A Mobile System for Treatment of Depression

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Abstract. This paper presents a mobile treatment system developed as part of the FP7 ICT4Depression project. The project targets the efficient treatment of minor and major depression. To this end, treatments that have traditionally been administered via relatively simple web-based interfaces, have been translated for use on a smart phone. The delivery of the treatments is supported by an evidence-based approach to patient progression and treatment adherence monitoring. The mobile system consists of a graphical user interface, biomedical sensors to measure the patient's affective state, a medication adherence system, an activity monitor and a server based reasoning system to combine the various sensor data streams and obtain abstracted information relating to patient status and progression, thereby allowing for appropriate feedback and advice for both patient and medical staff.

1 Introduction

In recent years depression has received significant attention as a disorder with a far-fetching impact on individuals and society as a whole. Studies show that in 2003 the occurrence of major depressive disorder ranged from 3% (in Japan) to 16.9% in the US with most countries showing a prevalence of 8% to 12% [1]. The burden of depression is on the rise and by the year 2030, depression is expected to have the highest disease burden in high income countries. There thus is a real need for effective treatment of depression within the cost constraints of health services.

Treatments have already been adapted for online use to allow for more cost effective treatment and such systems have been shown to be of value [2]. The aim of the ICT4Depression project is to take this approach a step further and provide various treatment modules not only on a personal computer, but also on a mobile phone. The advantages of this approach are that users can be provided with continuous treatment, are free to decide when to interact with the system, can be monitored throughout the day and can effectively include and integrate day-to-day duties and habits in their customized treatment. Of particular interest in this regard is the recent insight that the

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inclusion of user specific data in the form of ecological momentary assessments (EMA) is an important goal for future mobile treatment systems [3].

This paper describes the architecture and various sub systems comprising the mobile system used for treatment of depression in the ICT4Depression project.

The mobile system architecture is shown in Fig. 1. For reference, the other components of the ICT4Depression system are shown in the dashed box. The user interacts with the mobile system through a Samsung Galaxy S smart phone. A dedicated graphical user interface presents the user with information on the treatment, allows the user to execute those parts of the treatment that need user input, incorporates a calendar and acts as a sensor data aggregator for the biomedical sensors. These consist of a hand worn device for the measurement of electro-dermal activity (EDA) and blood volume pulse. Whereas the latter yields information on the heart rate, the EDA is an indicator for a wide range of emotional responses, thus providing the system an additional insight in the user's mental state. The second biomedical sensor is a chest strap that can be worn under normal clothing. The chest strap provides heart rate, respiration rate and an accelerometer that can be used to infer the trunk orientation of the user. The latter data is combined with motion data measured directly on the smart phone to obtain accurate information on patient physical activities.

