Passive vs. Active Measurement: the Role of Smart Sensors

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***Abstract*—The growing availability of ubiquitous computing capabilities can enhance life quality. New smart sensor devices are constantly appearing in various markets, including the health industry. The functions provided by such modern sensor devices enable system developers to create healthcare systems that were unimaginable earlier. More and more health monitoring devices provide functions that can ease the life of the elderly and ill people. However, this rich set of smart devices pose challenges to system developers and health industry specialists as well. In order to find optimal healthcare system solutions, lots of tests and trials have to be done. In our paper we present three different telemedicine systems of increasing complexity and some analysis results based on real-life clinical trials utilizing the described systems. We examine the willingness of users to use the systems and draw interesting conclusions from those examinations.**

Keywords-telemedicine; healthcare; smart sensors; measurement

I. INTRODUCTION

The western society is aging and there is an increasing pressure on the primary care system. Significant efforts are put on IT developments of the primary care in order to be able to cope with this increasing demand. The implementation of the interoperable Electronic Health Record (EHR) systems is in the focal point of these developments. The EHR systems themselves could only partially fulfill the *"right information,* at the *right time* for the *right person* in the *right format"* criteria. The available and integrated information sources are of critical importance. One such information source is telemedicine which could provide wide variety of raw and processed information with very fine granularity.

A key motivator behind these telemedicine systems is to overcome difficulties of health care services in a convenient and professional way. Systems of this type offer solutions for collecting various physiological data sets directly from the homes of the patients and they do this without the need of medical supervision. Additionally, by utilizing various data mining and signal processing techniques, these systems can process and aggregate the collected data and transfer and visualize the right information, at the right place, at the right time for medical experts or even for relatives.

In the recent years we have developed three different telemonitoring systems in two large R&D projects. The key differences between these projects were the budget and time constraints, which also affected the requirements and functionalities expected from each system. Being constrained by these factors different system architectures were developed. Each system was evaluated in a Living Lab (LL) experiment with the involvement of real patients and doctors. In this paper, we examine each system and summarize the observations relying on the LL tests.

The rest of this paper is structured as follows: Section II discusses related work and the novelty presented in this article. Section III outlines the setup and the capabilities of the different telemedical solutions applied. Section IV discusses the methodology applied during the clinical trials and Section V analyses the results.

II. RELATED WORK AND NOVELTY OF THE ARTICLE

The literature describing the results of the different telemedicine related projects is huge. The usability of different telemedical applications is studied in several articles and dissertations [1-4]. Despite of the massive literature we have not found studies and articles about comparing different telemedical approaches. Which is better: a mobile phone based telemedical system, a dedicated PC based or a dedicated home-hub based system? Is it worth putting efforts in implementing proactive systems? What is the cost of the complex measurement procedures? Do the current touch screen-based mobile phones serve as viable platforms for elderly people?

In this paper we show our findings about the aforementioned questions based on the evidences gathered from real clinical trials. The results are unique as we were able to conduct long-running real-life clinical trials using different telemedical solutions developed by our team.

III. SOLUTIONS COMPARED

In this section, three telemedicine systems are presented. All of them were applied in clinical trials and were used to collect physiological data. These data serve as a basis for the evaluation addressed later in this paper. En each case several sensor devices were integrated into the systems and a so-called *Hub* was also placed in the homes of the patients. The Hub is responsible for managing sensors, collecting and transmitting measured data to a central server. A set of web-based user interfaces are also provided by the server to make measured data available for doctors and nurses and even for relatives.

Although all telemedicine systems follow this common architecture, some variance can be observed between them. As a major difference the types of sensors that were integrated to each system were varying from system to system. In addition, a diverse set of physiological data were targeted to collect. Furthermore, various hardware devices were applied for the role of Hubs. Based on each hardware solution, the capabilities and functionalities offered by the Hubs were different in each system. The characteristics of a Hub defined whether a thin or thick client solution was built upon the device. Moreover, these kinds of distinctions affected the functionalities offered by the central server (for end-users and for Hubs), as well.

A. *Medistance*

In the case of the Medistance system [6], the integrated Hub was designed and developed for the minimal requirements (of a telemedicine system) on purpose. It is a dedicated device with the ability to communicate with sensors, collect measured data and transmit them to the central repository. In Figure 1, an overview of the Medistance system architecture can be seen.

