# The MONARCA Self-Assessment System – A Persuasive Personal Monitoring System for Bipolar Patients

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## ABSTRACT

An increasing number of persuasive personal healthcare monitoring systems are being researched, designed and tested. However, most of these systems have targeted somatic diseases and few have targeted mental illness. This paper describes the MONARCA system; a persuasive personal monitoring system for bipolar patients based on an Android mobile phone. The paper describes the user-centered design process behind the system, the user experience, and the technical implementation. This system is one of the first examples of the use of mobile monitoring to support the treatment of mental illness, and we discuss lessons learned and how others can use our experience in the design of such systems for the treatment of this important, yet challenging, patient group.

## Categories and Subject Descriptors

J.3 [**Computer Applications**]: Life and Medical Sciences—*Health*; H.5.2 [**Information Interfaces and Presentation**]: User-centered design.

## General Terms

Design, Human Factors.

## Keywords

Bipolar disorder, mental illness management, personal monitoring systems, Android, self-assessment

## 1. INTRODUCTION

Persuasive personal monitoring systems have been suggested for the management of a wide range of health-related conditions. These types of systems help users by enabling them to monitor and visualize their behaviors, keeping them informed about their physical state, reminding them to perform specific tasks, providing feedback on the effectiveness of their behaviors, and recommending healthier behaviors or actions. In addition to numerous studies on general behavior change [12], research has also targeted health-related behavior change such as physical activity [7, 3], healthy eating habits [14], cardiac rehabilitation [8], and the management of chronic illnesses like diabetes [9, 20], chronic kidney disease [19], and asthma [6].

So far, most of this research has targeted somatic diseases and few have targeted mental illness. But such persuasive monitoring systems could also have the potential to help with the management of mental illnesses such as depression, bipolar disorder, and schizophrenia. Such systems would be able to monitor data on mood, behaviors, and activities, providing timely feedback to patients in order to help them adjust their behaviors. A few studies have focused on estimation and improvement of adherence to medication using electronic monitoring in patients with depression [16, 11, 2] or schizophrenia [4]. As for bipolar disorder is concerned, using weekly text messaging has been suggested and studied [1]. Also more comprehensive electronic monitoring systems have been presented for patients with bipolar disorder including self-monitoring of medication, mood, sleep, life events, weight, menstrual data, etc. [21, 15, 13]. But so far none of these systems have included combined self-monitoring and objective system recording of the disorder, and none of them have build-in mechanisms for providing feedback directly to the patient.

Designing for mental illness poses several challenges. Due to the complexity of mental illness, it is unclear what data should be monitored. Symptoms vary from patient to patient, and may be difficult to recognize. It is difficult for patients to reflect on their own mood and behavior, and their families and others around them may only recognize symptoms if they understand the illness and know what to look for. In addition to the complexity of an illness and its symptoms, the treatment process is equally complicated. There is no singular treatment regimen or set of medications that will work for all patients. Treatment of mental illness therefore requires an ongoing process of experimenting with different combinations of medications, and learning how to cope with and reduce symptoms through healthy behaviors (e.g., good sleeping habits, daily routines, avoidance of alcohol, etc.).

This paper presents the MONARCA system, which is designed for the treatment of patients suffering from bipolar disorder. The system is designed to be used by both patients, clinicians, and relatives. The system consists of two parts. The first part is an Android application, which is designed for patients and allows them to enter self-assessment data, collects sensor-based data from the phone, provides feedback on the data collected, and helps the patients manage their medicine. The second part is a website which provides access to the system for patients, clinicians and relatives. In addition to accessing the data for each patient, the website provides


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detailed historical overviews of data and allows for customization of the system according to the need of each individual patient. In the website, clinicians can furthermore get a quick overview of all their patients, which enables them to focus on the patients in need of immediate attention.

The MONARCA system has been designed in close collaboration with a group of bipolar patients and psychiatrists at a large university hospital in Denmark. This paper describes the user-centered design process, the system and user-interface design, and the technical implementation. The main contribution of this paper is the presentation and discussion of the design and technical implementation of a persuasive monitoring system for mental illness.

## 2. DESIGNING FOR BIPOLAR DISORDER

Bipolar disorder is a mental illness characterized by recurring episodes of both depression and mania. Treatment aims to reduce symptoms and prevent episodes through a combination of:

- Pharmacotherapy – Mood is stabilized, and symptoms are controlled, using a customized and difficult to determine combination of one or more of the following: antidepressants, antipsychotics, mood stabilizers, and other drugs such as sleeping pills.
- Psycho-education – Patients are taught about the complexities of bipolar disorder, causes of recurrence of episodes, and how to manage their illness.
- Psychotherapy – Patients are coached to deal with their symptoms and find practical ways to prevent episodes through actionable behavioral and life-style choices, such as routine, sleep, and social activity.

One particular approach to treatment is predicting and preventing episodes by training patients to recognize their Early Warning Signs (EWS) – symptoms indicative of an oncoming episode [18]. Training is resource-intensive and its success varies highly from patient to patient. Some patients are never able to identify patterns in their episodes that reveal EWS.

Mood charting, or creating daily records of mood states and behaviors, can help patients identify patterns and track their progress [17]. Mood charts are available as paper forms[1], websites[2], or mobile phone applications[3]. Figure 1 shows an example of a paper-based mood chart, used at the university hospital in Denmark. We reviewed a variety of mood charting methods, and found significant limitations. Paper forms, which are handed out to patient by clinicians or distributed by medical organizations, are inconvenient to fill out and highly subjective. They are filled out inconsistently due to forgetfulness or symptoms. Subjectivity of measures, combined with a free form method of data collection, can result in data that is inconsistent due to changing scales or criteria based on subjective interpretation. Web-based or mobile phone solutions can make it easier for patients to report data, and also reduce data inconsistency by guiding data entry. However, existing websites and mobile phone applications tend to suffer from a lack of usability, a clinical perspective, and generalizability for a variety of patients.

