on one paramedics chest, it is constantly moving and the hands can get in the way. This might cause problems for the physician. 2. The paramedics are not able to see the physician. 3. The paramedic wearing the camera has to move towards and away from the patient depending on what view is needed.	1. Relies on tables, shelves etc. being present at the scene. 2. One handheld component(one paramedic has his/her hands tied during examination). 3. Camera could fall of the area it is clamped on during examination if not properly fixed to it.	1. Relies on tables, shelves etc. being present at the scene. 2. Camera could fall of the area it is clamped on during examination if not properly fixed to it. 3. The paramedics are not able to see the physician.	1. One handheld component (one paramedic has his/her hands tied during examination). 2. The tablet/smartphone has to be moved towards and away from the patient depending on what view is needed. 3. The paramedic holding the patient has to move with the camera and would therefore be standing further away from the patient during the full body assessment.

By reviewing the pros and cons from each solution, the two solutions that best fitted the requirements were selected. The solutions that were selected were first, the smooth surface mounted camera and a tablet/smartphone. The second solution was the head mounted camera and a tablet/smartphone on a tripod.

5.4 Low fidelity prototypes: 2 alternatives

As outlined in the previous section, two alternatives were selected for the next step, based on the summary in Tables 5.10 and 5.11 above. For solution 1, two prototypes were made from commercially available components. This was done in order to test how different kind of components would work. The prototype for solution 2 was also made from components already available in stores.

5.4.1 Solution 1: A smooth surface mounted camera and a smartphone

5.4.1.1 Setup 1: Many micro suction cups

The components used for this setup were two smartphones and one smartphone case with large numbers of nano suction cups on the back. One smartphone was handheld by one of the paramedic and the other smartphone was fixed in the phone case. The smartphone in the case was the smooth surface mounted camera since it sticks well to any smooth surface. The two smartphones are shown in Figure 5.10. The one to the left is in the suction cup case. The one to the right should be handheld by one paramedic.

Figure 5.10: Components of solution 1, setup 1.

Figure 5.11 shows an example how the phone in the case can be mounted on a smooth surface, a door in this example. The phone sticks to the door and keeps in place while the assessment is conducted.