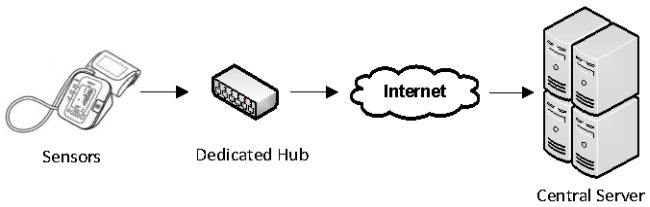

Figure 1. Architecture of the Medistance System

The only expectation this system needs to meet is to collect physiological data and to present them in charts and diagrams for doctors in web browsers. The main goal of the system is to provide a solution that enables the patients to seamlessly share their measurements with doctors. Accordingly, it does not deal with the enforcement of prescribed measurement scheduling, supervision and warnings.

B. *Telenor EDH*

In the Telenor EDH system, the set of integrated sensors is expanded. A smart phone is used to provide the Hub functionality, which brings mobility into the system. The client application running on the mobile phone enables the development of adequate user interfaces in order to help the users with the usage of Hub and sensor devices (Figure 2).

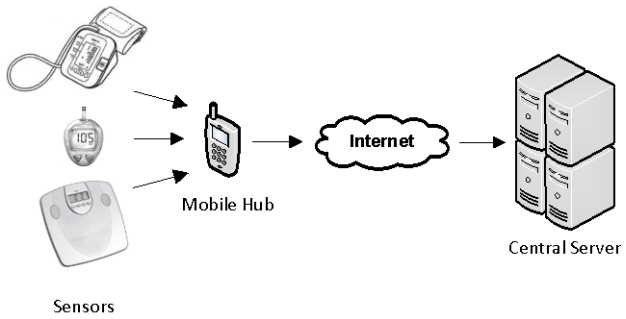

Figure 2. Architecture of Telenor EDH System

As an addition to the base functionalities of the Hub (i.e. sensor management and data transmission), the user interfaces support the correct measurements by providing user guides and illustrated flows. The measurement scheduling and related warning messages are driven by events downloaded and periodically synchronized from the central server. Accordingly, on the server side doctors have the facilities for setting up and configuring the scheduling and regularity of measurements even during runtime.

C. *ProSeniis*

The ProSeniis System [7] is the most complex in terms of functionalities. Unlike the Hubs applied in the Medistance and the Telenor EDH systems, a thick client was built upon a device that is equivalent to a personal computer. The hardware capabilities offered by the Hub were used for developing a rich client application with widely configurable software. In Figure 3, the architecture of the system can be seen.

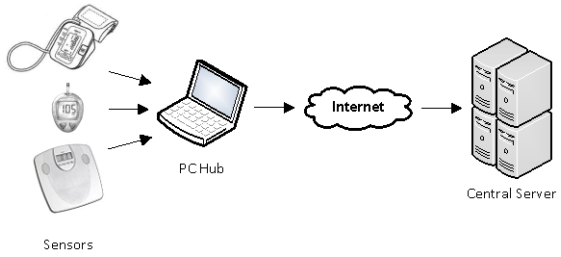

Figure 3. Architecture of Proseniis System

The thick client application includes measurement scheduling and signal processing algorithms that enables the evaluation of physiological data on demand. With the help of this assessment methodology the Hub can provide feedback to patients about their health status during run-time. Additionally, it can warn them about missed measurements or about the need of measurement repetitions. Moreover, doctors could control not only the scheduling, but the signal processors as well (by defining parameters and configuration for them). The system automatically synchronizes the modifications with the Hubs. Furthermore, the central server provides end-user programming functions in the form of an editor interface. This facility is useful for building custom data flows by combining available measurement specifications and signal processors. In practice, by using this functionality, doctors can fully define the business logic of the Hubs during run-time.

IV. METHODOLOGY

The results of the research projects were tested in clinical trials organized by the local living lab (LL) [5]. In the projects the LL is responsible for the communication between the patients and the workgroups by forming a common infrastructure for information collection. The aim was to provide information to the workgroups through an iterative workflow where there is usually no direct communication between the patients and the development teams. The long-term and mid-term projects were running simultaneously, both at the hospitals of the University of Szeged. The time frame

and the tools used in the experiments were different for the projects below.

A. Telenor EDH

The Telenor EDH project was an industrial project sponsored by Telenor Hungary, Inc. and NOKIA. The goal of this project was to develop a mobile platform for e-Health applications, so the home hub can be a mobile phone (smart phone) instead of a PC, or other dedicated device in the patient's home.