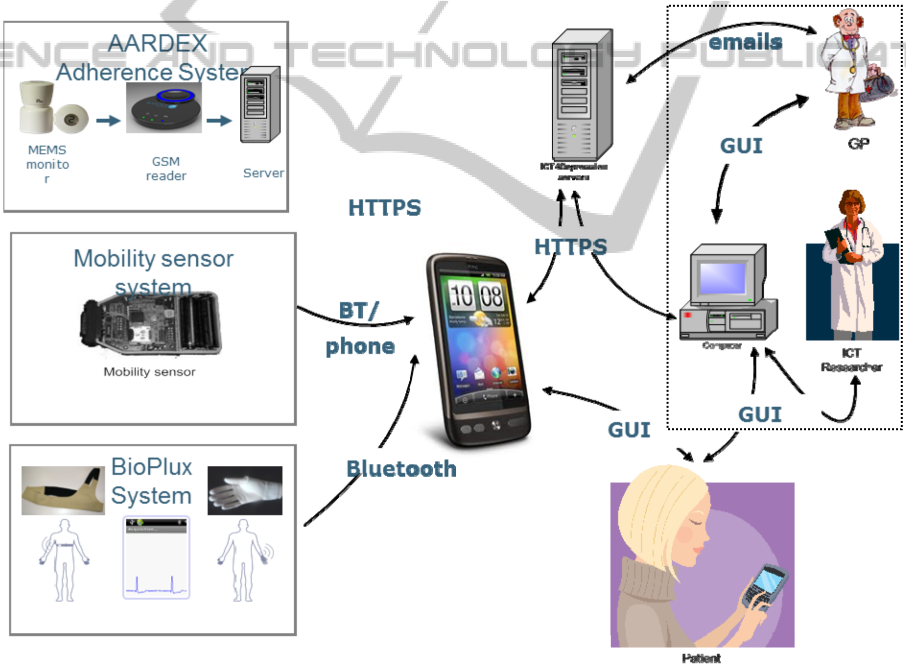

Fig. 1. Overview of the ICT4Depression System.

Treatment of depression is normally supported by medication and the adherence to the prescribed medication regimen is often low. For this reason, a smart pill box is used to monitor medication intake. All sensor data is sent to a dedicated server where analysis of the data takes place in a reasoning system that incorporates models of the user and their progression. This system can assess whether the treatment is successful and provides the medical staff and user with advice for further treatment. The rest of this paper will discuss the system in more detail. In Section 2 the graphical user interface will be discussed after which the various sensors will be introduced in Section 3. Sections 4 and 5 introduce the reasoning system and server infrastructure respectively and conclusions are presented in Section 6.

2 Graphical User Interface

The patient has access to the ICT4Depression system through a smart phone interface. The interface is developed using html and java scripts, which are stored on the phone such that the application can also be used if there is no connectivity. For conformity in the presentation of the treatment modules to the patient *and* for ease of treatment module development, a structure of available module screens was developed.

The first category of screens is the *navigation screen*, which is depicted in Fig. 2. Its primary function is to facilitate navigation through and around the application. Through the use of these screens, patients can access further navigation controls, read module content or undertake module centric activities.

The *module content screens*, as depicted in Fig. 3, allow the patient to read about the treatments available in the ICT4Depression application.

The third category of screen is the *patient input screen*, an example of which is shown in Fig. 4. This page type requires interaction between the patient and the module to assist in the patient's treatment.

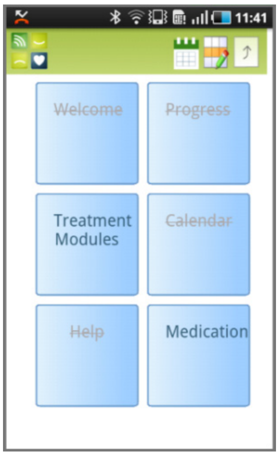

Fig. 2. Navigation Screen.

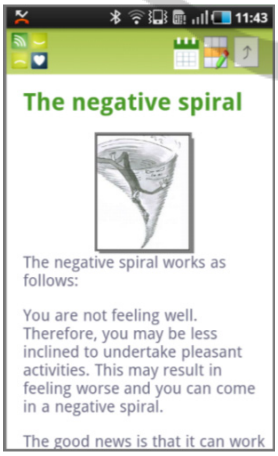

Fig. 3. Module Content Screen.

Fig. 4. Patient input screen.

A logo is present on every screen which acts as a link that will allow the patient to immediately link back to their home page. Because the patient should be able to return to the source screen, a button with sitemap functionality is integrated into the application. On clicking this button, the patient is able to navigate back to a previous screen. An additional button for inclusion in the ICT4Depression application is the calendar quick link. This button enables the patient to view, edit and add module activities to their personalised calendar as necessary. Finally an activities quick link was included to enable patients to access their exercises and activities from anywhere within the application.

3 Sensor Systems

One of the innovative aspects of this system is the use of sensors in various ways to elicit information on the user’s well-being and treatment progression. To this end, biomedical sensors are used to measure heart rate, breathing rate and electro-dermal activity, the phone itself is used to measure user physical activity and a medication adherence system monitors the user’s medication intake.

