Development and Evaluation of Assistive Technology to improve Chronic Care

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***Abstract*— Due to the demographic evolution there is an increasingly pressing question for additional support in the healthcare. Technology can relieve this pressure by providing tools for automated monitoring and objective assessment of a person's health condition towards a long-term and ambulant follow-up. In this research project, which was part of a PhD, three practical cases were treated. The first case described how demented elderly in the final stage of their life can be observed to determine their discomfort level. In the second case adults were asked to wear a simple knee sensor and physical activities were determined automatically. In the third case, paediatric patients suffering from epilepsy were monitored during the night and abnormal activities were indicated. This resulted in three different monitoring setups but they all have in common that they consist of sensors which can easily be placed in the room of the patient and/or attached to the patient. Monitoring systems were designed to be as comfortable as possible for the monitored person/patient in order to make long-term observation feasible. Also off-the-shelf technology was used to reduce cost and time-to-market. And finally, all these systems were implemented and validated in practice in order to contribute to a faster integration of technology in the healthcare sector.**

I. Introduction

Today we notice a rising life expectancy in the Western countries. Together with an aging population we see an increasing prevalence of age-related diseases such as dementia. This results already in a lack of places in living and care centres. We also notice that the Western population has an unhealthy eating and exercising habit. This can be seen in a significant increasing prevalence of lifestyle diseases such as obesity and cardiovascular diseases. This means that not only the older persons but also the active population is confronted with health problems. Besides the growing number of persons reliant on care, we see that there are fewer (young) professional caregivers available. This means that the demographic evolution in the Western countries has made that the current healthcare systems are under enormous pressure.

In addition to the demographic evolution, we also experienced a technological (r)evolution. In our daily lives, we are becoming more familiar with (mobile) technology and we are approaching a turning point in the healthcare sector where technology will increasingly find its way into healthcare applications. Therefore, this research project, which was part of a PhD, is looking for opportunities to use technology in the healthcare in order to support in chronic care. Because today there is already a need for technology to support healthcare tasks, we are looking for technology that is immediately usable in real-life conditions.

II. Material and Methods

This research project focuses on developing and evaluating assistive technology to improve chronic care. Therefore a methodology is presented and used to develop and evaluate monitoring systems. As there is a need for more and immediately employable technological support in the healthcare following items got special attention during this work.

It is obvious that the systems should improve the patient's Quality of Life and assist caregivers (professional or informal) in performing their job. Therefore the combination of hardware and software should work in a real environment and with a minimal impact on the user and his environment. Next, as these systems work in real-life conditions the data processing should be performed quickly and accurately in order to meet the real-time constraints. Hence, we look for opportunities to execute the (sometimes computationally intensive) algorithms in real-time. Finally, the added value of these systems is the clinical information and results that can be extracted in a simple and useful way from the measurements. Therefore, we also evaluate the usability of these applications in a real-life environment.

In this work we will develop and evaluate assistive technology on three different target groups which are from old to young: demented elderly persons, adults in the prevention and rehabilitation of lifestyle diseases, and children with epilepsy. For each of these target groups a specific application will be developed and is briefly described in the next sections.

A. Discomfort in demented elderly

For demented elderly persons we investigate the ability to automatically detect pain or discomfort based on their facial expressions [1,2]. A camera seems to be an appropriate instrument for a continuous observation of the patient's facial expressions. Therefore a video acquisition system (ViAS) is developed as shown in Figure 1 [1]. In order to be able to label the video-images recorded by the ViAS we developed a digital discomfort label tool (DDLT) [2]. Initially, the DDLT was not intended to be used as standalone application but it became clear that the DDLT had more potential than only an easy tool for labelling images. The DDLT allows performing discomfort or pain assessment in a digitalized way. Timing information is automatically interpreted and final scores were calculated.

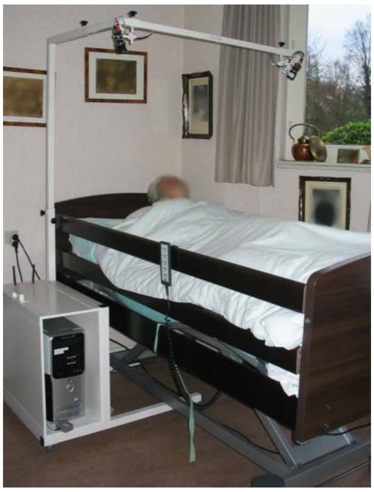

Figure 1: The flexible and mobile video acquisition system.