1) Subjects and Duration

During the project time frame three groups of patients were monitored with different type of sensors. The members of first group of patients were suffering from diabetes mellitus, the second group consisted of patients with different heart conditions, and the patients of the last group were suffering from hypertension. Ten patients were selected for each group.

The clinical trial has lasted for three months, divided to two phases. Tier 1 had duration of one month; Tier 2 has lasted for two months.

2) Materials used

For the different patient groups different devices were allocated:

- *Patients suffering from diabetes*: Nokia (low-end) smartphone, Dcont blood glucose meter, A&D UC321-PBT weight scale.
- *Patients with different heart conditions*: Motorola (high-end) smartphone, TensioDay TD3 blood-pressure monitor, A&D UC321-PBT weight scale.
- *Patients suffering from hypertension*: Omron blood-pressure monitor, Medistance data transfer hub.

3) Protocol

The clinical investigation plan has determined the minimum amount measurements to be taken by the participants of the trial. These minimum requirements differ in the given patients groups:

- *Patients suffering from diabetes*: one daily blood glucose measurement was expected, except in the first 2 days, when six measurements were required (before and after breakfast, before and after lunch, before and after dinner). Weight measurement was prescribed every morning, as well.
- *Patients with heart conditions*: one blood-pressure measurement and one weight measurement was expected every morning in the duration of the trial.
- *Patients suffering from hypertension*: in Tier 1 patients were expected to measure their blood-pressures twice a day, two times every occasion (2x2). In Tier 2 patients had to measure their blood-pressures twice a week, two times on every occasion.

In Tier 1, in addition to the system logs, every patient had to log their measured values in the logbook provided by the project.

B. ProSeniis

The ProSeniis project has aimed to develop a telemonitoring system to receive valuable information of the patients' everyday activity and their current health status. The target groups of the patients were the ones suffering from neurological diseases, such as dementia, Parkinson's disease, and also stroke. The project is funded by the National Office for Research and Technology in Hungary and concentrates on the development of a ready-to-use remote home care solution including the hardware, the software and the medical protocols.

1) Subjects and Duration

Three groups of patients were involved in the project suffering from different illnesses. The members of the first group of patients are suffering from mild/moderate dementia, the second group consists of stroke survivors, and the patients of the last group are suffering from Parkinson's disease. For each group, three patients were selected. Also there is a control person, who is not suffering from any neurological diseases. In total there were 41 patients involved in the project.

The project's trials had three phases, Tier 1 lasted for two months, Tier 2 for another 2 months and Tier 3 lasted for 8 months.

2) Materials used

The following devices are used in the project:

- Intel Health Guide as home hub
- A&D UA767-PBT blood-pressure monitor
- A&D UC321-PBT weight scale
- CardioBlue ECG holter
- Bayer Breeze 2 blood glucose meter
- Actigraph
- QuietCare motion sensors

3) Protocol

The protocol of the clinical trial expected daily measurements from each patient from all groups:

- *Patients suffering from dementia*: blood-pressure measurement, constant use of Actigraph, constant use of QuietCare.
- *Stroke survivor patients*: blood-pressure measurement, ECG measurement, constant use of Actigraph, constant use of QuietCare.
- *Patients suffering from Parkinson's disease*: blood-pressure measurement, constant use of Actigraph, constant use of QuietCare.
- *Control person*: blood-pressure measurement, ECG measurement, weight measurement, blood glucose measurement, constant use of Actigraph, constant use of QuietCare.

V. RESULTS

During the experiments the aforementioned systems gathered a total of 16,000 individual measurements. The analysis of these measurements leads to some interesting results. Since the systems under test concern different types of patients and collect different sets of usage data, we had to find a metric that is common in all systems. *Willingness* turned out to be such a good metric. In our terminology willingness means the ratio of the number of the planned measurements and the actual number of the measurements carried out by the patients. For example, willingness (for a specific measurement type at a specific patient) of value 110% means that the patient did the measurement process 10% more than it was prescribed. (Note that willingness is not the same metric as *popularity*.) Table I contains the willingness factor of each system.

Note, that only blood-pressure, blood-sugar and weight measurements were considered during the analysis, since these are the common measurement types that are covered more or less by all the systems.