3.1 Biosignal Acquisition System

Two wearable sensor form factors can be used by the patient enabling the measurement of multiple biosignals. The devices are controlled by the mobile phone through an Application Programming Interface (API) and corresponding software development kit (SDK) and are used to sample raw sensor data. The relevant characteristics, like the heart rate [4] or skin resistance changes [5,6] are detected and extracted from the signal. Finally, the resulting data are sent to the mobile phone via the wireless Bluetooth protocol. In the next sections we describe the Chest Strap and Glove prototypes.

3.1.1 Chest Strap

The chest strap, which is shown in Fig. 5 has three embedded sensors and one acquisition system. The sensors are an ECG (Electrocardiography), Respiration sensor and tri-axial accelerometer that are situated in the chest of the wearer. All the embedded electronics are easily removable and reassembled, to allow the wearer to machine-wash the chest band when the need arises.

Fig. 5. Textile enclosure and device for chest use.

The chest strap form factor allows an easy and seamless placement of the acquisition system and sensors. In the following pictures, the acquisition system and the sensors are embedded inside the textile band. It is slid in the narrow space between two seams. This creates the needed stability to obtain a good respiration signal. The chest band opening that houses the acquisition system and the sensors, is closed by means of a metallic snap or a zipper. The three electrodes of the ECG sensor must be aligned with three small holes in the textile and then the snaps must be closed. This is essential to obtain the ECG signal and it will help also in maintaining the system in its place while in use. The technical specifications are described in Table 1.

Table 1. Specifications of the chest strap device.

Sensor	Specifications
Accelerometer	±5G 3-axis MEMS technology
Respiration	1 Hz low-pass filter Piezofilm technology
ECG	Gain 1000 0.05-30 Hz band pass filter 110 dB CMRR > 100 MOhm input impedance

3.1.2 Glove

The glove has two embedded sensors and one acquisition system. The sensors are an EDA (Electro-dermal Activity) and BVP (Blood Volume Pulse) that are situated in the palmar side of the non-dominant hand of the wearer (for this document the left hand is used). All the embedded electronics are easily removable and reassembled, to allow the wearer to machine-wash the glove when the need arises.

The acquisition system and the sensors must be placed in the correct locations before the user puts the glove on. The BVP sensor is passed through a small opening in the textile. This sensor will stay in its place by means of Velcro or a metallic snap. For the EDA sensor, the process is also very simple. The two wires with metallic electrodes must be aligned with the two small holes in the textile and then the snaps must be closed. Fig. 6 depicts the sensor system and placement in the hand. Through the integrated sensors, this system enables us to acquire heart rate and skin conductance response (SCR). The technical specifications are described in **Table 2**.

Table 2. Specifications of the glove device.

Sensor	Specifications
EDA	3 Hz low-pass filter > 1 TOhm input impedance
BVP	Double emitter/Single detector setup Infrared wavelength range

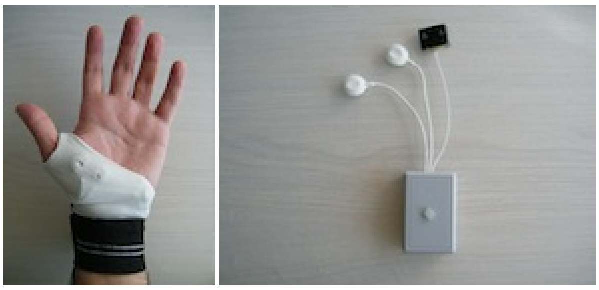

Fig. 6. Textile enclosure and device for hand useTextile enclosure and device for hand use.