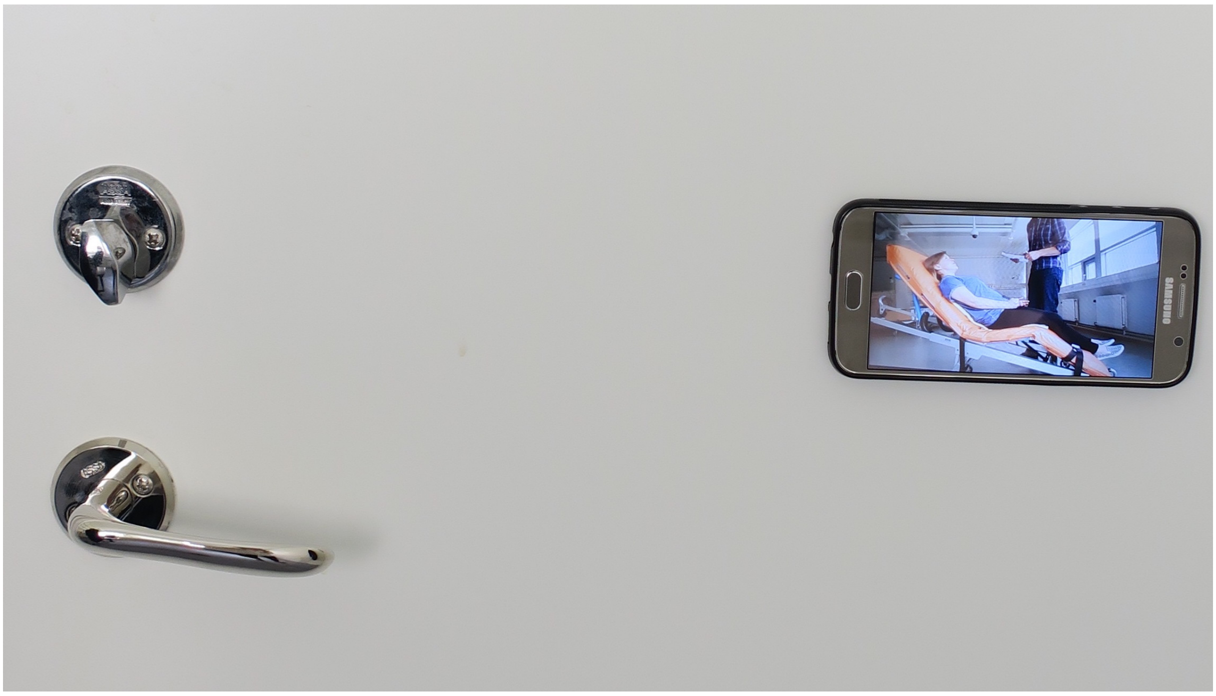

Figure 5.11: The smartphone in the case, after being mounted on a door.

5.4.1.2 Setup 2: One large suction cup with flexible arm

Two smartphones were also used in this system setup along with Joby® Suction Cup & GorillaPod Arm. One smartphone was fixed on the GorillaPod arm and the other hand-held by one paramedic. The GorillaPod arm is fixed to the suction cup and the suction cup can be mounted on any smooth surface. The arm is very flexible and allows for the camera to be moved in order to get the best view of the patient. The components for this setup are shown in Figure 5.12. To the far right is the suction cup that can be mounted to any smooth surface by turning the red ring. To the left of the suction cup is the GorillaPod arm and then the phone holder that is screwed on the arm. The two components to the left are the smartphones, one handheld and the other placed on the phone holder mounted to the arm.

Both system setup 1 and 2 were made to present solution 1, a smooth surface mounted camera and a handheld smartphone.

Figure 5.12: Components of solution 2, setup 2.

When the Suction Cup & GorillaPod Arm has been mounted on a smooth surface it looks as in Figure 5.13 the phone is mounted on a door and the arm can be bent to maximize the quality of the field of view. This is to show how the arm can be mounted in different ways for different situations.

Figure 5.13: The smartphone on the arm, after being mounted on a door.

5.4.2 Solution 2: A head mounted camera and a camera on a tripod

The components for this setup included two smartphones, a Joby® GorillaPod tripod and a GoPro® head strap. Figure 5.14 shows the head strap used for mounting the camera. The integrated camera in the smartphone was used as the head mounted camera as well as the camera on the tripod.

Figure 5.14: The head strap with a smartphone.

The Joby® GorillaPod, shown in Figure 5.15, has flexible legs that can be bent different ways depending on each situation.

Figure 5.15: Smartphone mounted on a tripod.

5.5 Workshop: Low fidelity prototypes tested

5.5.1 Test cases

In the beginning of the workshop, the prototypes were presented. The components of the prototypes were tested with regard to functionality. After evaluating the components, it was concluded by the participants in the workshop that the large suction cup with flexible arm had more advantages than the tripod. For this reason it was decided to eliminate the camera on the tripod from the tests. As a result, the three system setups were to use two different types of smooth surface mounted cameras along with handheld smartphone and a smooth surface mounted camera with a head mounted camera. The patients' symptoms and environment were kept the same for all 3 cases and the whole mNIHSS was performed each time. The workshop cases are shown in table 5.12 for a better visualization.

In all tests the patient is an older woman living in a small room at a nursing home. The ambulance nurses arrive to find the woman lying on the floor unable to move on her own. Despite being unable to move, the patient can understand the questions she is being asked. She is paralyzed on the left side of the body, with noticeable face drooping on the left side. In addition she is having some speech difficulties so it's hard to understand her.

The recommended work process for test 1 and 2 are the same. When arriving at the scene of the potential stroke the ambulance nurses bring the appropriate equipment from the ambulance into the home. Included in this are the components of solution 1, which is the smooth surface mounted camera and a smartphone. While one of the ambulance nurses starts by taking the vital signs of the patient, the other starts the setup of the system. First is the observation of a smooth surface, walls or doors, that offer a good overview of the patient. When finding a good surface for the camera, it is fixed into position. Then the application is started on the smartphone and contact is made with the physician at a distance. When contact is established, the assessment using the NIHSS can begin.