B. Ambulatory activity monitoring of adults and elderly persons

For adults we will try to predict their physical activities based on knee angle measurements [3]. Therefore an instrumented knee brace is developed as shown in Figure 2. This knee brace includes an inductive sensor and is able to measure the performed knee flexion/extension (F/E) in ambulatory circumstances. To reduce the processing power and increase the applicability in real-life we selected to use the uncalibrated sensor data. This means that only relative knee F/E angles were measured. We developed a classification algorithm which can detect strides during normal walking, fast locomotion (such as jogging, running, and sprinting), stairs descend, and stairs ascend in real-life and ambulatory circumstances. This activity classification algorithm is based on peak detection in the knee F/E angle signal measured and a classification tree. To evaluate the usability in real-life each of the subjects is asked to put on the knee brace by themselves. Next, a real-life but predefined track is traversed. The track consist of indoor and outdoor paths including obstacles such as stairs, slopes, and different surfaces like paved road, grass, and gravel. At the end of the track the subjects are asked to increase their locomotion in three different levels, namely, jogging, running and sprinting. The recorded knee angles are labelled by video observation during the track traverse.

Figure 2: Knee brace designed by TNO Medical Devices; placement of accelerometers, coil, data logger, microcontroller and electronics to feed the LC-circuit.

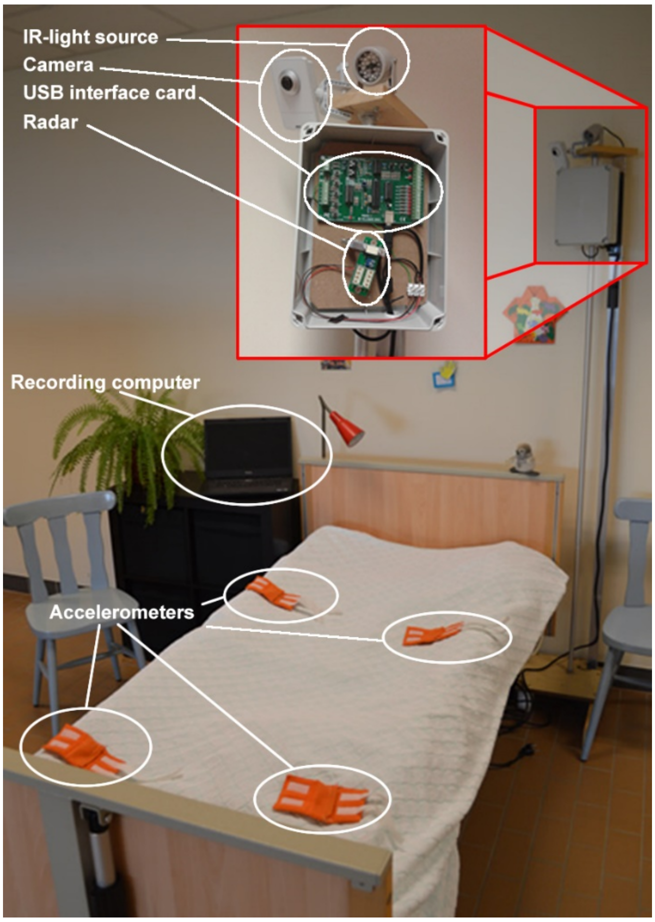

Figure 3: Movement Acquisition System placed in a home-like environment: camera, radar, IR-light source and USB interface board are attached to the tripod, accelerometers are worn in elastic bracelets around wrists and ankles, and a laptop receives and stores all movement data recorded by all of the sensors.

C. Screening of abnormal nocturnal movements in paediatric patients suffering from epilepsy

For children with epilepsy we search for the ability to recognize overnight abnormal movement. A movement acquisition system (Figure 3) and a screening tool is developed which can be installed at home in the sleeping room of the child [4]. The movement acquisition system registers all nocturnal movements and stores them in a dataset containing movement information registered by a camera, four accelerometer and a movement detector based on the radar principle. Abnormal nocturnal movements are: movements containing heavy movement (with high acceleration), movements with a long duration, or a combination of both. Therefore we selected duration and size of the movement as two features to classify the movement. To distinguish between normal and abnormal movement we selected an unsupervised automatic classification model based on novelty detection as reported by Cuppens et al. [5]. This model uses a probability density estimation based on the Parzen window method [6]. A threshold on the probability density function (PDF) separates normal from abnormal movement. We choose to set the default threshold on a probability of 95%. This means that the 5% movements with the lowest probability to be normal are classified as abnormal movements. Because we are discussing a screening tool, this threshold is not fixed. The caregiver or physician may, at their discretion, adjust the threshold.

III. RESULTS

A. Discomfort in demented elderly

The video acquisition system (ViAS) was developed and tested on six patients [1]. This resulted in a unique dataset which consisted of more than 80 different recorded and labelled sessions. This unique dataset was the starting point for developing a discomfort recognition algorithm. Such algorithm translates the patient's facial expression into a discomfort score. However, only a few discomfort features (frowning and opening/closing mouth) were implemented into a classifier.

