

# Smartphones for In-home Diagnostics in Telemedicine

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**Abstract**—Many contemporary telemedical applications rely on regular consultations over the phone or video conferencing which consumes valuable resources such as the time of the doctors. Some applications or treatments allow automated diagnostics on the patient side which only notifies the doctors in case a significant worsening of patient's condition is measured.

Such programs can save valuable resources but an important implementation issue is how to ensure effective and cheap diagnostics on the patient side. First, specific diagnostic devices on patient side are expensive and second, they need to be user-friendly to encourage patient's cooperation and reduce errors in usage which may cause noise in diagnostic data.

This article proposes the use of modern smartphones and various build-in or attachable sensors as universal diagnostic devices applicable in a wider range of telemedical programs and demonstrates their application on a case-study – a program for schizophrenic relapse prevention.

**Keywords**—Smartphones, Actigraphy, Telemedicine, In-home Diagnostics

## I. INTRODUCTION

**T**HE ITAREPS (Information Technology Aided Relapse Prevention in Schizophrenia) program is a telemedical prevention program developed by experts from Prague Psychiatric Center, based on the original idea of Dr. Filip Španiel, for recognition of early warning signs of psychotic disorder relapse [1], [2].

Each week patients are asked via a mobile phone message (SMS) to submit answers to a short questionnaire. The questionnaire consists of ten questions targeted primarily to detect prodromal symptoms of schizophrenia.

The observed prodromal symptoms include: sleep worsening, decrease in appetite, declined concentration, social withdrawal, restlessness and aggressivity, strange thoughts, loss of energy, inability to cope with daily tasks, hearing voices, decline in hygiene and other non-specific behavioral changes.

The SMS messages sent by the patients consist of 10 numbers ranging from zero to four expressing the relative level of worsening since the last evaluation. Received messages are automatically process by the ITAREPS back-end and in case of significant worsening the system notifies the related outpatient psychiatrist with an alert in order to allow interventions such as medication increase. Figure 1 depicts the weekly life-cycle of the program.

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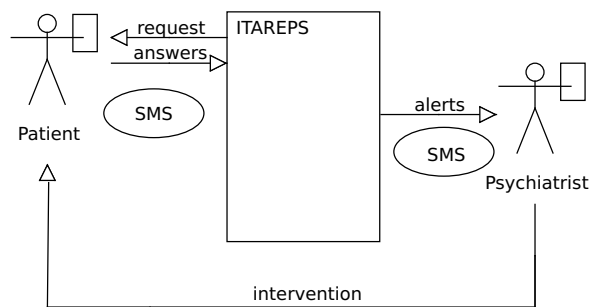


Fig. 1. ITAREPS life-cycle

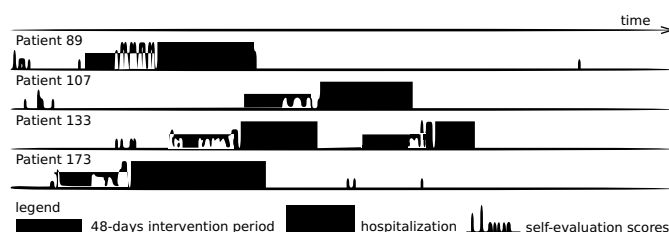


Fig. 2. Exemplary Patients

## II. NOISE IN DATA

Prediction performance of the ITAREPS program measured on the passive branch<sup>1</sup> of a recent double blind study [2] shows the system performs very well with sensitivity = 0.56 and specificity = 0.78. Moreover recent research revealed those figures may be further improved by applying data-mining techniques on the historic data ITAREPS produces [3], [4].

The estimated performance of a Naive Bayes classifier applied to the passive patient data gives sensitivity = 0.76 with the same specificity.

Still the subjective self-evaluation technique which is based on the weekly questionnaires generates high amount of noise in data which decreases the overall prediction performance of the system.

Some patients report their worsening precisely and their score starts increasing already several weeks before hospitalization as seen in figure 2 which depicts the historic development of four exemplary patients<sup>2</sup>.

<sup>1</sup>The passive branch is used for various experiments as it is not contaminated with interventions such as medication increase.

<sup>2</sup>The high horizontal segments are hospitalizations and the lower segments are intervention periods -7 to -56 days before hospitalization which give an opportunity to prevent relapse through intervention. Vertical lines show the average value of the messages, the higher the line the higher the score – greater worsening.