The design of the MONARCA system was done in a user-centered design process involving both patients and clinicians affiliated with the psychiatric clinic of a large university hospital in Denmark [10]. Patients and clinicians participated in numerous collaborative design workshops – three-hour sessions which were held every other week for twelve months. Workshops involved discussions about how patient were affected by their illness and how they coped with in daily life, as well as designing overall goals for the new system and more detailed system features and functionality, based on presentations and hands-on use of paper-based mockups and early prototypes of the system [5]. Thus, all design decisions were based on these workshops, focussed on the patients' and clinicians' knowledge, ideas and feedback, based on prototypes and the participants' daily life.

[1]E.g. HealthyPlace Bipolar Mood Chart at `healthyplace.com`

[2]E.g. Mood Chart at `mood-chart.com`

[3]E.g. Optimism at `optimismonline.com`

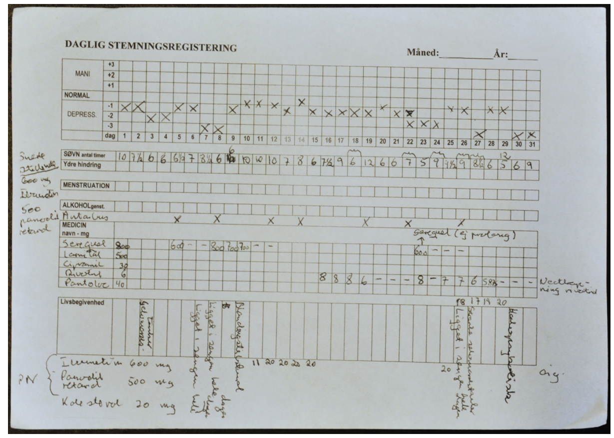


**Figure 1: An example of a mood chart used at the hospital. The chart tracks mood, sleep, external obstacles, menstruation, alcohol, medication and life events.**

**Figure 2: A patient, designer, and psychiatrist working together on a design activity using prototyping materials.**

Design activities at the workshops began with hands-on brainstorming and lo-fi prototyping (see Figure 2). We provided materials such as documents summarizing the goals of the system, images of existing tools and methods, large poster paper, writing materials, scissors, tape, etc. The sketches that came out of this initial brainstorming formed the basis for the first mockups. At each of the following workshops we (i) discussed targeted design goals and system features in depth, and (ii) received feedback on the next iteration of the mockups. Mock-ups presented during workshops progressed from sketches and wireframes into interactive prototypes.

One of the main goals of the user-centered design process was to design a system to help patients manage their own illness through monitoring and persuasive feedback. From a clinical viewpoint, the psychiatrists stated that the following three parameters are crucial in keeping a bipolar patient stable:

1. Adherence to prescribed medication: Taking all medications on a daily basis, exactly as prescribed.

2. Stable sleep patterns: Sleeping 8 hours every night and maintaining a consistent routine of going to bed and waking up.

3. Staying active both physically and socially: Getting out of the house every day, going to work, and engaging in social interaction.

At first glance, this list may seem simple, but the psychiatrists also stated that each of these items are very difficult to achieve for many patients, and achieving all three at the same time every day is inherently challenging in combination with a mental illness. Hence, the core challenge is to create technology that would help – or 'persuade' – patients to do these three things daily. Based on the 12 month design process, the group of psychiatrists and patients came down to the following core set of requirements for the MONARCA system:

*Self-assessment* – Subjective data should be self-reported on a one-page self-assessment form on the mobile phone, including mood, sleep, level of activity, and medication. Some items should be customizable to accommodate patient differences, while others are consistent to provide aggregate data for statistical analysis. An alarm should daily remind the patient to fill out the form.

*Activity monitoring* – Objective data should be collected to monitor level of engagement in daily activities (e.g., based on GPS and accelerometer), and the level of social activity (based e.g., on phone calls and text messages) should be collected. In order to protect patient privacy, this data can be abstracted for analysis.

*Historical overview of data* – When the patient has submitted data using the self-assessment form on the mobile phone, a two-week snapshot of their basic data should be shown for immediate feedback. On the website, both patients and clinicians should have access to a detailed historical overview of the data, giving them the means to explore the data in depth by going back and forth in time, and focusing on specific sets of variables at a time.

*Coaching & self-treatment* – Psychotherapy should be supported through everyday reinforcement in two ways. The system should support customizable triggers that can be set to have the system notify both patient and clinician when the data potentially indicates a warning sign or critical state. Moreover, patients should have access to adding their own EWS, empowering them to understand their own signs.

*Data sharing* – In order to strengthen the psychotherapy relationship, data and treatment decisions should be shared between the patient and his/her clinician. Similarly, sharing data with family members or other caregivers should be supported in order to support the treatment process. Finally, sharing data among patients will help with personal coping and management efforts by re-assuring patients that they are not alone, and helping them see how others manage their illness.

## 3. THE MONARCA SYSTEM

The MONARCA system consists of two main parts; an Android mobile phone application and a website. As shown in Figure 3, the mobile phone application is used by patients. The website consisting of three main parts designed for three different groups of users: (i) patients can see and update their personal data; (ii) clinicians can get an overview of their patients and dig into detailed data for each patient; and (iii) relatives can – if granted access by the patient – look at (but not update) the patient's data.

