REMOTE PATIENT MONITORING SYSTEM WITH DECISION SUPPORT

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ABSTRACT
Remote patient monitoring (RPM) has been considered a highly potential and cost-effective means to increase patient's motivation for self-care. The paper describes an architecture which combines decision support (DS) functionality with the RPM system. The new approach provides automatic feedback to patients while health professionals are only alerted when there is a need to review the patient data or contact the patient. The objective is to decrease the workload of the health professionals while maintaining high quality and patient compliance in chronic disease care. The combined RPM/DS system is being implemented in a primary care environment for a clinical trial to be carried out for evaluation of the concept.

KEY WORDS
Health care information systems, Remote patient monitoring, Clinical decision support system, Personal Health Record

1. Introduction
A major part of all healthcare costs are caused by severe health complications arising as a consequence of uncontrolled chronic diseases. Potential cost reduction has motivated the research for new ICT-based concepts for improving the care of chronic patients. Remote patient monitoring (RPM) has been considered a highly potential and cost-effective means to increase patient's motivation for self-care. Recent studies, have demonstrated that RPM may improve control of chronic diseases [1] and may reduce the need for physician office visits of diabetes and hypertensive patients [2]. Consequently, also high demand has been predicted for commercial RPM applications [3].

In a number of studies it has been shown that improved health outcomes are obtained only when RPM is combined with human support given by a health professional [4]. The need for human resources may lead to cost increases mitigating the potential savings of RPM. This paper introduces an RPM system with Decision Support (DS) mechanisms aiming at reducing the health professionals' workload. The RPM/DS system supports both patients and health professionals by providing decision support reminders (alerts, notifications and advice). The reminders help the patient to control the disease at home and guide him/her to contact the health professional when needed. The health professional receives a reminder only when there is a need to have a look at the patient's monitoring data. This approach is expected to considerably increase efficacy since the professional can focus on those patients which are most in need for support.

Currently, clinical decision support systems are widely deployed for the support of health professionals and resulting benefits in patient care have been shown in several studies [5]. Concerning patients, decision support is in many cases limited to provision of generic information on diseases and drugs. Some clinical DS engines, such as the Evidence-Based Medicine electronic Decision Support (EBMeDS), provide specific patient-oriented DS reminders, which can be made available through patient portals [6]. Additionally, interactive tools for diagnostic decision support for patients are available [7]. The idea of using evidence-based DS for supporting RPM processes is quite new. Such system, particularly addressing real-time RPM, capable of handling streaming data has been proposed earlier in [8], envisaging a system, which accepts and interprets real-time context data and biosignals from body sensors together with less dynamic clinical and administrative patient data. However, complete RPM/DS implementations integrated to operative clinical processes and information systems are not known to the authors.

The present paper contributes to the state-of-the-art by describing an evidence-based RPM/DS system integrated to the clinical information systems and processes of a primary care centre. The system is currently being
implemented and will be evaluated in a clinical study to be carried out in years 2011-2012 in Sipoo health centre, Finland.

2. System architecture

The overall architecture of the RPM/DS system is shown in Figure 1.

![Figure 1. RPM/DS system architecture](image)

The core component of the RPM system is the Personal Health Record (PHR) database which stores all the data resulting from measurements carried out at home. Additionally, clinical data content, e.g. medication and laboratory data, is transferred to the PHR from the Electronic Health Record (EHR) system. The EHR system (Mediatri) is the primary tool used by the health professional for managing clinical patient data.

The Personal Healthcare Monitoring Report (PHMR) recommended by the Continua Health Alliance has been adopted as the interface for exchanging information between the PHR and other applications external to the clinical domain [9]. The PHMR defines constraints to the HL7 Clinical Document Architecture (CDA) relevant for the particular application in RPM. The PHMR specification provides the mechanism to semantically define the data items inserted to the PHR allowing data to be provided from different measurement devices and their respective back-end servers. In the current implementation, a mobile phone based application (Monica) is connected to a monitoring server which communicates with the PHR database by the PHMR interface. The patient uses the Monica application for reporting monitoring data to the PHR.