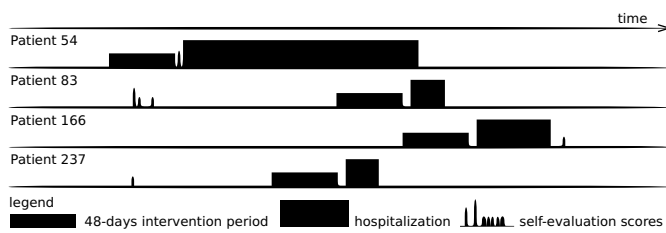


Fig. 3. Non-responders

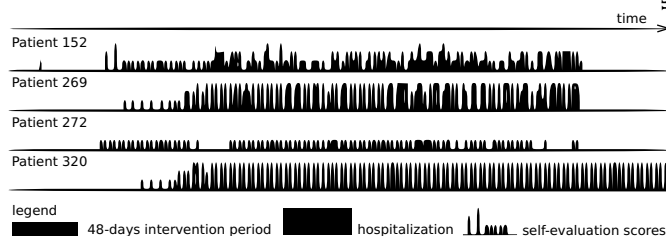


Fig. 4. Noisy Patients

TABLE I  
PREDICTION PERFORMANCE COMPARISON

Experiment 1	AUC	Experiment 2	AUC
all patients (72)	0.799	pre-selected patients (37)	0.961

Than there are patients who tent to produce different kind of noise:

- 1) Non-responders – patients who just send zero messages most of the time, regardless of hospitalizations. Figure 3 shows four typical non-responders.
- 2) In contrast to non-responders, *noisy patients* send high scores all the time without any relation to hospitalizations. See figure 4 for typical examples.

In general noise in data causes decrease in the overall prediction sensitivity and specificity with less hospitalizations predicted and higher rate of false alerts.

The ROC curve in figure 5 shows relapse prediction performance for all 72 patients participating in the passive branch and compares it with the prediction performance measured on a set of 37 pre-selected patients who tent to have the lowest noise in their self-evaluation.

The selection criteria uses a minimum threshold on average scores within the intervention period and a maximum threshold on scores outside the intervention period.

Table I gives and imagination of the potential prediction performance of a system similar to ITAREPS which would be able to help patients improve their self-evaluations and significantly reduce noisy. Performance is quantified using AUC<sup>3</sup>.

Of course such experiment has to be considered with caution, as there may be other objective reasons for patients to miss worsening before hospitalization or to report worsening without consequent hospitalization.

For some schizophrenic patients prodromes may be extremely quick with an relapse immediately following pro-

<sup>3</sup>Area Under Curve

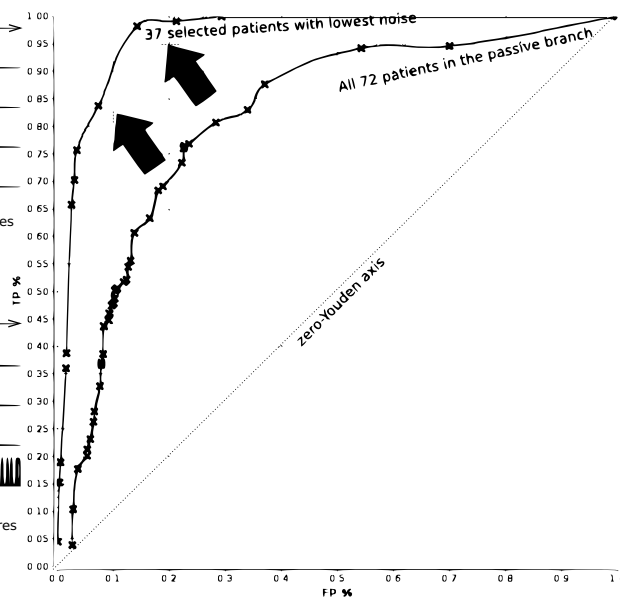


Fig. 5. Prediction Performance

dromes [13]. In fact some of the non-responders may be patients with very quick prodromes. For others there may be worsening which have been naturally improved (no medication increase) without consequent relapse. Of course such cases cannot be improved with any method, but some less noisy diagnostic method than subjective self-evaluation could bring an improvement in prediction performance somewhere in the area between the two ROC curves in figure 5.

