Home telecare and rehabilitation system with aspect oriented functional integration

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Abstract

Modern home telecare is shifting from emergency conditions detection to the wellness monitoring, treatment plan observation and rehabilitation. Because of such shift the telecare attracts more beneficiaries besides of traditional elderly and chronically ill people. From the other side, more complex systems for simultaneous treatment and safety monitoring involve more stakeholders – physiotherapists, primary doctors, carers and patients. Possibly contradicting requirements and perspectives of different partners are rising significant system usability and planning problems. In the paper we describe an extendable and requirement conflict tolerant software framework for home health hubs (HHH) for simultaneous motor rehabilitation (post-stroke and -arthroscopy) and patient safety observation. Aspect oriented software design and -requirement engineering (AORE) are used to representing interest or viewpoints of different participators.

1 Introduction

Due the scalability problems of traditional healthcare service models there is growing tendency to decentralization, shifting care from the hospital to the community. Home-centred healthcare has become an important health management issue [1, 2]. In near further home telecare shall become an efficient extension of hospital treatment procedures [3, 4]. In the paper we describe how to extend classical (passive) home vital signs monitoring solutions with user friendly (active) motor rehabilitation functionalities. The development focuses on a flexible agent based software framework minimizing the home patient safety risks, simplifying treatment and training plan setup and monitoring. The framework is universal and applicable for different homecare scenarios of patient monitoring and training in home rehabilitation assistant (HRA) system. Our current software implementation for home health hub (HHH) device is mainly targeting post-surgery and post-stroke training. Focused exercise training is beneficial for stroke recovery [5] and essential therapy component after surgeries. Training quality on such cases rely on the availability of skilled therapists or training robots. Unfortunately assistive machines are intended for hospital use only and have limited accessibility due the price constraints.

As stressed by Sabatini already in 2005 there is a need for ambulatory monitoring systems providing objective assessment of human functional abilities outside of laboratory settings [6]. One reason of lack of integrated systems supporting both home safety monitoring and training support is the complexity of handling the requirements of different parties: patient in comfort zone, primary care doctor focusing on patient’s general safety, physiotherapist targeting recovery of joint movements. Today’s home training procedures composed by physiotherapists are intentionally conservative to avoid any potential risk to patient’s safety. Additionally, it would be too complex for patient or direct carers to (manually) adapt individual treatment plan according to changes in health condition or gained progress. Such adaptive treatment would be possible, at least in some extent, with decision support systems capable of handling interests of different stakeholders.

A practical agent based software framework is described in the paper using aspect oriented software design (AOSD) and -requirement engineering (AORE) methodology for designing the telecare system for formally safe home rehabilitation and patient monitoring. Developed prototype software is able to instruct user during exercising in real time and takes into account of personal defeasible safety rules.

2 HRA instrumentation

Home rehabilitation assistant (HRA) system targeting machine supervised patient exercising contains subcomponents: HHH as data acquisition gateway and user interface device; generic vital signs sensor system (VSSS); micro-electro-mechanical sensor system (MEMSS) for patient physical activity and exercise quality monitoring. The HHH (Image 1) acquires and analyses sensor data, interacts with the patient and communicates with the hospital EHR repository over the Internet. For realizing HRA functionality on HHH we reuse our existing telemedicine home gateway solution [7] (Image 1). The sensor data, patient parameters, configurations, and system states are kept in the in-memory database organized as whiteboard data exchange solution.

Besides the extended VSSS subsystem (containing BP and SpO2 meters, weight scale, sensorized box of pills), HHH serves as a MEMSS data processor in real time. Comput-
ized analysis of exercising data is essential for presenting intelligible numbers to the physiotherapists.

Image 1 Home Health Hub with sensors

Several different practical methods of human motion and gait analysis are concluded in a review [8]. Several off-the-self MEMSS based (patient) physical activity monitoring products exist from different vendors - activPAL, PAM-Sys, ActiGraph and others. However, such devices typically act as standalone activity loggers or can just recognize basic patterns of walking, sitting, lying. Extensive review of experimented activity classification methods for human activity recognition by MEMSS is presented by Preece [9]. Tests with an original MEMSS system [10] (Image 2) showed that limb training quality can be sufficiently correctly monitored using neural networks (NN) and k-nearest neighbor (kNN) classification methods and 3 gyroscope sensor nodes.