The patient may also access the PHR contents via a web interface (Medinet). Decision support functionality scans through the PHR content and provides patient-specific reminders for the patient and the health professional. The knowledge base includes rules defining under which conditions and to which party - patient or professional - each reminder should be given. An inference engine uses the rules for selecting the most appropriate reminder in the present context. The PHR server requests reminders from the DS module always when new data are uploaded to the PHR by the patient. The reminders are displayed for the patient in Monica and Medinet user interfaces. The health professional's reminders are directed to the nurses' worklist in the Mediatri user interface.

3. Mobile application

The experiences from earlier studies show that good usability of end-user applications is essential. It is important to note that high usability requirements apply to the whole process including the service initialization phase when the patient starts the self-care programme. In order to avoid the obstacles in preparing and configuring the application for use, we have adopted the approach of providing the patient with a dedicated phone to be used for reporting instead of using the patient's own device. The major advantage of this approach is that the application can be optimized for the particular phone type and user support can be more easily provided. The cost of the mobile phone and related communication costs are low compared to the total costs incurred by the patient's disease and should be easily motivated for the healthcare payer.

The Monica application (Figure 2) is particularly designed to be used by mobile phones with a touch screen. The touch screen user interface enables large and intuitive user interface components to be used. In order to be simple and robust the application provides only the most essential functionality: reporting measurement data and receiving related feedback. Monica employs a wizard-approach which guides the patient through a set of interactive panes. The panes allow the patient to enter measurement data and subjective health status information.

Examples of panes included in a typical RPM data reporting sequence are shown in Figure 2. The requested measurement data items are entered by changing the previously reported value. After sending the data the patient receives a decision support reminder based on the present value and the previously reported values. After that a graph showing the latest value compared to earlier values is displayed. The wizard guides the patient to watch through the results and reminders after which the patient can move back to the start page. The items to be requested from each patient can be dynamically adjusted via a specific web-application (Monica professional) available to the care personnel.
4. Personal health record

The Personal Health Record is complementary to the Electronic Patient Record (EHR) and provides a patient-centric platform for managing all personal health-related information contents. Moreover, it provides an environment for exchanging information between the patient and the health provider's care processes. It is expected that the availability of the PHR motivates and empowers the patient to take more responsibility of his/her own health maintenance and care.

The Medinet PHR provides versatile support for the remote patient monitoring process. In the start of the process the patient fills in a specific questionnaire, which reveals information on the personal life-style and health risks. The information is used as a basis for the self-care plan which is entered in the PHR. The self-care plan defines personal goals to be met and the measurements to be carried out at home in order to follow-up the progress. The plan is defined in mutual understanding between the professional and the patient. During the RPM process all the data reported by the patient at home and the related DS reminders will be collected in the PHR. The patient can follow the accumulated data in graphs and tables by the web based user interface. The PHR also includes other relevant information, such as messages sent between the patient and health personnel and clinical contents, such as medication and laboratory data. Additionally, the PHR contains general guidance for the patient and links to external health information resources. This way the PHR provides an integrated and personalized view to all relevant information related to the patient's health.

It is critical that access to the PHR contents is securely controlled. The patient's authentication is based on the TUPAS protocol and password list, which is largely also used for network banking in Finland. Concerning the health professionals, accessing the PHR is subject to consent given by the patient. If the consent is given, the health professionals can access the PHR from within the health centre's network after signing in with their network password or smart card.

5. Decision support

The selected decision support mechanism for RPM data follows the same architectural approach as the Evidence-based Medicine Electronic Decision Support (EBMeDS) system [11], which has been integrated with the Mediatri EHR system earlier. The basic idea is to keep the knowledge base containing the decision support rules separated from the personal health data contents (the PHR) and the inference engine. This allows the decision support rules to be separately maintained without the need for large software modifications as the rules are changed or new rules are added. The other advantage of the architecture is that the inference engine and knowledge base could provide a common and open DS request interface for several PHR installations. This would be possible if PHR data is available in standard form, such as the PHMR [9], and can be mapped to the DS request interface.