### III. DIAGNOSTIC CLIENT

As ITAREPS has employed mobile phones and the short message system, the author of this article suggests to push this effort to the next level and use modern smartphones and their sensors to build a universal diagnostic device which should be able to partially replace the subjective self-evaluation scales with objective measurements of patient's condition worsening.

This research isn't unique and there already exists a similar very recent effort [10] which aims at using smartphones to prevent relapse for the bipolar disorder.

The following sections introduce the design of a next generation diagnostic client application which aims at:

- 1) Acquiring as much data as possible about the patient condition development automatically using objective measurements rather than subjective self-evaluations.
- 2) Making any interaction with the patient as pleasant and simple as possible to maximally encourage patient to cooperate and thus lower the chance of error in the provided inputs.

### IV. SENSORS

Smartphones are mass-produced and thus very cheap, they offer a straight-forward development environment, enough memory to store the collected data and communication possibilities to communicate the data on-line with the data centers.

Modern smartphones offer a wide range of different sensors which may reveal important information about significant changes in patients everyday routine. Such changes may be indicators of the upcoming condition worsening.

Several studies in field suggest the circadian rhythm and quality of sleep are relevant prodromes for various psychotic diseases such as schizophrenia or bipolar disorder [5]–[8].

One of the most useful sensors with respect to sleep and circadian rhythm is definitely the accelerometer build in most of the today's smartphones or even the recently arrived smartwatches.

In general the use of accelerometers in medicine is called actigraphy [11] and it has many interesting applications.

The latest set of research articles suggest that in the clinical setting, actigraphy is reliable for evaluating sleep patterns and in the diagnosis of circadian rhythm disorders [11].

Article [12] shows how one accelerometer attached to the patients hand can be used to detect various daily activities such as hygiene, eating, cooking, watching tv, sleeping etc.

In addition to the accelerometer, another interesting sensor on board of most today smartphones is the GPS which allows to track different places the patient has visited and thus learn his daily routine in order to find divergences [10].

In case we take this idea to excess, we could even measure the patients social interaction using the build in social network integration applications or tracking his phone calls (of course privacy matters have to be taken in consideration here).

With smartphones we are not limited only to sensors which are already part of the device. Various communication interfaces of the phone (such as USB, bluetooth, network connectivity...) may be used to connect the device with additional external devices/sensors for example for measuring blood pressure, blood glucoses, body weight etc.

Smartphone's user interface featuring touch screen is very intuitive and user-friendly. Various diagnostic tests may be designed to be amusing and game-like to encourage patient's cooperation.

## V. SENSORS AND PRODROMES

The following list shows the schizophrenic prodromes discussed earlier and how or whether they could be addressed with a smartphone diagnostic application.

*Sleep worsening* – Automated sleep tracking. The patient places the phone on the bed or uses watches with accelerometer to capture a sleep actigraph. The actigraph is than used to measure quality of sleep [11].

*Decrease in appetite* – At this stage decrease in appetite needs user interaction. In certain times of the day the application asks the patient whether he had his breakfast / lunch / dinner already and whether it was small / medium / large.

Another future work option is to track patients weight on regular bases. This would lead to less interactions. Either it would require a bluetooth enabled scale or relying on the patients input.

Based on the findings in [12], eating is an activity with the far greatest accuracy in detection using the accelerometer. This implies changes in appetite may be deduced from the time spend daily with eating.

*Cognitive skill worsening* – May be addressed with a set of game-like cognitive tests measuring the patient's short-term memory, reaction time, concentration etc.

*Social withdrawal* – With help of GPS and the patient's input the application can make a database of places separated into groups such as family, friends, work, home.

Article [10] even suggest an automated method to identify meaningful locations from the GPS data stream. Consequently the application may measure time the patient tends to spend in those places.

Social withdrawal may be related to significant increase of time the patients stays at home. Also social interaction through phone calls or social networks may be a source of diagnostic data related to social withdrawal. One of the activities which may be recognized from the actigraph is webcam chatting [12].

*Agitation, restlessness, irritability* – This prodrome can probably only be addressed by a self-evaluation question issued regularly to the patient similarly to current ITAREPS questionnaire although there may be indication of such behavior from the daily actigraph.