The system design, including the hosting and deployment setup, is illustrated in Figure 4. It is a simple system setup consisting of

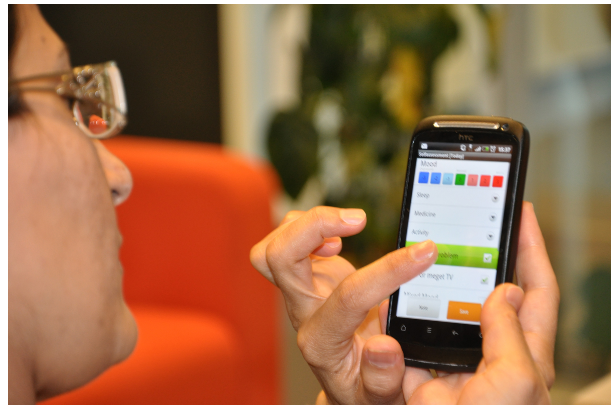

**Figure 3: A bipolar patient using the Android phone app for filling in her self-assessment data by the end of the day.**

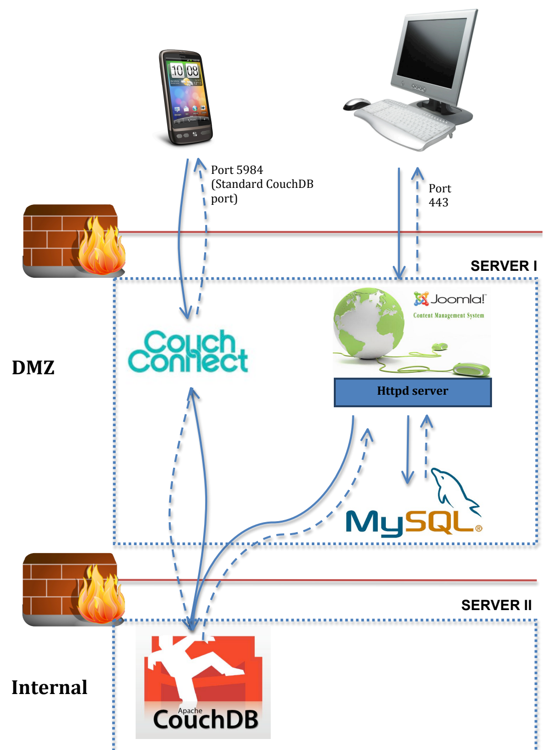


**Figure 4: The MONARCA System overview.**

two clients (the phone and the browser), one server in the demilitarized zone (DMZ) (SERVER I) and one server in the Internal zone (SERVER II). Overall, the system setup consists of the following main components and communication pathways: (i) an HTC Desire, Android based smartphone is used for data collection and data visualization; (ii) a standard web browser on a PC; (iii) CouchConnect, which is a data synchronization process using the CouchDB for synchronizing data between the smartphone and the CouchDB. (iv) CouchDB, which is a database storing all patient-related data (v) Joomla, a Content Management System (CMS) that runs the web application, and (vi) MySQL, a database holding the configuration and the web pages for the Joomla CMS.

In the following, we will detail how the patients and the clinicians are using the system, the interaction design of the system, and its technical implementation, including how sensing is done on the phone.

# 4. ANDROID PHONE APPLICATION

The main goals of the MONARCA phone application are; (i) to provide an input mechanisms for patients to fill in their self-assessment data; (ii) to collect objective sensor data from the phone; (iii) to provide a simple historic visualization of the data entered; (iv) to provide feedback and suggest actions to take in situations that presents risks; and (v) help patients to keep track of their prescribed medication.

The main reason for using a mobile phone application, is that the phone is usually always with the patient. This is useful not only for the objective sensing of the activity of the patient, but also for collecting the self-assessment data, since the phone is available much easier than a web browser. The user interface of the MONARCA Android phone application is shown in Figure 5, consisting of a main screen, linking to 5 different subscreens; (i) Self-assessment, (ii) Visualizations, (ii) Actions to take, (iv) Medicine and (v) Settings.

## 4.1 Self-Assessment and Sensed Data

Based on our close collaboration with the bipolar patients and psychiatrists, we have identified a set of self-assessment data points that the MONARCA system should collect. A constant concern was to make the self-assessment for the patient as simple and easy as possible and avoid overloading with numerous of things to report. Therefore, we have constantly been striving to reduce the set of self-assessment items and have ended up with an absolute *minimum se*t of things to monitor for a bipolar patient. These self-assessment data can furthermore be divided into a set of *mandatory* self-assessment data, which is absolutely crucial to collect over time in the treatment of a bipolar patient, and a set of *optional* self-assessment data points, which are very useful to have as a supplement to the mandatory ones.

The mandatory self-assessment items are:

- *Mood* measured on a 7-point HAMD scale spanning from highly depressed (-3) to highly manic (+3).
- *Sleep* indicated in half-hour intervals.
- *Subjective Activity* on a 7-point scale spanning from totally inactive (-3) to highly active (+3).
- *Medicine Adherence* indicating whether prescribed medicine has been taken as prescribed, have been taken with modification, or not taken at all.

The optional self-assessment items include:

- *Universal Warning Signs*, which are signs that a psychiatric clinic can set up for all its patients. Such signs can e.g. include experience of so-called 'mixed mood', 'cognitive problems', or 'irritability'.
- *Early Warning Signs (EWS)*, which are *personal* signs that are tailored specifically for a patient to look out for. For example, if a patient starts sleeping in the living room rather than the bed room, this is a sign for him that a manic phase is starting.
- *Alcohol*, as measured in number of drinks.
- *Stress* measured on a 5-point scale from 0 to 5.
- *Menstruation*, only applied to females.
- *Note*, a free text entry done with an on-screen keyboard

All self-assessment data is entered on the phone's self-assessment screen as shown in Figure 5(i). In addition to these self-assessment data, the phone is collecting more objectively sensed data. This includes *physical activity* data as measured by the accelerometer in the phone and *social activity* as measured by the number of phone calls and text messages sent from the phone. More details on the objective measurement is described in section 4.3.