For the third test, the recommended work process is different from the first two tests. The equipment the two ambulance nurses bring into the home of the patient includes the components of solution 2, a head mounted camera and a smooth surface mounted camera. While in the ambulance driving to the scene, one of the nurses starts the setup of the system by starting the head camera and placing it on his head. When arriving at the patient home the rest of the setup can be begin. This involves finding a smooth surface where the smooth surface mounted camera can be mounted and placing it there. When starting the application on the smartphone a contact is made with the physician. The NIHSS assessment can begin.

Table 5.12: Workshop cases.

	TEST 1 smooth surface mounted camera, handheld smartphone	**TEST 2** smooth surface mounted camera (different kind), handheld smartphone	**TEST 3** smooth surface mounted camera, head mounted camera.
Environment	A small room at a nursing home.	A small room at a nursing home.	A small room at a nursing home.
Patient	Older woman lying on the floor.	Older woman lying on the floor.	Older woman lying on the floor.
Recommended Work Process	Find a smooth surface where the view of the patient is acceptable. Fix camera to the surface. Start application on tablet/smartphone and make contact with physician.	Find a smooth surface where the view of the patient is acceptable. Fix camera to the surface. Start application on tablet/smartphone and make contact with physician.	Start the setup in the ambulance on the way to the patient home, by placing the headcamera on the head. While at the scene, find a good location for the smooth surface mounted camera. Start application and make contact with physician.
NIHSS TESTS	Full mNIHSS.	Full mNIHSS.	Full mNIHSS.

5.5.2 Physician view

In order to simulate the physicians view, two tablets were used. One tablet was used for the overall view and one for the facial view of the patient. Since the system should show two simultaneous views for the physician, the two tablets were placed side by side. For video and audio connection between the tablets and the smartphones, Skype™ was used. One smartphone was connected via Skype™ to one tablet and the other to the second tablet. This way the physician was provided with the two views simultaneously. This setup is shown in figure 5.16. To the left is the facial view and to the right is the overall view.

Figure 5.16: Two tablets for the physician view, one for overall and the other for the facial view.

This simulated setup for the physician provided a realistic sense of what the solution could eventually look like. It was useful to be able to see the two views of the patient simultaneously as well as being able to hear both paramedics and the patient. It seemed as though it would work in a simulation environment to use two tablets and two Skype™ connections, even though some connection problems were experienced in the beginning.

5.5.3 Results: Test 1

Using the handheld smartphone proved to be effective since it was easy for the paramedic to see what he was capturing each time. This provided a good view of the patients face for the physicians assessment on the other end. The patient did not find it disturbing to have the paramedic holding the phone so close to her face if being informed beforehand about the filming.

Since the patient was lying on the floor it was challenging to find a good place for the smooth surface mounted camera. The physician was not able to see the patient when she was lying on the floor. This problem was addressed by moving the patient to the stretcher where the overall view was better and proved to work well. The smooth surface mounted camera was mounted on the wall in front of the patient but would preferably be mounted to the side of the patient. The paramedic holding the phone required for the close up was moving around a bit in the beginning so it was hard for the physician to see the face of the patient clearly. The phone had to be held closer to the patients face.

It was difficult for the paramedics to hear the physician since the audio was provided by the speakers in the smooth surface mounted camera and therefore was a bit far away from the paramedics working on the patient. For this same reason it was also problematic for the physician to hear the paramedics. When the audio is provided by the speakers in the phone it can get confusing for the patient. The patient is listening to the paramedic doing the NIHSS but also hears the physician. The results obtained during Test 1 in the workshop are listed in Table 5.13. It shows the actors experience in terms of setup, audio and video.

Table 5.13: Results: Test 1.

	Setup	**Audio**	**Video**
Paramedic Experience	Effective to use handheld device, easy to capture face of patient. Challenging to find a good place for smooth surface mounted camera.	Speakers in smooth surface mounted camera. Difficult at times to hear the physician clearly.	Some connection problems but overall acceptable.
Patient Experience	Did not mind the recording if being informed before.	Confusing to hear both paramedic and physician.	-
Physician Experience	Handheld device was moving a lot in the beginning. Difficult to see the whole patient.	Diffucult at times to hear the patient clearly.	Overall good, effective to have two simultaneous views of patient.

5.5.4 Results: Test 2

Similar experience was observed with the handheld smartphone in this test, where it was relatively easy for the paramedic to hold the phone close to the patients face, as well as being able to see exactly the view of what was being recorded. The physician was able to see clearly the face of the patient since the handheld smartphone was held closer to the patients face than during test 1.