3.2 Physical Activity Monitor

On the mobile phone the accelerometers are used to obtain a better insight in user physical activity behaviors. Raw acceleration data is used in a physical activity monitoring algorithm to determine periods of lying, sitting, standing, walking, running and energy expenditure. To obtain further insights in the user's activities, the phone's GPS is used to obtain a geo-location based perspective on user behavior without continuously tracking the user location. The user defines a list of places in which they perform social and exercise activities. Whenever the GPS indicates that the phone is within a preset distance from any of these points, this is logged and thus an indication of the frequency and duration of time spent in these locations is obtained.

3.3 Medication Adherence System

Sub-optimal adherence to prescribed medicines is frequently the principal obstacle to successful pharmacotherapy in ambulatory patients, especially when unrecognized clinically, as often occurs [7]. Sub-optimal adherence is highly prevalent, associated with poor outcomes of treatments that, when administered correctly, have well-established benefits. For unclear reasons, sub-optimal adherence and its consequences have been a largely neglected aspect of therapeutics. Across all fields of ambulatory pharmacotherapy, a large number of patients do not adhere to effective treatments including circumstances in which life-saving medicines are available for life-threatening diseases.

Electronic monitoring of ambulatory patients' dosing histories has repeatedly revealed that their drug intake is frequently irregular, spanning a wide spectrum of deviations from the prescribed regimen. It is strongly skewed toward under-dosing, created by delayed and omitted doses, sometimes occurring in multiple, sequential omissions of prescribed doses. Those deviations, in turn, tend to nullify therapeutic actions of the drugs in question, contributing thereby to worsening of disease, and increased health care costs.

Given the clinical and economic impact of non-adherence, urgent actions need to be taken to enhance patient adherence to drug therapies. During the last decade, many interventions have been tested but few of them have addressed simultaneously both the intentional and unintentional aspects of non-adherence to medications [8]; [9]; [10]; [11]. These successful interventions rely on the two principal values of electronic monitoring: first, it provides objective and reliable information on patient's dosing history, which defines the extent of the exposure to the prescribed medication; second, the dosing history serves as a crucial element of intervention methods to manage adherence to medication [12].

Until recently, those interventions took place at clinical visits, typically every few months, and were corrective by nature. Today, new ICT technologies allow the remote monitoring of patients' adherence to drug therapies, providing timely information to both caregivers and patients to support effective medication management.

3.3.1 Adherence Monitoring System

The adherence system is depicted in Figure 7. This system covers the chain needed to:

- Monitor adherence data
- Wirelessly transfer adherence data to a dedicated server
- Provide information on adherence to different types of client

The main goal of the adherence monitoring system is to assure the collection of adherence data but, more importantly, to facilitate their integration in external systems. These systems require different levels of integration. Some may simply need a visualization of adherence data while others expect more advanced feedbacks based on the detection of highly contextual adherence issues (e.g risk of treatment discontinuation in depressed patients, detection of drug holidays in HIV patients). Some systems may push the integration a step further by accessing raw adherence data for pharmacokinetic-pharmacodynamic modeling.

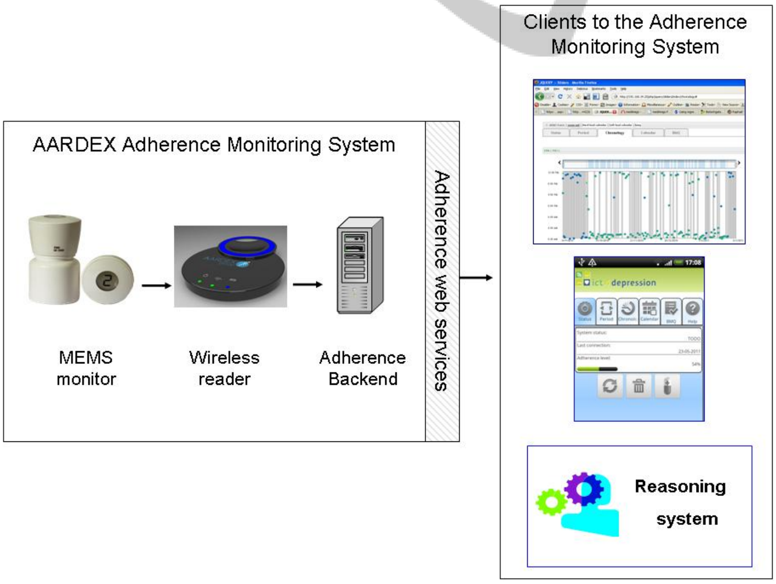

Fig. 7. Adherence monitoring system.