## 4.2 Technical Implementation

A core technical requirement for the MONARCA phone application was that it should allow patients to enter and review their data at any time, even without network connectivity. Therefore, the application was designed to allow for data entry while offline with data synchronization when online. To achieve such data synchronization, the application is built around the Apache CouchDB[4], which is a document-oriented database that can be queried and indexed in a MapReduce fashion using JavaScript. CouchDB also offers incremental replication with bi-directional conflict detection and resolution, and it provides a RESTful JSON API than can be accessed from any environment that allows HTTP requests.

The client running on the phone consists of a single Android application which is structured as illustrated in Figure 6. Overall, the application consists of; (i) a CouchDB database for Android, running as a native process in the same process as the application; (ii) a few services, interfaces and classes which implement the application specific interaction with the database; (iii) a set of user interface Activities, which are responsible for the interaction with the user and data presentation, and (iv) a few background services responsible for gathering objective data from the sensors in the phone.

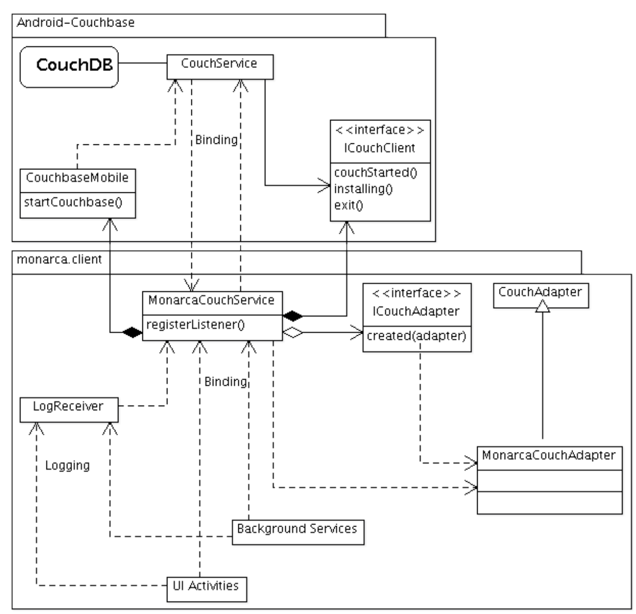


**Figure 6: The MONARCA Android Architecture.**

The `Android-Couchbase` component is an open source library running and managing the CouchDB database. Its main functional part is a native process, in which the actual database is run-

[4] `http://couchdb.apache.org/`

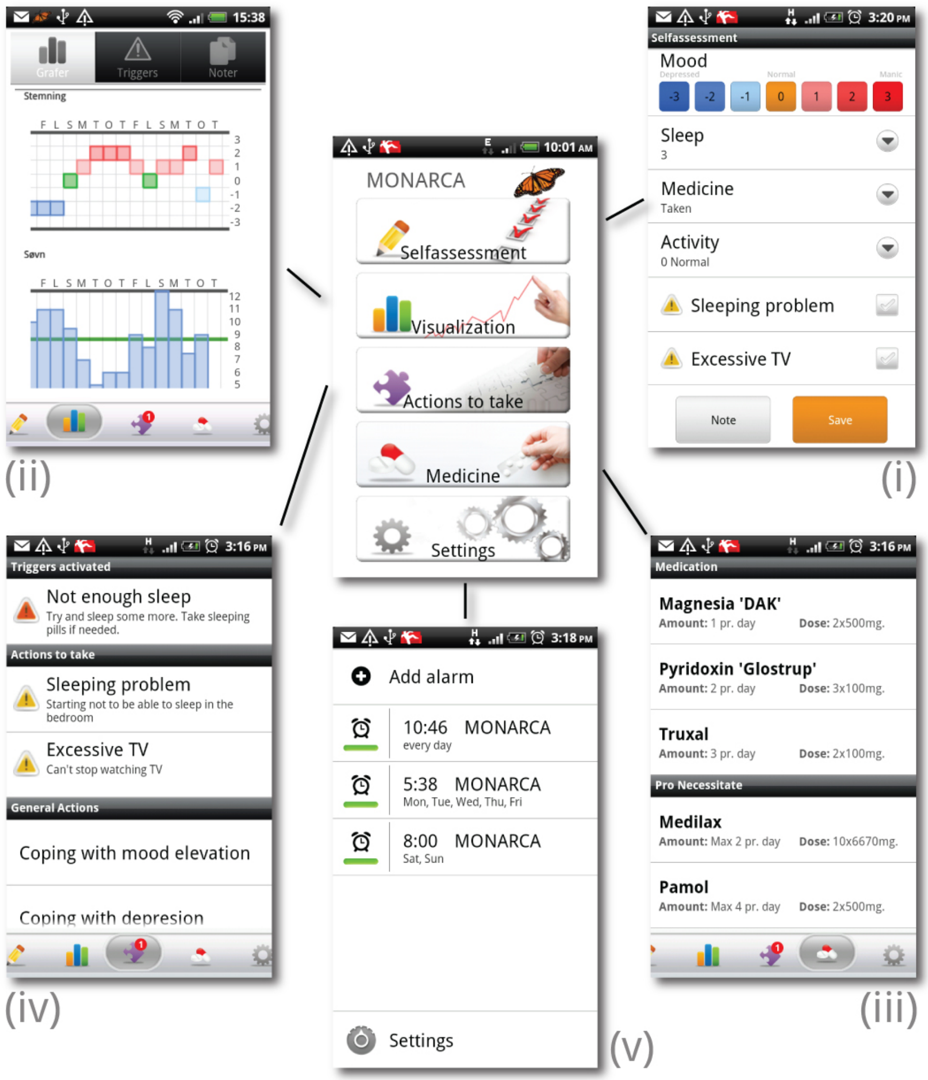


**Figure 5: The MONARCA Android user interface.**

ning. The life-cycle of this process is managed through the `CouchService`, making use of the `CouchbaseMobile` class. Notifications on changes in the state of the database are provided through the methods of `ICouchClient`.