Image 2 Prototype MEMSS for hand training

3 HRA use scenario

We see the purpose of HRA as a low cost assistive tool guaranteeing correct exercising without immediate physiotherapist supervision. A physiotherapist initially instructs the patient and also configures the HRA equipment at hospital. During the calibration session the patient does exercises that the physiotherapists evaluates correct or incorrect. The HHH records signal patterns of MEMS sensors used later as reference data for exercising assessment. For each exercise reference data for training a neural network has to be recorded.

For creating the rehabilitation plan the physiotherapist first choses and adjusts exercises for the patient. The plan is the basis for the system to monitor patient’s training at home, give reminder alarms and recommendations as well as the basis for the evaluation of the patient’s independent training. Some important details, however, does not fit into the exercising schedule, these must be added as separate rules. For example, the patient is required to measure BP and HR at given times or in relation with exercising sessions. The exercising plan could be affected by the measurement results, for example if the BP is too high before the exercising the session might be delayed.

As an essential enhancement the proposed solution supports simultaneous training and safety monitoring. The preconfigured HRA system tracks the treatment plan fulfillment at home. Primary care doctors or carers can insert additional safety rules to the HHH. All patient movements are collected while the sensors are operational. During an exercising session the system monitors if the patient is doing correct number of exercises in the required order. Also the similarity measure with the reference is calculated for individual movements and displayed to the patient with a multimedia guiding option.

All of the event log and statistics that are gathered during the home rehabilitation period is recorded for physicians and can be uploaded to the hospital information system using previous telemedicine framework [11].

4 Aspect oriented approach for realizing HRA software

Due to the functional complexity of proposed HRA solution there is a need for provably correct approach for solving contradictory requirements. A fundamental principle in addressing system’s complexity is separation of concerns. It is important in the analysis phase to define the application decomposition and identify the inventory of concerns that lay ground for modularization and structure of a future requirements model. Aspect oriented requirement engineering (AORE) is a methodology that can help to improve requirements completeness, maintainability, and reduce cost of software development [12, 13]. AORE is suitable for distributed systems applications lacking system’s “global picture” [14] or integration of independent, goal-oriented tasks. The model is put together using all viewpoints of stakeholders and AORE analysis techniques. Aspect oriented software development (AOSD) aims at addressing crosscutting concerns by providing means for their systematic identification, separation, representation and composition. Crosscutting concerns (CC) are encapsulated in separate aspects and composition mechanisms are later used to weave them with other modules.

4.1 Implementation of HRA system

Now we describe actual HHH software which is realized as the optimal set of aspects gained from AORE methodology. Each aspect is following its own goal independently from the targets of others. All aspects are implemented as one or more software agents dealing with specific type of data items on the HHH whiteboard corresponding to certain activities and situations. Thanks to the AORE meth-
odology new agents can be added to the HRA system in runtime which significantly improves the system usability. Particular agents to be present in certain cases are defined by the treatment plan and its constraints. All components of the system are intended to run independently and complement the overall system behavior without need to explicitly know about the presence of other agents. Cross-cutting and general interoperability is achieved by the utilization of whiteboard where every agent could interact with the entire knowledge existing in the system for intervening ongoing workflows. An agents does not overwrite values given by other agents, instead of that it adds its own version and marks itself as the source. All the aspects and agents are ordered by priority. Depending on the situation the agent picks the value with the highest source priority or the value inserted by someone with lower priority compared to itself.

One of the key issues of the system is its scalability which means introductions of new aspects and agents in the future. The HRA solution is currently implemented on an off-the-self Linux running HHH device with a sub-gigahertz ARM processor. On the given platform writing 1500 rows of bulk data to the HHH whiteboard takes 100ms. A long term average reading time of one row is around 100us. Assuming that the agents are performing simple tasks and using small number of rows on the whiteboard, it is possible to run the HRA effectively with around 100 independent software agents.

### 4.1.1 Treatment plan aspect

Treatment plan aspect is responsible for steering the patient to follow the treatment plan. The aspect is split to several smaller agents. “Treatment plan follower” agent checks current time and the original treatment plan inserted by the doctor. When it is time to start exercising again, the agent prepares data structures for upcoming exercising session. Original treatment plan is left unmodified; all adjustments are done to the copy.

“Exercising plan feeder” agent checks for and interprets the actual session plan whenever it is present and generates guidance messages for the patient. As the agent reads from the whiteboard what the patient is supposed to do and what exercises are already done it can determine what the patient should do next. The output is not directly rendered to the screen but saved back to the whiteboard to be picked up by corresponding agents.

A slightly different task is given to the “sequence checking” agent. The patient could do whatever movements regardless of the exercising plan and system’s messages. As the order of exercises, which includes relaxation in certain points, is relevant then the patient should be notified if he or she does something wrong in respect to the plan.