The architecture of the adherence system is based on the following elements:

- The MEMS monitor is a pill container with integrated electronic micro circuitry designed to record the date and time of each opening and closing of the container. It also provides direct basic feedback to the patient through an LCD screen.
- The wireless reader is used to download data from the MEMS monitor and wirelessly transfer these data to the adherence backend.
- The adherence backend stores adherence data and supports their interpretation. This backend can be accessed in a secured way through web-services by different clients.
- Finally, specific components have also been developed to facilitate the integration of adherence data into those clients. An android and a javascript adherence module have been developed.

4 Reasoning System

One of the key elements of the overall system is an intelligent reasoning system to support the patient in a highly personalized manner. The system essentially combines the data that has been obtained from sensors (including the information that the patient has provided to the system, e.g. rating of mood) to an overall picture of how the patient is functioning. Based upon this overall picture, the system can then decide to provide feedback to the patient (in the form of motivational messages or reminders), but the system can also decide to suggest therapeutic changes. Four main parts are distinguished that establish this behavior: (1) a data abstraction component, (2) a virtual patient component, (3) an evaluation component, and (4) a communication component. In Fig. 8 the overall structure of the reasoning system is shown.

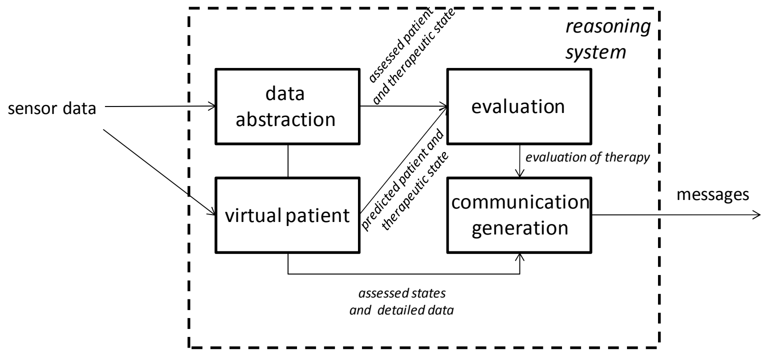

Fig. 8. Overview of the reasoning system.

On a high level, the reasoning system first abstracts the data to determine the current state of the patient (e.g. how much is the patient involved in the therapy). Besides assessing the actual behavior of the patient, the reasoning system also comprises of a virtual patient that makes predictions about the state of the patient (the component *virtual patient*) given his/her characteristics (obtained from the sensor data) and the type of therapy. In the *evaluation* component the current state of the patient is evaluated as well as the therapeutic success. This is performed by analyzing the measured state itself, but also by comparing these states with the predictions of the virtual patient. Finally, in the component *communication generation* the evaluation is used to advice a different therapy in case another therapy is expected to be more successful. Furthermore, more instant forms of feedback are generated based upon the sensory data including the sending of reminders, and providing of motivational messages. Below, each of the components is treated in more detail.

4.1 Data Abstraction

In the data abstraction component the idea is to compose an abstract overall picture of the patient. This overall picture indicates the patient state and the trends in the patient state (e.g. the general patient state is good, but the trend is negative) and similar for the therapeutic state (e.g. the involvement is bad, but an increasing trend in involvement can be seen). In order to establish this behavior, a dedicated language to express complex temporal patterns called the Temporal Trace Language (TTL) has been used (cf. [13]). First, the measurements are abstracted in a temporal fashion (e.g. calculating the average mood during a day), thereafter trends are identified in this abstracted data (e.g. the average mood was good during that particular day). Finally, the trends of multiple measurements are aggregated into a single overall patient and therapeutic state, which makes the approach more robust against missing data. In this aggregation, each particular measurement is assigned a certain weight in the overall compilation of the picture.