The MONARCA application logic is implemented in the `monarca.client` component. In order to create a robust and easy to use application, it is important to ensure that the database is always running before a component tries to operate with it. As a result, the MONARCA application has a set of components, which are responsible for communicating and using the Android Couchbase:

- `MonarcaCouchService` is a background service that provides an easy way to manage the CouchDB. When created, it binds to the `CouchService`, receives an instance of the `ICouchService` interface, and attempts to start up the database. Depending on the state of the database, this might take up to a minute. Clients have to register an `ICouchAdapter` listener to receive a `Monarca CouchAdapter` instances once the database is up and running. Once the client is notified, the registered listener is removed.

- `ICouchAdapter` provides the `created()` callback method, which is called when the database is ready for communication. Hence, all database communication routines of a component should be placed inside this method.

- `MonarcaCouchAdapter` provides application specific operations with the database, making use of the RESTful interface provided by the CouchDB.

- `LogReceiver` is a subclass of `BroadcastReceiver`. It acts as a "sink" for logging messages inside the MONARCA application. When a component needs to log a specific message, all it has to do is to construct an Android `Intent` with one of the actions provided by the `LogReceiver` and the content which needs to be logged. Once created, the Intent is broadcasted, intercepted by the LogReceiver and appended to one of the many log documents in the CouchDB.

The User Interface of the MONARCA system (Figure 5) is based on the Android `Activity` interface. The self-assessment screen (Figure 5(i)) is a simple screen that takes input entered by the patient and uses the CouchDB setup described above to store this data.

The Medicine screen is a simple screen that takes data from the CouchDB and lists it (Figure 5(iii)). The patient cannot modify the medication on this screen. The more complicated Visualization screen, the Trigger mechanisms, and the Alarm setup is further detailed below.

#### 4.2.1 *The Visualization Screen*

The visualization screen, consisting of three tabs; graphs, triggers and notes, (Figure 5(ii)), is the central feedback mechanism to the patient since it is shown every time the patient has entered his or her self-assessment data. The graph visualization display is designed to be very simple and aesthetically pleasing, while giving an overview of the data entered into the application. The triggers and notes are visualized through simple listings of the activated triggers and entered notes history. The visualization is restricted to the past 14 days, whereas longer periods of data can be reviewed on the website.

Due to the lack of mature plotting libraries for Android, the graph visualization screen is implemented using 'flot'[5], which is a pure Javascript plotting library for jQuery. The Graph Visualization screen consists of a `WebView`[6] component, which is a subclass of `View` with the ability to display web pages. The `WebView` loads a HTML file that defines the layout and contains a set of Javascript functions, which are responsible for drawing the graphs. The graph data is stored in a set of Java objects in the Android application, and `WebView` offers a way to bind these Java object to JavaScript so that the object's methods can be accessed from JavaScript.

#### 4.2.2 *The Triggers Mechanism*

The *Automatic Trigger* feature in the MONARCA system is made up of a set of rules that apply to any self-assessment data being entered. For example, an automatic trigger can be set up to trigger if the patient reports that he has been sleeping less that 6 hours 3 days in a row. Automatic triggers play a crucial role in continuously feedback to the the patient as they consistently track patterns over time and can warn both the patient and the psychiatrist about things to be aware of.

When a trigger is activated, a notification is posted using Android's *Notification Manager* mechanism. The trigger is then displayed as an item in the notification view on the Android phone (typically in the top pull-down curtain). When clicking the notification, the patient is taken to the *Actions-to-Take screen* (Figure 5(iii)), which lists all active triggers.

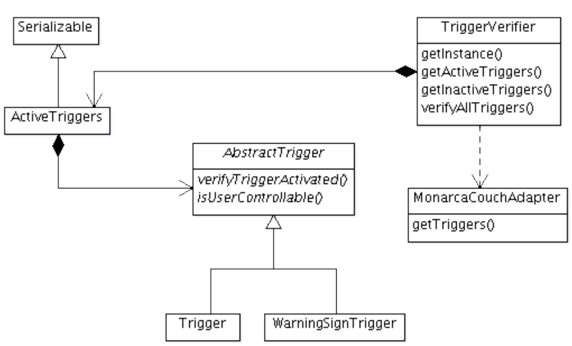


**Figure 7: Triggers verification mechanism**

[5]`http://code.google.com/p/flot/`
[6]using the WebKit rendering engine to display web pages

As illustrated in Figure 7, `TriggersVerifier` is the central point of the trigger mechanism. It is a singleton providing methods to verify the triggers and to retrieve the active / inactive triggers in the system. As the self-assessment can be changed only by the patient, we verify the triggers after filling in the self-assessment form as well as right after the application is launched. After each verification, the list of active triggers is broadcasted as an intent and can be caught by any component implementing a `BroadcastReceiver`.

Whenever a trigger is triggered, this is logged into a special document in the database. In this way, triggers can be shown on the overview of patients that the clinicians have in the website (see Figure 13). Thus, clinicians are constantly aware of activated triggers and can look into the cause of this.