System	Measurement	Min.	Avg.
Medistance	Blood-pressure	137%	198%
EDH Symbian	Blood-sugar	24%	114%
	Body weight	42%	81%
EDH Android	Blood-pressure	95%	176%
	Body weight	91%	134%
Proseniis	Blood-pressure	30%	159%
	Body weight	12%	127%

TABLE I. WILLINGNESS FACTORS OF EACH SYSTEM (WITH MINIMUM AND AVERAGE VALUES)

As it can be seen from the table the willingness values are very heterogeneous and some of them were surprising even for us. After some investigation it turned out that several non-technical factors affect these values along with the technical ones. The most relevant metrics are:

A. The type of measurement and the types of illnesses they are related to

As a major non-technical factor, the type of illness the patients suffer from determines the willingness. For example, patients suffering from heart problems are more willing to do blood-pressure measurements on a daily basis than they are to do weight measurements at the same rate. This statement is clearly supported by the EDH Android and the Proseniis measurements. Additionally, the Medistance-related trial has shown that in the case of heart problems, even willingness of around 200% can appear on average.

B. Whether the measurement is directly visible at the Hub's user interface

As an extreme case, one can see that the body weight measurement on the EDH Symbian system has the lowest willingness value out from all the systems. Considering that this type of measurement offered a definitely easy process, this was a surprising result. After some further analysis we discovered that this was the only measurement type that does not have a direct function button on the Hub's dashboard interface. The weight sensor initiated the measurement process and the users were able to accept the data upload but no other function was to be interacted with for a successful result. This fact can make the users doubtful about the availability of the weight measurement functions and can let them forget even about the existence of that type of measurement as well.

C. The complexity of the measurement process

As a simple metric for measuring process complexity we used the number of steps that were required in order to complete a measurement process. Considering this metric the measurements can be classified as follows. The measurement requiring the least number of steps is the EDH Symbian weight measurement with only 2 steps involved. The measurement requiring the most number of steps is EDH Symbian blood-glucose measurement that leads through a relatively long 8-step process. All the other measurements consisted of 4-5 steps. Excluding the EDH Symbian weight measurement (see previous subsection) we can state that measurements of higher complexity enjoy smaller willingness levels. Additionally, the LL got negative feedbacks from users exercising the longer procedures due to complexity, so it can also be determined that the popularity is also decreased in such complex cases.

D. The device role that is used to initiate the measurements

At the start of the data analysis it was anticipated that the measurements initiated directly from sensor devices had higher willingness levels. (We classify these measurements *passive* as opposed to *active* measurements where the Hub initiates the measurement process.) A sound reasoning behind this would be that in these types of measurements the user interaction steps follow the way the information naturally flows (i.e. the sensor-hub-center route) and thus constitute a process that is easier to understand. However, the willingness results do not show such clear trends in this field, since the measurements with the highest and lowest willingness levels all utilize the passive method.

E. Whether alerts help the users to remember the required measurements.

Generally, the presence of user alerting features can obviously lead to higher willingness levels. Simply put, with the help of a dependable alerting the users do not forget to do the measurements prescribed for them. However, the analysis has shown that in the case of the selected set of patients, the availability of such a mechanism did not play a role, at least with regards to willingness. The ProSeniis system containing a proper alerting system performed on the average. However, it is important to note that the selected patients were well aware of their illnesses. This way, most of them could easily remember to do measurements as part of their daily routines (similarly to their pre-trial lives).

F. Conclusion of analysis results

Excluding one measurement type, the willingness values were above 100%. A key reason of such a high willingness level lies in the patient-sample selection process (i.e. the selected people were the ones willing to participate in the

trials). On the whole, measurements related to blood-pressure were had the highest willingness values. The measurement (and thus the illness) type has proven to be a major factor with regards to willingness. Additionally, the applied forms of user interaction determined the willingness values of the various measurements. When the possibility of the interaction was not clearly visible for the patient, the willingness level was low. On the other hand, when the interaction involved a relatively complex process, the willingness values lowered.

Surprisingly two factors that were anticipated as major ones affecting the willingness were not significant. One of them, the initiator device role can be considered unimportant when sampled from the selected patient set. The effects of the similarities between the natural data traversal path and the order of steps of a measurement process need further investigations. On the other hand, the vanishing effect of the presence of an alerting system is reasonable considering the selected patient sample. However, this is also an area where further (even social and psychological) tests should be run.

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