The digital discomfort label tool (DDLT) is tested in practice and so far 98 observation sessions are conducted [2]. The system is able to record meta- and assessment data and store it wirelessly into a central database. Timing information is automatically interpreted and final scores are calculated automatically. Users reported the automatic (sub) score calculation as one of the major benefits for them. No manual rules or calculations have to be applied to get the final scores, and this is experienced as very convenient. Users are pleasantly surprised that both pain and discomfort assessment scores are available while it takes the same effort as one classic assessment instrument. Also the direct feedback of the scores is experienced as useful as the caregivers get much faster information of the patient's state.

B. Ambulatory activity monitoring of adults and elderly persons

This study included ten young and healthy subjects (6 males and 4 females, mean age 27.7 years, SD 3.1 years). A good distinction can be made between the performed activities. An accuracy of 95.9% is reached for normal walking, 90.3% for stair ascend, 78.3% for stair decent, and 82.2% for fast locomotion [3]. We can conclude that it is possible to predict the performed activities in an ambulatory setting with an acceptable performance. Next, we noticed that the position of the brace slightly influenced the accuracy of the classification but still acceptable performances were obtained.

C. Screening of abnormal nocturnal movements in paediatric patients suffering from epilepsy

A total of 56 nights involving four paediatric patients were recorded. The relevant events indicated by the screening tool were visually inspected by a specialist and compared with the epileptic seizures reported by a clinical caregiver (91 seizures in total) [4]. This caregiver observed the patients on a semi-continuous basis during the night. The set of relevant (abnormal) events proposed by the screening tool, contained 51.6% of the epileptic seizures reported by the caregiver. Additionally, 72 extra seizures were identified using the screening tool, so not reported by the clinical caregiver. Including these extra seizures, the screening tool identifies most of the epileptic seizures with a mean sensitivity of 67.3%. Moreover, a night of 12h can be reduced into a screening time of 30 to 45 minutes.

IV. DISCUSSION AND CONCLUSION

In this research project a methodology is presented to develop and evaluate assistive technology to improve chronic care. It was shown that experimental set ups and mathematical models could be developed to design and evaluate monitoring systems to monitor a person's health condition in real-life. This resulted in three different monitoring setups but they all have in common that they consist of sensors which can easily be placed in the room of the patient and/or attached to the patient. Monitoring systems were designed to be as comfortable as possible for the monitored person/patient in order to make long-term observation feasible. And finally, all these systems were implemented and validated in practice.

Beside the technological challenges there are some other obstacles to overcome in order to fully integrate technology in chronic care. There are several reasons why telemonitoring systems are not included as common practice in providing care.

First, there is a lot of effort put in providing scientific evidence on the positive effects of telehealth but this research is often questioned. Therefore more randomised clinical trials and longitudinal studies are required to prove the effectiveness and economic impact of telemonitoring [7].

Next, an adaptation of the current healthcare will be required to have telemonitoring systems to become a procedure in the treatment of chronic diseases. Therefore awareness and knowledge of the stakeholders in healthcare must be raised so they think more positively and correctly about the appropriate use and value of telemonitoring [8].

- The first stakeholder, and the owner of the process, is the ***patient*** itself. It is obvious that the patient should benefit from being telemonitored. A patient's QoL can only be maintained or increased by telemonitoring when the patient is comfortable with the technology and with the idea of being observed.
- A next stakeholder is the ***caregiver*** (formal and informal). Prevention and treatment can benefit from telemonitoring solutions but it may not be seen as some kind of *dehumanization* of healthcare. The technological applications should allow caregivers having more contact with their patients and focus more on the patient's needs, supported by technology.
- The ***government*** is also a stakeholder in healthcare. Today politicians and other policymakers have significantly different, and often inaccurate, understanding of what eHealth, mHelath and telemonitoring is about [8]. Therefore politicians should get a clear view on the (economic) benefits of implementing telemonitoring (or telehealth) in the current healthcare systems.
- Finally, stakeholders such as ***healthcare providers***, ***social*** and ***economic organisations*** and the ***society*** are also involved. The society should especially benefit from these technological solutions on social and economic level. Telemonitoring should allow persons aging in place or rehabilitate in their trusted home environment. Furthermore telemonitoring should enable affordable and high quality healthcare today and in the future.

This doctoral research described a methodology that can be used in the development of technological systems in the healthcare sector. It is shown that off-the-shelf technology can be used to improve the quality of life of the patient, and support the caregiver (from professional caregiver to informal caregiver) in performing care. Hopefully this will contribute to a faster integration of technology in the healthcare sector.

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