#### 4.2.3 *The Alarm Mechanism*

Self-assessment is done by patient on a daily basis. The best approach is to fill in the data as soon as it is available; e.g. *sleep* could be entered in the morning, whereas *activity* and *stress* should be entered at the end of the day. The application itself provides no restrictions of when or how many times the self-assessment data can be entered. But in order to help patients remember to do the self-assessment, the MONARCA app has an alarm system, which resembles the regular Android alarm module. In this alarm mechanism, the patient can set up multiple alarms with a wide range of customizable options, such as time of day, days of week, repeating alarms, what ringtone to use, etc. When the alarm goes off, a dialog is shown, providing the user with three options: *OK*, will take the user to the self-assessment screen, *Snooze* will snooze the alarm for a configurable amount of time, and *Dismiss* which is provided as a sliding tab forcing the user to perform more than just a simple click. A snapshot of the dialog is depicted in Figure 8.


**Figure 8: Alarm dialog**

If users have filled in their self-assessment and do not want to be bothered by any other alarms that day, they can configure this behavior by checking the *Alarms and self-assessment* option in the general alarms settings. This option will disable the alerts for the present day, once the self-assessment is done.

### 4.3 Objective Data Sampling

As described previously, the MONARCA system collect objective data on the behavior of the patient in terms of physical and social activity by sampling data from the phone's accelerometer and telephone plus messaging subsystems. From a technical point of view, this sampling is implemented as a background service, running also if the MONARCA application is stopped. To ensure this behavior, we start these services when the phone is started.

### 4.3.1 *Physical Data Sampling*

Accelerometer data is sampled every 5 minutes, reading five consecutive samples from the accelerometer sensor. The samples consist of three real values, representing the values of the forces for each of the three axes in a three dimensional Cartesian coordinate system. The values for each axis are averaged out and we store one instance with the three averaged elements in the database.

Our goal for the data sampling was to create a simple mechanism for collecting data that roughly correlated with physical activity. Hence, we do not apply any activity recognition algorithm, but instead we do some trivial processing on the collected data and display it in the visualization on the phone and the website. This is done by computing a single number for each day, based on the accelerometer readings. The number represents the average of all instances for a specific day. We have observed, based on existing measurements, that this average is mostly between 0 and 40. It cannot be a negative number because we are working with absolute values, but sometimes it can exceed 40, in which case we the number is still interpreted as 40.

### 4.3.2 *Social Data Sampling*

Social activity is monitored by sampling the number of *incoming* and *outgoing* phone calls, the *duration* of the calls, as well as the number of *incoming* and *outgoing* SMS messages. This data gives information about the patient's social activity and can indicate possible state changes. For example, if on one hand the patient does not use the phone at all, s/he might be entering a depressive state; on the other hand, if the number of outgoing calls is high, the patient might be entering a manic state.

## 5. WEBSITE

The website runs on a Windows 2008 R2 server, using a WampServer version 2.1 running Apache 2.2.17, MySQL 5.5.8 and PHP 5.3.1. The website is also accessing the central CouchDB, described in the *Technical implementation* section. On the WampServer we have installed a Joomla 1.6.0 content management system (CMS), which we use for generating all the web pages, managing user account, and other CMS related functionalities.

Joomla is an open source content management system, based on PHP using a MySQL database. It has a front-end holding all the end-user web pages and a back-end, where the administrator(s) can configure the whole site. We have installed Joomla version 1.6.0 along with 3 extensions. The first is Jumi 2.0.6, which allows us to embed custom PHP code into a standard Joomla web page, enabling the web page to get data from the CouchDB and display and edit it within the web page. For the PHP interaction with CouchDB, we use the "PHP on Couch" library. Joomla has a very simple infrastructure, in which the content to be displayed on a page is edited as a Joomla article. Articles can be edited via the standard Joomla editor and can be organized in a traditional menu structure.

Furthermore we have installed j4age 4.0.2.3 and JoomlaWatch 1.2.12, which monitors the site in regards to which users log in, what pages they visit, time spent at the different pages, and their system information in regards to IP and browser type. This data is very important in regards to the actual usage of the portal.

### 5.1 User Interaction Design

The main flowchart for the web pages in the MONARCA website are show in Figure 9, and the flowcharts for the patients', clinicians', and relatives' part of the website are shown in Figure 10, 11, and 12 respectively.

Within Joomla you are given a user group functionality, which allows you to add users to different user groups and limit the menus and articles to only be shown to specific user groups. In this way we can have both patients (see figure 10), clinicians (see figure 11) and relatives (see figure 12) logging into the same system, and only displaying content relevant to them. An example of the clinician's "patient overview" can be seen in Figure 13, as well as an example of a patient's graphs in Figure 14, which is displayed in the same way for both clinicians, patients and relatives. The look-and-feel of the web pages is based on the '*shape5_intrigue*' template, modified to suit the needs of our system.