Since the audio was troubling during test 1 it was connected via the handheld smartphone in test 2. This resulted in a lot of improvements from test 1 where the paramedic using the handheld smartphone was able to hear the physician clearly. However the physician experienced some trouble hearing the paramedic.

The flexible arm on a suction cup proved to be more efficient than the suction cup case. It allowed for good control for positioning the camera in the best way for the whole body view. The suction cup arm with the smartphone was easy to set up and easily controllable and therefore the physician was able to see the patient when lying on the floor as well as after she was moved to the stretcher. The view of the whole body proved to be good and the physician was able to see clearly the overall view of the patient from the side. Table 5.14 shows the results from Test 2. Experience of actors involved are divided and listed in terms of setup, audio and video.

Table 5.14: Results: Test 2.

	Setup	**Audio**	**Video**
Paramedic Experience	Effective to use handheld device, easy to capture face of patient. Sufficient to position smooth surface mounted camera because of flexible arm.	Speakers in handheld device. Could hear physician clearly.	Overall acceptable.
Patient Experience	Did not mind the recording if being informed before.	Confusing to hear both paramedic and physician.	-
Physician Experience	Good view of patient face. Good overall view of the patient.	Difficult at times to hear the paramedic. However, improvement from test 1.	Overall good, effective to have two simultaneous views of the patient.

5.5.5 Results: Test 3

For test 3 the handheld smartphone was replaced by a head mounted smartphone to be used for the close up of the patient. It proved to be difficult for the paramedic to move in a way so that the view of the patients face would be acceptable. Since the paramedic is always moving around, the patient is not always in the cameras field of view. The physician had to repeatedly instruct the paramedic on how to move so that the patient was shown in the field of view. This affected the quality and duration of the NIHSS assessment conducted by the paramedic. When having to think about both assessing the patient while filming at the same time was difficult for the paramedic. In addition the smartphone was too heavy to be mounted on the head of the paramedic. It was troublesome for him to move in a normal way when being aware of the head mounted smartphone.

The patient was able to see the physician on the other end through the screen of the smartphone mounted on the paramedics head. This was very confusing for the patient. The audio had similar problems as in test 2, where paramedics and physician experienced some problems hearing each other.

As mentioned before the tripod in this system setup was replaced by the smooth surface mounted camera used in test 2. The overall view of the patient was comparable to that in test 2 and was mostly good quality the whole time. The results from Test 3 are visualized in Table 5.15 where they are listed in terms of setup, audio and video. The experience from the actors, paramedic, patient and physician are observed.

Table 5.15: Results: Test 3.

	Setup	**Audio**	**Video**
Paramedic Experience	Head mounted camera did not work. Disturbing for paramedic when physician has to tell him how to move to get a good view.	Speakers in head mounted device. Not good, since physician always had to interrupt paramedic and tell him to move to a different position.	-
Patient Experience	Confusing to be able to see the physician on the head mounted device.	Confusing to hear both paramedic and physician.	-
Physician Experience	Not good, since paramedics was always moving around. Not able to see the face of the patient. Overall view of patient was good.	Difficult at times to hear clearly what was said.	Overall good, effective to have two simultaneous views of patient.

6

Results 2: High Fidelity Prototype and Evaluation

6.1 Requirements: Iteration 2

In the second iteration, a high fidelity prototype was evaluated. It was developed based on the results/requirements in the previous chapter. The requirements for iteration 2 are listed in Table 6.1.

Table 6.1: Requirements: Iteration 2.

	Requirements
	System
Paramedic	1. Easy to carry.
	2. Easy and quick setup.
	3. Not too many components.
	4. Durability.
	5. Case to fit the components.
	6. One handheld device for close up.
	7. One paramedic attends to patient.
	8. One paramedic sets up the system.
Physician	9. Able to see face and overall view of patient.
	Video
Paramedic	1. Two visual fields.
	2. Good field of view.
Physician	3. Two simultaneous visual fields.
	4. Good field of view.
Patient	5. Not able to see the physician.
	Audio
Paramedic	1. Headset for the paramedic interacting with physician.
Physician	2. Headset for interaction with paramedic.
Patient	3. Not able to hear physician.