*Strange and unusual thinks happening around* – This prodrome can probably only be addressed by a self-evaluation question issued regularly to the patient similarly to current ITAREPS questionnaire.

*Loss of energy and interest* – The physical aspect of this prodrome may be measured using actigraphy or GPS [10].

*Not coping with everyday tasks* – This prodrome may be addressed through specific cognitive tests.

*Hearing voices* – This prodrome can probably only be addressed by a self-evaluation question issued regularly to the patient similarly to current ITAREPS questionnaire.

*Deterioration in personal hygiene* – Article [12] suggest hygiene as a daily activity can be detected from the actigraph with a 90% accuracy. The frequency and duration of performing this activity may be a base for the objective measurement of this prodrome.

*Marked behavioral changes* – May be limitedly deduced from changes in the everyday routine which are measurable using actigraphy and GPS.

## VI. THE SMARTPHONE APPLICATION

A proof of the concept smartphone application for the Android platform has been implemented as part of this research.

The application produces SMS messages<sup>4</sup> in the same format as send by the patients, but the provided values are based partially on the objectively measured aggregated data from the sensors. This allows to use the ITAREPS back-end as it is without any modifications. Also patients who use the new application can coexist with patients who are answering the questionnaires within the same system.

Relative worsening is calculated for each prodrome by comparing measurements from the last week with the current week. The resulting value is than discretized in five folds, from zero to four.

Sensors provide much more information about patient's development than the questionnaires. That's why raw sensor

<sup>4</sup>The smartphone's SMS API is used to send those messages.



Fig. 6. Application Screenshots

data is also captured for consequent data-mining analysis to find new successful predictors of relapse.

The application consists of pluggable *tasks* which are scheduled for a certain time of execution. There are foreground tasks which require user interaction and background tasks which run periodically without notifying the user.

The currently implemented foreground tasks include: cognitive tests such as memory and reaction time tests, consumed food inquiry which runs three times a day, medication inquiry where patients fill in the amount of pills left in their package so that the answers may be checked for consistency and other configurable questionnaires which allow easy to use interaction with patients through the touch screen and components such as a rolling wheel or sliders.

Background tasks include: sleep tracking and pedometer based on data from the accelerometer sensor and a synchronization task, which periodically sends the measured data to the server.

The application uses Android Sensor API to access the phone's sensors, CPU wake locks API to keep the data collection enabled even when the phone is not active anymore, the RTC Alarm API to wake the phone up in scheduled times and the SQLite database to store and back-up intermediate data before they are synchronized with the server.

## VII. APPLICABILITY

The design of the Android application allows pluggable tasks so different sets of tasks may be used to track different features of the patients' development not only for schizophrenic patients but also for other diseases in different preventive telemedical programs.

For example the ability to track physical activity may be very useful in various weight management programs, in

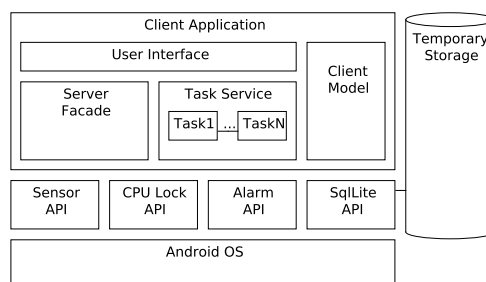


Fig. 7. Application Components

fighting obesity or preventing various coronary or respiratory diseases.

The ability of tracking and reminding of medication usage is generally applicable to many different areas from psychiatry to diabetes, coronary diseases etc.

Various cognitive tests or training programs may help patients suffering various cognitive disorders.

Similar smartphone applications may even be used to build a generic preventive platform to track the general life-style habits of their users, alert on dangerous trends and advice on improvements in order to help timely prevent various widespread life-style diseases.

## VIII. CONCLUSION

This article demonstrates an approach to improve quality of collected data in a telemedical program using smartphones as diagnostic devices. The implementation is mostly specific to the ITAREPS program but similar approaches may be applied also in other preventive telemedical programs which currently rely on subjective self-evaluations.

Even the efficiency of this approach needs to be first validated in a future work trial, at least the potential effect of data quality improvement has been measured on the passive branch of the double-blind study using ROC curves.

Similar experiment may be performed in other telemedical programs to see whether developing a smartphone-based diagnostic device would be worth the effort.

## ACKNOWLEDGEMENT

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