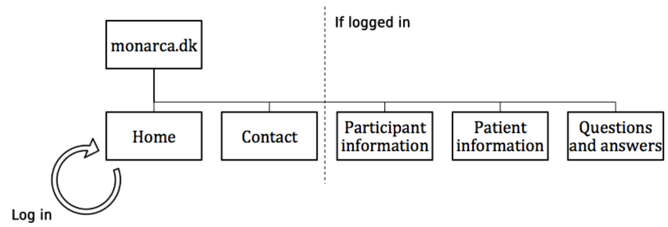


**Figure 9: Website - Entrypoint flowchart**

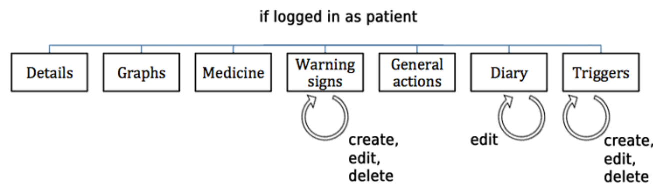


**Figure 10: Website - Patient flowchart**

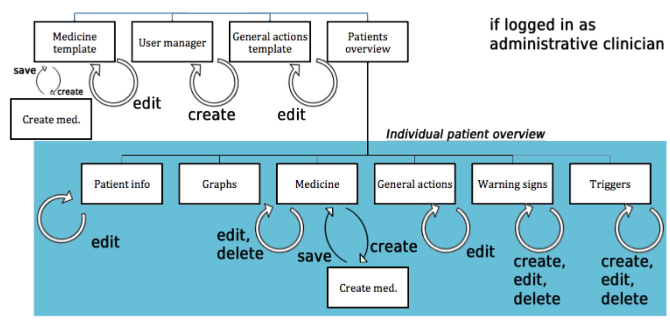


**Figure 11: Website - Clinician flowchart**

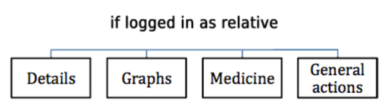


**Figure 12: Website - Relative flowchart**

### 5.2 Data Synchronization

CouchDB offers a powerful synchronization mechanism, which allow us to keep the different CouchDB instances that run on every phone in continuous sync with the central CouchDB running on the DMZ server. Each phone only synchronizes data that is relevant for this phone, i.e. data which is associated with the patient using this phone. The sync feature offered by CouchDB is called replication. Replication is triggered by sending a POST request to the `_replicate` URL with a JSON object in the body that includes

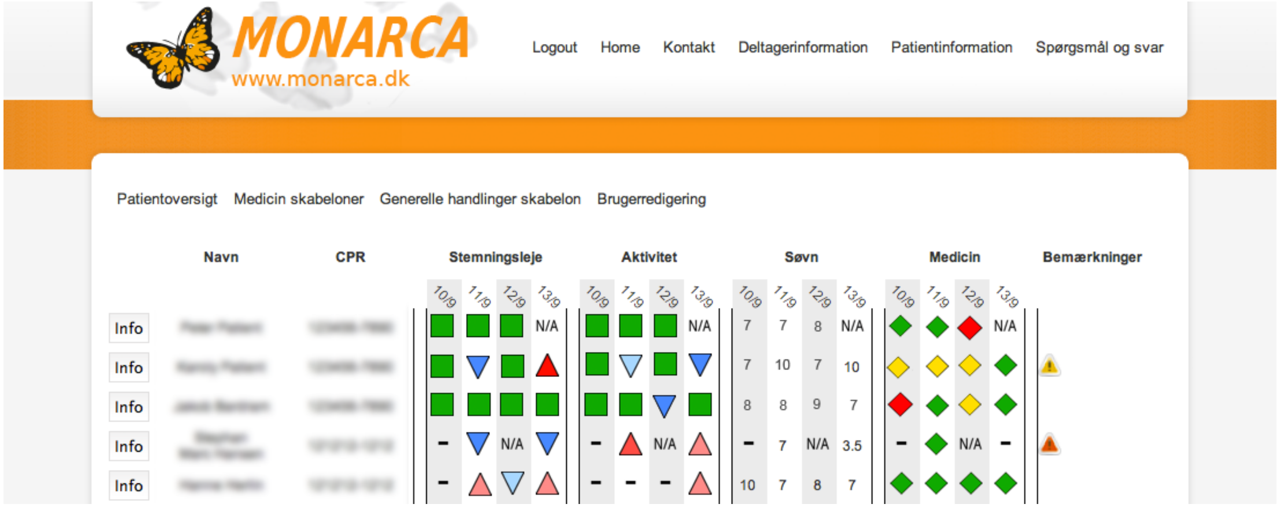


**Figure 13: Website - Clinician overview. Each line is a patient (name and ID number in the left columns), showing mood, activity, sleep, and medicine data for the last 4 days. Triggers and Early Warning Signs are shown in the far right column.**

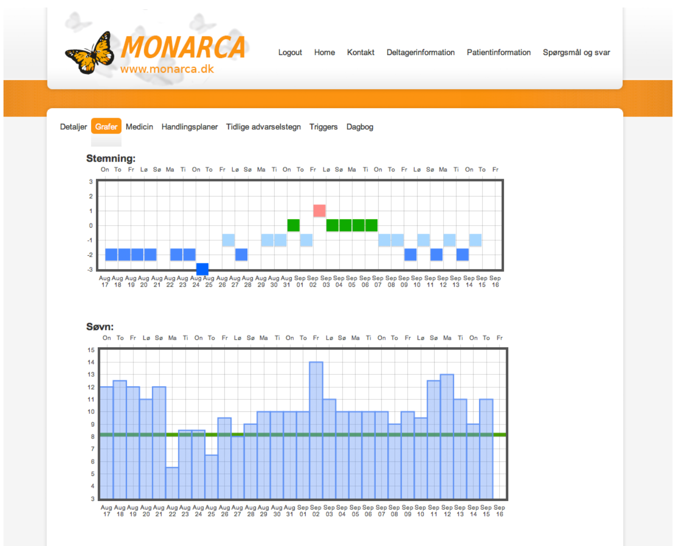


**Figure 14: Website - Patient graphs**

a source and a target member. When synchronizing data, we issue a replication from the server to the phone to receive changes that might have been created by the website and a replication from the phone to the server, in order to transfer the collected subjective and objective data from the phone to the server.

From version 1.1, CouchDB introduced native support for SSL communication. Therefore, we replicate encrypted data through a secure channel. To replicate only data relevant to each user, we make use of the filter mechanism of the CouchDB. Before replicating a document, CouchDB will apply any existing filters to check if the document can or cannot be replicated.

# 6. DISCUSSION AND LESSONS LEARNED

We are about to start a full-scale pilot trial the MONARCA system. But as part of the design process, we have handed out phones and solicited user feedback from the patients who were part of the design group and who was associated with the clinic. Based on this input obtained during the design process, combined with our observations during the technical implementation, this section discusses what lessons were learned in the design and implementation of the MONARCA system.