4.2 Virtual Patient

The second component concerns a so-called virtual patient model. This model is able to make predictions about the development of the patient during a certain therapy. In order to do so, dedicated computational models are present that express the states within the patient (e.g. mood, appraisal) and how these states influence each other. In addition, the therapeutic influence is also modeled. The models incorporated in the virtual patient prediction component are described in more detail in [15,16,17]. As an input for these models, the characteristics for the patient as provided in a questionnaire are used. The output of the prediction is the development of the general patient state and therapeutic development over time given a certain therapy which is followed.

4.3 Evaluation

The evaluation component creates an assessment of the patient by comparing the predictions using the model with the actual state of the patient. In case the patient is significantly underperforming, a process is started to evaluate alternative therapies and see whether these might be more effective. This evaluation again takes place using the virtual patient model, thereby possibly altering the parameters of the model to make sure that the model is an accurate description of the patient. As a result, the component derives whether a therapeutic change should be advised. A more detailed description of the evaluation process can be found in [14].

4.4 Communication Generation

The final component is the generation of communication to the patient. This communication can either concern information about a therapeutic switch (due to the evaluation made in the previously discussed component), but can also involve motivational messages and reminders. The messages are generated using dedicated rules that express in what situation what information should be communicated to the patient. Note that not only the high level assessment are hereby considered, but also the immediate sensory information, for instance a positive mood rating by the patient could trigger a message expressing that it is good to hear that the patient is feeling well.

5 System Server and Infrastructure

The server main goal is to work as an information repository to be accessed in a web, decentralized and in an interoperable fashion. The current clients are developed within the project consortium, but this architecture allows expandability and openness to new market players.

The repository uses the Microsoft SQL 2008 database management system. To ensure the standard data protection, the database TDE (Transparent Data Encryption) [18] feature was used. For the information exchange the option in use was the Web Service development over the WCF (Windows Communication Foundation) [19] targeting .NET Framework 4. This framework, as other modern frameworks, allows the use of WS (Web Services) standards, which enable the development of service oriented applications. As such, the ICT4Depression is a SOA (Service Oriented Architecture) that relies on WS to send and receive data. The main advantage is the loose coupling between client applications and repository. This implies that any client created on any platform can connect to the ICT4Depression system according to established information access policies, as long as the essential contracts [20] are met. The current client applications are WS client applications, a web client PHP application and a mobile application running on Android. They implement the therapy modules and use XML/JSON over HTTPS to communicate to the server, which implements both the synchronous and asynchronous web method invocation.

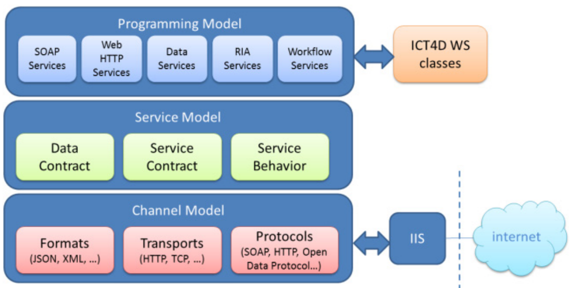

Fig. 9. ICT4D SOA layers.

6 Conclusions

In this paper a mobile system designed for the continuous treatment of depression is presented. The mobile system uses a smart phone to provide the treatment to the user, obtain input from the user and display feedback and advice. Biomedical sensors and the phone itself measure parameters which are linked to emotional markers to obtain further information on the user's well-being and treatment progression. The user's adherence to the set medication regimen is monitored using a dedicated medication adherence system. All information is gathered in a server where a reasoning system analyses the data, determines the treatment progression and provides feedback to the user. The system will be tested with real users in 2012.

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