Since the audio seemed to be troubling at times during the workshop it was recommended that using a headset in stead of the speakers in the smartphone would be preferable. It is also recommended that only one paramedic is interacting with the physician while the other attends to the patient. It seemed to work well having two simultaneous view for the physician to look at, so that was preserved as a requirement. During the workshop the patient felt it was confusing to be able to hear the physician as well as listening to the paramedic. When the patient was able to see the physician as well, it became even more confusing. It was therefore recommended that the patient should not be able to see or hear the physician.

6.2 High fidelity prototype

Since the smooth surface mounted camera by itself might not be able to work in all situations, two other components for mounting the camera were included for the high fidelity prototype. If for any reason, the smooth surface mounted camera cannot be fixed in place, the paramedics have the option to use a tripod or a clamp instead.

The components for the high fidelity prototype are a Joby® gorillaPod arm with a suction cup, GorillaPod tripod and action clamp. Two smartphones, two tablets and two headsets are included in the system. The GorillaPod with a suction cup is used to resemble the smooth surface mounted camera. The integrated cameras and audio in the smartphones are used for AV connection between paramedics and physician. The components for the overview camera mount with the fixed smartphones are shown in Figure 6.1. Figure 6.1a shows the smartphone mounted on a tripod, Figure 6.1b shows the smartphone mounted on a suction cup with flexible arm and Figure 6.1c finally shows the smartphone mounted on the clamp with a flexible arm.

(a) Mounted on a tripod.

(b) Mounted on a suction cup with flexible arm.

(c) Mounted on a clamp with flexible arm.

Figure 6.1: The smartphone mounted on various components.

For storage, all components were enclosed in a case where the paramedics could easily access them. This case containing the components is shown in Figure 6.2.

Figure 6.2: Components for paramedics enclosed in a case.

6.3 Simulations: High fidelity prototype evaluation

6.3.1 Scenarios

Since the test cases conducted during the workshop worked well and showed how the system could be used for various situations they were reused during the simulations. When evaluating the revised prototype it was constructive to use same cases for both workshop and simulations in order to compare the results from the two. The recommended work process is however different and is described in the next section.

For scenario 1, the patient is an older woman living in a small room at a nursing home. The ambulance nurses arrive to find the woman lying on the floor unable to move on her own. Despite being unable to move, the patient can understand the questions she is being asked. She is paralyzed on the left side of the body, with noticeable face drooping on the left side. In addition she is having some speech difficulties so it's hard to understand her.

A middle aged man is the potential stroke patient in scenario 2, he is sitting on a sofa in his own living room. He is having speech difficulties where the words coming out do not make sense. A feeling of numbness in his right hand is also present.

6.3.2 Recommended work process

The recommended work process is the same in both scenarios and is listed below. The paramedics were asked to follow this work process, however they should do what they felt was most natural.

1. When arriving at the scene, the case containing the components is carried to the patient location.

2. One paramedic attends to the patient while the other starts the setup of the system.

3. A smooth surface is observed where the full view of the patient is good.

4. If a smooth surface is located → The smooth surface mounted camera is fixed to this surface and activated.

5. If no smooth surface is observed → Use the tripod or the clamp for the fixation of the camera.

6. The application is started on the handheld smartphone and a contact is made with the physician.

7. The handheld smartphone is held in front of the patients face.

8. The mNIHSS assessment can begin.

- The paramedic wearing the headset and holding the smartphone is the one interacting with the physician.

- The patient is assessed with the whole mNIHSS in each scenario in order to best simulate a real life situation.

- The paramedics should do the mNIHSS where the patient is located (e.g. the patient should not be moved to the stretcher before doing the tests).

6.3.3 Physician view

The physician view during the simulations was similar to the one during the workshop. Two tablets were used for the two views of the patient, where one tablet viewed the overall of the patient and the second tablet showed the close up of the patient. However a different application was used for the AV link between paramedics and the physician. The application used was developed by Professor Boris Magnusson and colleagues at Lund University with the aim to create a video conference system for remote consultation with physicians in the prehospital setting. It works similar to Skype™ but is specially designed to fit the prehospital environment. A clearer image during the video calls was experienced when using this application compared to using Skype™.