The treatment plan “adjusting agents” adjust the session plan accordingly to the constraints and rules. For example, if the patient has completed all previous sessions during the last five days without deviation from the plan the next session could increase the number of repetitions for some exercises.

### 4.1.2 Correctness aspect

Correctness of movements is considered as a separate issue and handled by “Correctness evaluator” agent who analyses incoming movements by comparing them to the examples recorded at the hospital and calculate the similarity measure SM. These evaluations can be presented to the patient during the exercising session for indicating if the patient is doing exercises correctly or not. At the end of the exercising session when all movements have been captured and evaluated the “guide agent” could present the media guide if some exercises have high failing ratio.

### 4.1.3 Rehabilitation progress aspect

The aspect of progress is basically concerned with the results of the rehabilitation and monitoring its progress. “Statistical analyzer” agent prepares reports for the doctor. The agent runs only once per day and looks back at the exercising session plans and committed exercises. Similarly it can look back at the exercises of previous days and make conclusions of how much the patient is exercising, whether the patient can tolerate more load than before, is the trend of the correctness of movements satisfactory, has the movement range of the joint increased etc. Quick reports are useful for getting overview of important circumstances of the rehabilitation when revisiting the hospital.

### 4.1.4 Daily living aspect

“Inter-session activities counter” agent pays attention to movements committed outside the exercising sessions. Provided that the sensor is online and registers patient activity when there is no exercising session going on, this information should be taken into account. If wireless sensors are used and some movements of daily living (like opening doors, picking up objects) are similar enough to the prescribed exercises and are recognized by the system the agent can adjust upcoming exercising session. When a new session plan is created the agent could decrease the number of recommended repetitions in the case where it can identify considerable load to the damaged joint to avoid overburden.

### 4.1.5 Safety aspect

Safety requirements have to be continuously fulfilled in runtime therefore a set of agents deal with safety monitoring and reporting of dangerous situations to various stakeholders. For example, when the “emergency agent” detects fall down and no further activity within the next moments, it initiates an emergency call to summon help. Also other critical situations are monitored depending on the patient’s conditions and available sensor readings.

The “doctor alert generator” agent concentrates on the events that cannot be classified to emergencies but still need intervention. While minor problems of following the treatment plan do not need to be reported in real time as the doctor checks the data at the patient’s next visit to hospital, then occasions of major violations could be checked earlier. For example, if there are no traces of any exercis-
ing activity in the past three days it sends a notification messages to the doctor. The “patient alert generator” agent outputs local warning messages intended for the patient. The patient should be informed about the actions and situations which are unfavorable. Whenever some exercising fairly exceeds limits recommended by the session plan or the patient performs movements too vigorously the agent creates outputs warnings.

4.1.6 Input-output aspect

The agents responsible for direct input and output actions form the input-output aspect. Each sensor device (MEMS system, vital signal sensor) is handled by corresponding input “adapter agent”. Adapter agents communicate to the sensors and receive raw data, restructure it and store on the whiteboard.

“Output agents” are adapters to output devices like the screen or speakers and also the agent for network communication. The screen adapter searches the whiteboard for information about the contents of different virtual windows (warnings, correctness measures, feedback, etc) that it renders to the physical screen areas.

The “output manager” performs as a mediator between the system and the output adapters. Incoming exercises are displayed on one virtual window, warnings are played by speakers, etc. If there are several possible messages suitable for one channel then they are sorted by the source priority and the information with the greatest impact is chosen. When the situation on the whiteboard is updated the agent also reappraises its output.

4.1.7 System aliveness aspect

Self-monitoring mechanism is two-layered. Every agent registers itself on the whiteboard when started and updates its personal aliveness token. The “self-monitoring” agent constantly monitors all registered tokens and restarts the malfunctioning agent. The self-check agent guards itself with the hardware level watchdog that reboots HHH immediately if contact is lost. Such multi-layer watchdog solution reduces the number of unnecessary restarts.

5 Conclusions

Complex monitoring and control systems involving different stakeholders are difficult to develop, maintain and use because of different viewpoints. Based on an example of patient monitoring and motor rehabilitation involving requirements of physiotherapists, patients and clinicians we demonstrated that aspect oriented requirement engineering is a practical and approach for such systems. At certain extent, essential functionalities of home based rehabilitation were presented as aspects which demonstrate applicability of AOSD techniques for user adaptive telecare. HRA software agents were described and implemented driven by AORE analysis results and tested within a whiteboard based agent software framework. The presented aspects form an optimal set for the considered HRA task.

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6 References