The decision support process is described in Figure 3. The process is triggered when new data is entered to the PHR by the patient (1a). Alternatively, the process starts for each patient after a period of two weeks if no data has been entered (1b). When requested (2) the inference engine provides DS reminders using the PHR and knowledge databases (3,4,5,6). Most of the reminders are forwarded to the patient (7). In the cases, when contact to health professional is recommended the reminder is also directed to the EHR worklist for the attention of the care personnel (8,9).

Concerning medical content, the decision support rules are based on the EBM guidelines [10]. The rules divide into four categories according to their respective output (reminder content):

- Indication of a possible measurement error. Given, if the result is inferred to be likely a measurement error a new measurement is requested.
• Alert to contact the health centre. Given, if the measured parameter indicates a value beyond safe limits.
• Notification with medical content e.g. related to health risks, when reported values are not satisfactory. Given, if a health parameter is not within the recommended range and indicates non-compliance with the care plan targets.
• Positive feedback including related medical content when patient is doing well. Given, if a health parameter is within the recommended range and indicates compliance with the care plan targets.

When requested for a reminder the inference algorithm checks all pre-defined reminders and their respective rules in the knowledge base and selects the most appropriate one. The fulfillment of a rule is evaluated based on a subset of data stored in the PHR, including RPM data, other clinical data and personal goals. In the case where several rules are fulfilled, one of the candidate reminders is selected for output. The selection algorithm takes into account the pre-assigned priority of the rule (highest for suspected measurement error and contact alerts), previously given reminders and the positivity of the reminder. The algorithm also includes a random component introducing “natural” variability to the sequence of reminders, when possible without compromising the delivery of high priority alerts to the patient. The overall objective is that the patient finds the reminders useful and that they support the patient in disease management and efforts to achieve a positive life style change.

6. Evaluation trial setting

The system described above is being implemented for a trial to be carried out between January 2011 and March 2012 in Sipoo Health Centre, Finland. The objective of the trial is to evaluate the new care model related to the use of combined RPM and decision support. In particular, the target is to obtain experimental data and evidence on:

• improved health outcomes in terms of change in the level of blood pressure (hypertensive patients) and glycohemoglobin (diabetes patients).
• positive effects in terms of subjective quality of life, change in BMI, care compliance and health risks
• change in patient visits and telephone contacts
• maturity of the technology and the acceptance of the technology by users including both patients and the care personnel

The trial setting takes into account the fact that all patients will not be compliant for technology-supported self-care. The study includes patients in the age range of 30-70 years. Patients which are estimated to have insufficient capabilities for using the measurement devices and applications at home are excluded from the study.

The study protocol is depicted in Figure 4. A group of 100 patients will be enrolled for the study. They are randomized into two groups of 50 patients. During the nine month study period the patients of the intervention group carry out measurements of blood pressure, glucose, body weight and activity as relevant concerning their chronic condition. The patients use the Monica and Medinet applications to upload data to the health centre and to receive respective reminders. Patients belonging to the control group will receive standard care in the health center as before. Both groups will attend a medical examination in the beginning and end of the study period.

Figure 4. Evaluation trial protocol.

Figure 3. Decision support process.
7. Conclusion

Despite of extensive efforts there are so far few examples of successful installations of remote patient monitoring. There are two main obstacles to pass. Firstly, the health providers need to invest in RPM technologies and offer these services to their patients. This may happen only if the benefits of RPM are clearly pointed out for the healthcare payers. In particular, the offered RPM technology and process shall not increase costs. Secondly, once the investments have been made and RPM services are operational, the patients and professionals should use them. This may happen only if the offered services are easy to use and if they are useful as compared to the conventional care model.

Based on recent studies [12] more than 80% of US citizens around 30 years are online internet users, while the corresponding percentage is still as high as 56% for the age group of 64-72 years. Based on this, it can be expected that a considerable part of the total population are potential users of technology-assisted self-care.

We have described a new technical solution which integrates decision support functionality in a remote patient monitoring system. The potential benefit of the new approach is that the RPM process can be maintained with less human resources lowering the step for the health provider organizations to adopt technology-assisted self-care. Specific attention has been paid to the usability of the applications for both patients and health professionals. The pilot study to be carried out in the Sipoo Health Center seeks to provide evidence on the achievement of the resource savings and user acceptance in practice.

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