6.3.4 Results

In scenario 1, where an older woman was lying on the floor, both paramedics attended to the patient before turning on the camera and contacting the physician. When vital signs had been established, the system setup was performed by one paramedic. A contact was made with the physician and the NIHSS assessment was initiated. Figure 6.3 shows a still image from when scenario 1 was simulated.

Figure 6.3: Still image from the recordings while simulating scenario 1.

Scenario 2 was performed in continuation to scenario 1. In this scenario, where middle aged man was sitting on a sofa, a contact was made with the physician before the setup of the system was started. This was a more effective way of using the system since the physician was able to observe from the start as well as participate in the positioning of the camera. A still image from the simulation of scenario 2 is shown in figure 6.4.

Figure 6.4: Still image from the recordings while simulating scenario 2.

The paramedics felt it was more natural that the headset was worn by the paramedic attending to the patient and the smartphone was handheld by the other paramedic. This way the paramedic assessing the patient with the NIHSS was the one interacting with the physician. The setup was relatively easy even though it took a bit of time setting up in the beginning. Also there were some problems experienced with the handheld phone as to how to hold it in a good way and not to drop. It was observed that it was almost dropped few times during the examination.

From the physicians' perspective, the view from the overall camera was somewhat the same as from the close up camera handheld by one paramedic. The paramedic moved the camera so that it would show relevant view for each NIHSS assessment test. Although sometimes the paramedic held the device too close to the patient. This resulted in the physician not being able to fully observe and participate in the assessment. The physician was not able to contribute to the positioning of the overview camera during scenario 1. However this was changed during scenario 2 where the physician was contacted before the setup of the system. Considerable improvement was observed by this modification.

Using headsets resulted in good audio quality, both for paramedic and physician, even though it would be preferable to use wireless headsets. A drawback was experienced on the physicians' end since he was only able to communicate with one paramedic. It would have been valuable being able to talk to both paramedics. The results from simulating both scenarios is summarized in terms of setup, audio, video in regards to paramedic experience and physician experience, in Table 6.2.

Table 6.2: Results from scenario 1 & 2.

	Setup	Audio	Video
Paramedic Experience	Relatively easy. Lightweight components. Handheld device sometimes difficult to hold.	Good, but use wireless instead	Good
Physician Experience	Very similar view from overall and close up cameras. Tends to get too close with the handheld device.	Good, but would want to interact with the other paramedic as well.	Good

6.4 Postsimulation questionnaire

The answers to the postsimulation questionnaire handed to the paramedics that took part in the simulations showed that overall the system worked well. It was easy to use and provided good video quality. The technology used in the system is what most ambulance personnel are familiar with, which is beneficial. The setup components for the overview camera, suction cup with a flexible arm, tripod and clamp with a flexible arm were practical. However, the smartphone was not easy to hold and would have been dropped several times in real situation. The wire headphones also did not work well and the case containing the components was not ideal. A challenge when using the system was to work out a process in the team where the system fits in.

6.5 Final recommendations

For storage of the components, use a case that contains more than one alternative components for the overview camera so that it can be used in various situations. This case should not bee too large, easy to carry but further have a specific space for each component. Paramedics can observe the scenery surrounding the patient and establish which component to use each time for the full body view of the patient.

A contact with the physician should be established by one paramedic before attending to the patient. This allows the physician to take part in positioning the overview camera in order to optimize the full body view of the patient.

A handheld device should be used for the close up of the patients face and yet keep in mind to have some distance between the device and the face of the patient when applicable. For the handheld device there should be a shaft or a handle mounted to the device in order for the paramedic to have a better grip. This should make it even easier capturing the close up view. It should be less likely that the paramedic drops the device.

A wireless headset should be provided for both paramedics as they will then both be able to hear the physician. The physician can instruct either one of them in terms of NIHSS assessment and positioning of the cameras.

7

Discussion

The treatment options available for acute stroke, such as tPA and thrombectomy, require initiation within specific time frame. This time frame is usually very small and therefore the time to treatment has to be kept at minimum. To address this problem, different solutions have been developed in various countries, with many aiming to decrease the time to treatment. One way to decrease this time is to improve the decision support in the prehospital setting. Decreasing delays that frequently occur in the prehospital phase can in return decrease time to treatment and therefore help patient get a better outcome after treatment.