## 6.1 Using Smart Phones for Self-reporting

The overall question when designing the MONARCA system was clearly whether patients would be able to use the application for self-reporting data. So far they had been using paper-based forms, as seen in Figure 1, which are rather robust and easy to use for everyone. By giving the patients the MONARCA system, we were asking mentally ill patients to handle rather sophisticated smartphone technology, and it was by no means obvious that they would be able to use the application.

However, all the participants reported that it was much easier to use the phone-based self-assessment approach rather than using the old paper-based ones. As one of them explains:

> *"First of all [the phone] reminds me to fill in my self-assessment. [And] all the data is gathered in one place, and not scattered on different pieces of paper. It provides an overview of the data, which you can't do yourself – unless you use a lot of time on it, which you don't – and because you have it with you everywhere you go.*

The participants found that entering self-assessment data was quick and smooth. They also found that the system is monitoring a useful set of data, and providing them with the option to enter personal warning signs gives them leeway to adjust for personal needs. However, in an early version of the system, the patients could only enter data for the current day. This was seen as very problematic because despite the alarm, you could often forget or be unable to fill in the self-assesment. Hence, the need to go back and fill in data for yesterday was deemed important.

But overall, based on input from the patients, we have good reasons to believe that this kind of smartphone-based self-reporting and persuasive monitoring systems would also be feasible and beneficial for mentally ill patients. None of the patients who had been using the phone wanted to go back to the paper-based forms.

## 6.2 Phone versus Website

The use of a phone application and a website in the MONARCA system follows the common schema in most of these kinds of systems. The idea is often that people use the mobile phone as an input device, and use the website for looking at, and working with data and configuration parameters. However, during the design process and the short term use of the system, it became quite evident that few of the patients used the website. When they were initially handed the phone, the system was updated with their medicine, warning signs, triggers and general actions. This was done together with their clinician. When the patients then entered the website a few days later, there were not much for them to do there, mainly because they had only collected data for a few days. For example, the graphs were not really useful for such a short period.

Initially, not all the self-reported data or the objective data was visualized on the phone, but was only shown on the website. But all the patients found this highly annoying; they wanted to be able to get access to all data on the phone, and the visualization needed to incorporate all data. Hence, the visualization screen in Figure 5(ii) had to be updated and incorporate much more data. This was mainly because the users found it cumbersome to be forced to log into the website all the time. As one of the participants explained:

> *"I am tired of not having all the history on my phone because all the work takes place on it. I have actually only logged on the website once, and thought: 'What should I use this for?'. It is useful for setting up the system, but you could do this with your doctor or on the phone itself.*

This actually came as a bit of surprise to us, and in the future design of these kinds of systems, it is important to consider the exact role of a smartphone application and how it is linked into a server-based system, like a website. The conclusion from the MONARCA design process so far is, that users tend to want as much as possible ready-at-hand on the smartphone. But this clearly puts up some significant challenges in designing theses things to be simple to use due to limited resources on the smartphone.

## 6.3 Technical Lessons

From a more technical point of view, the technical design and implementation of the MONARCA system has learned us a couple of things. First, the use of the CouchDB setup has proved to be extremely strong. It is of utmost importance that data collection on the smartphone – especially objective sensor data – runs and works also in offline mode. Hence, asynchronous data synchronization is core to an application like MONARCA . Moreover, the document-based, no-schema nature of the CouchDB made it possible to extend the database and its content dynamically as needed. As such, once the Android version of CouchDB became stable (in version 1.1), this has helped us set up a rather robust distributed system capable of managing a rather sophisticated two-way synchronization setup with self-reporting and objective data floating in from phones, while updates to medicine and triggers float the other way.

Another technical aspects of the design of the MONARCA system is the use of power on the Android phones. Apparently, power management on the Android platform is hard, and one has to be very careful when sampling objective data. Even though we did manage to implement a solution which has a tolerable drain on the batteries, the constant need for charging the phone was a common complaint from the users. As such, when designing such data sampling apps on the Android phone, power-aware computing techniques are important to apply.

# 7. CONCLUSION

An increasing number of persuasive personal healthcare monitoring systems are being researched, designed and tested, but few of these have been targeted mental illness. In this paper we presented the MONARCA system, which is a persuasive personal monitoring system for bipolar patients based on an Android mobile phone and a website.

Based on user-centered design process lasting for 12 months, and involving a set of bipolar patients and psychiatrists in an affective disorder clinic at a large university hospital in Copenhagen, Denmark, we have solicited five core requirements for such a system supporting patient self-management; (i) self-assessment; (ii) activity monitoring; (iii) historical overview of data; (iv) coaching & self-treatment; and (v) data sharing.

We presented the MONARCA system, and described how it is designed to help patients manage their own illness through monitoring and a feedback mechanism using data visualization and triggers. The mobile phone part of the system has a set of unique features for allowing patient do simple self-assessment, for objective monitoring of physical and social activity, for keeping track of medicine adherence, for data visualization, and for setting up triggers and early warning signs. The system is built around the CouchDB, which provides the technical backbone for a very robust and stable system that works even under unstable network conditions. Moreover, the patients and clinicians can view all data on a shared website, which also allows clinicians to have an overview of several patients at once.

The MONARCA system is one of the first examples of using mobile monitoring to help the treatment of metal illness and holds promises for the treatment of this important, yet challenging, patient group. Preliminary feedback from users showed that this system would be very beneficial in the daily life of a bipolar disorder patient, and would be a huge advantage over the current paper-based forms they use. The feedback also helped us identify areas for improving the design of the system, which will be incorporated before the pilot test begins in the near future.

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