From literature study, it seems as though most previous projects focus on ambulance fixed solutions rather than a fully mobile one. A few projects have also been developing systems to use in hospitals in order to incorporate a full stroke assessment at bedside. Overall the advantages of using the solutions appear to be greater than the challenges and overall show promising results. However a lack of stable network connections seem to be a common drawback in many of the projects.

The proposed solution in this thesis offers a way to incorporate neurological assistance from the earliest stages in the prehospital stroke care. For the fact that it is completely mobile, it can be brought to the scene of the patient. Depending on cellular network connectivity the system can be used almost everywhere. The physician is included at the time when the paramedics arrive at the scene of the patient. This means that the physician is provided with a realistic sense of the patient status from beginning of evaluation.

Incorporating this solution at the scene of the patient could improve the accuracy of triage. If this solution can be brought in the ambulance as well, the physician should be able to monitor the patient all the way to the hospital. This could help improve the rate for which tPA is used a long with improving the decision making, e.g. whether a patient is eligible for mechanical thrombectomy at Sahlgrenska University hospital.

Whether this solution is applicable in both rural and urban areas is still unknown since during the ride alongs, it was noticed that in the area of Borås and Ulricehamn more work on the patient is done in the ambulance compared to the Göteborg region. In Göteborg more work is done in the patient home since the transporting times are less and decision is more often made before the transportation starts. Therefore it can be argued whether or not a mobile system such as in this thesis would be appropriate to use in more rural areas. If the system were to be used in smaller towns and more rural area, it could be beneficial to spend more time in the patient home and use the system to its fullest. The decision making could be made easier and the paramedics would not end up spending time on the road and going to a hospital further away when more nearby hospital or stroke center would have been more appropriate.

The solution is very dependant on a good network connection. This can be problematic where the connection is poor. This means that it depends on the patient location whether the solution works how it should. When working with a good network connection like when conducting the simulations the solution works well.

The simple design allows for little training needed for the use of the system since the paramedics should be familiar with the technology used. Even though some time is required for the setup of the system it can save time in the end since it is less likely that transportation errors are made with the physician being able to observe and take part in the evaluation of the patient.

Since during the simulations very similar views were observed from both cameras it can be questioned if it is necessary to include two cameras in the system. However, since the patient environment is forever changing, including more components should be important for it to work in all situations. The integrated cameras in the smartphones were chosen in the evaluation of the prototypes since they are easily available. They proved to work well in these situations, with good camera quality and good field of view.

7.1 Workshop, iteration/phase 1

The workshop provided valuable information on the usability of the low fidelity prototypes. This information was used for the revision and making of a high fidelity prototype. It was important that the workshop was conducted before and as a preparation for the final simulations since it was possible to perform a more basic test on the proposed solution.

Using a smartphone on a flexible arm with a suction cup that sticks to any smooth surface is more effective than having a smartphone in a suction cup case that sticks to smooth surface. The flexible arm allows for more control for the field of view of the smartphone camera.

For the close up view of the patient it worked well to have a smartphone handheld by one of the paramedic. The paramedic was able to see clearly on the screen of the smartphone what he was filming each time, which proved to be very beneficial.

It does not work for the paramedic to have a head mounted camera since it is too disturbing having to think about assessing the patient and filming simultaneously. In addition, it is not effective for physicians' evaluation since the paramedic is always moving and the patient is not constantly in the field of view of the head mounted camera. The physician is not able to see the close up of the patient the whole time and this affects the quality of the assessment on the physicians' end.

It is recommended that both the physician and the paramedic responsible for filming should be wearing a headset. This should avoid confusion for the patient as well as maximizing the quality of the communication between the paramedic and the physician.

7.2 Simulations, iteration/phase 2

One ambulance team (two paramedics) was included in the simulations where important feedback was established. Questionnaires were handed out and the answers analyzed. However, it would have been more valuable to have more ambulance teams in order to get more feedback on the use of the solution. When more users are involved it can provide more reliable information to be used in the revision of the prototype. Incorporating a working physician with experience in assessing stroke would have also provided very useful information.

The work process recommended during simulations involved asking the paramedics not to move the patient to the stretcher before performing the NIHSS assessment in order to observe how the system would work in various settings and locations of the patient. However, it might be more natural for them to move the patient to the stretcher and doing the NIHSS tests from there. If the patient is always moved to the stretcher, the system could be designed keeping that in mind so it would not have to fit as various settings.

In the scenarios conducted during the simulations the view from the smooth surface mounted camera was similar as to that from the handheld smartphone. The paramedic holding the smartphone moved it so it would show relevant view of the patient during each test in the NIHSS. This provided a good view for the physician to assess the patient but the use for the full body view camera in these cases might not be crucial. Nonetheless, they could be applicable in some cases, where it would be important to include them. The paramedics should then evaluate each case differently and establish what components should be relevant to use each instance.

The results from simulating scenario 1 and scenario 2 were very comparable, since the patient environment was quite similar. This was a limitation and it would have been beneficial to test more environment cases.

Using commercially available components for the system allowed for it to be very easy to use since most people are familiar with technology such as smartphones. There was nothing that came as a surprise when using the system and it was easy to learn for the paramedics during the simulations. Although before the start of using the system, all persons involved should get relevant training.

Since today the only consultation with a physician is through telephone the system should provide more reliable decision making when the physician is able to see the status of the patient and take part in performing the NIHSS.

7.3 Future Work

If continued with the design solution proposed in this thesis, the high fidelity prototype has to be revised according to results from simulations and recommendation in order to make it more effective. The whole interactive design process, described in chapter 4, should then be conducted again. The design process should be iteratively repeated until the solution meets all requirements. When all requirements are met, clinical trials can be conducted from the final prototype.

Ideally more people are involved in the design of the system as well as simulations. More ambulance teams using the system during the simulations would provide more feedback on the use of the system. Incorporating a working physician with experience in assessing stroke would also provide very useful information. More variety of environment and patient situations can be simulated in order to observe how the system fits in more situations.

Procedures would have to be developed for the use of this system. These procedures would then be ran in a simulation environment. This is important so that the system is used in the way it is intended. Other aspects that could affect the performance of the system should be tested as well, e.g. if the patient wears glasses. The reflection in the glasses could make it difficult for the physician to assess the patients' eye movement.

The work of this thesis did not focus on the quality of the network connection and it was assumed during the workshop and simulations that the connection is always good. This would have to be tested with more variations in the patient environment and using mobile connection. A consistent factor in previous projects involving real-time bidirectional communication in from ambulances is the poor network connection. With constant evolution in wireless technology and higher bandwidth this problem however should not persist.

Since the aim of the ViPHS solution is to have it's 3 parts working together the final ViPHS solution should be able to work seamlessly with ViPHS ambulance and ViPHS BOST. Integrating the NIHSS in the system where the physician is able to observe on the screen in real time what scores the paramedic is giving the patient could be beneficial.

8
Conclusion

Since acute stroke is a very time sensitive and deadly disease, the need for accurate diagnosis and treatment is very high. In this thesis, a design of a mobile ViPHS solution has been proposed to be used at the scene of a potential stroke patient. By conducting workshop and simulation involving intended users, the solution has been evaluated. A final recommendation of an effective system has been suggested as well. Based on feedback from intended users during the iterative design process, the solution was implemented to be used in ambulance for decision support in acute stroke cases.

The recommended solution should work well in the prehospital environment where there is a potential stroke. It should be easy to use for both ambulance personnel as well as physicians since it contains components people are very familiar with in their everyday life. The system seems to be effective, however it is dependant on a good network connection. This can be problematic if the patient is located at a scene were there is a bad connection. Since the cellular network is always improving and usually the patients are located where there is an acceptable connection, this should not be a major challenge.

There are many evidence supporting that the use of real-time AV communications in the prehospital setting in acute stroke is feasible. Although most projects have been evaluating ambulance-based solutions, the results in this thesis are promising when it comes to incorporating this AV link at the scene as well.

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A

Appendix 1

A.1 Postinterviews from simulations

1. How did you think the system worked overall ?
2. What would you change for it to work better ?
3. What were the three things you liked the most ?
4. What were the three things you liked the least ?
5. Was the solution easy to use ?
6. Was it easy to carry ?
7. Was the setup of the solutions easy ?
8. What were the advantages to this solution compared to current practice ?
9. What were the challenges experienced when using the system ?
10. Is there anything you would like to add regarding the use of this system ?