Intelligent System for Premature Babies Healthcare at Home based on Case-based Reasoning

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Abstract. eHealth is offering a new way of delivering health services through the internet. Most eHealth applications are presented as new business arena with dubious clinical support. This research presents an eHealth system where users use technology within a home care program of patients with early hospital discharge. In particular, our work concerns premature babies' care that can shorten their recovery period at home, where they can enjoy a more familiar environment. To guarantee the clinical monitoring of the patients, the eHealth system relies on case-based reasoning, an artificial intelligence methodology for developing intelligent systems that enables personalized patient's treatment. In this paper we review the architecture of our system which has been developed in the framework of the MoSHCA project. It consists of three main components: the mobile, the server and the connection with the Hospital Information System. Case-based reasoning is used in several of the components to provide adequate support to both, babies and their families at home and physicians at the hospital regarding the baby care and follow-up.

Keywords: eHeath, Mobile Computing, Healthcare, Intelligent Systems, Case Based Reasoning, Medical Decision Support System, Interoperability, Clinical Terminology

1 Introduction

E-health has become an emerging field in which health professionals and health consumers create and seek information. E-health refers to health services and information delivered through the internet and related technologies. The evident benefits of eHealth is the reduction of cost of healthcare, higher efficiency through better medical records management, and fewer or shorter hospital stays, among others [1].

This work deals with the premature babies' case. Every year around 500,000 kids are born prematurely. These babies need special medical attention in the neonatal intensive care unit (NICU). They need hospital supervision until their systems and organs can function with no external assistance. Recent studies show that during part of this time the baby needs only supervision rather than medical treatment and that this time is shorter if spent in a familiar and loving environment. However, complications might arise at any time and the vital signs of the baby should be closely monitored. To monitor babies at home, mobile devices offer an invaluable service. This work is related to developing an application for home care of premature babies thanks to mobile devices. The work is framed in the MoSHCA project.

MoSHCA [2] is a mHealth project designed to improve the patient-doctor interaction and control of diseases. The number of people with chronic or long treatment diseases is growing worldwide. Self-management of such diseases is crucial in the prevention of serious and costly complications. MoSHCA provides intelligent, user-friendly, secure, medical and well-being decision-making embedded software, utilizing medical sensors that synchronize with the mobile phone, and this in turn with medical information systems. MoSHCA enables the home care of several patients that otherwise should extend their hospital stay. The authors of this paper are two of the partners of the MoSHCA project (IdIBGI and the eXiT research group of the University of Girona) which focus on the case use of the system for home care of premature babies.

The aim of this paper is to present the architecture of the intelligent system developed for the premature babies' application, with special use of case-based reasoning (CBR) which enables a personalized care of babies. Our goal is to provide an application to premature babies' cares with an intelligent reasoning module that provides recommendations and supports them in the baby care, while keeping them under the control of clinical staff.

The paper is organized as follows: next section provides a brief overview of the related work. Section 3 describes the use case which motivates the proposed intelligent system. Section 4 outlines Case-Base reasoning as the underlying method of our intelligent system. Next, the architecture designed and the different components are described in Section 5. Finally, the last section provides concluding remarks and directions for further research.

2 Related work

CBR has already been applied in a number of different applications in medicine [3, 4]. CBR is appropriate in medicine for some important reasons; cognitive adequateness, explicit experience, duality of objective and subjective knowledge, automatic acquisition of subjective knowledge, and system integration [5].

Currently there are some cases of applications for mobile using CBR, but mainly on tourism applications. In the healthcare domain, CBR on mobile applications has also been used in the field of smoking cessation [6]. The authors state that mobile based messaging systems have already experienced acceptability when backed by the motivation to undertake certain behavior changes, according to the results of several experiments. CBR enables in this case, the personalization of messages. Other health applications on mobile phone lacks of intelligent components, as we are developing.

There are some applications available off-the-shelf [7, 8], most of them designed to collect information at home that is processed later on by physicians. The monitoring that they are currently performing consists on filtering out the information entered by the cares manually, and locally, at the mobile device, they perform a simple filtering of the values entered according to some given allowed ranges. In [9] a physiological monitoring application for Android mobile devices is presented. The application has been designed for connecting to any Bluetooth health device and it enables data transfer to a remote server.

From our understanding, mobile devices has much more capacity, and are currently able to host most sophisticated applications. Particularly, we focus on including Artificial Intelligence based decision support techniques to make mobile applications smart.

3 The premature babies' use case

Usually, preterm infants are discharged when they achieved a certain weight, typically around 2200g. However, there are some babies that only need supervision rather than medical treatment while they achieve this weight. Then, when a baby is suitable for minimal medical care, parents can measure the vitals of their infant comfortably at home and submit the results to be efficiently reviewed by the doctor. In that doing, three functionalities are analyzed under the case-based reasoning approach: monitoring, reasoning and alerting. Such functionalities are understood as follows:

- Monitor functionality: raw data health indicators of the patient are obtained and stored in an internal storage. Table 1 shows the variables consider in this use case. Sensors used include baby pulse-oxymeter and a baby scale, which provide the information in a wireless basis, a skin thermometer and a transcutaneous bilirubinometer. None of these devices is considered invasive for the baby. A context provider may gather some quality parameters (i.e. timestamp, precision, accuracy) that will be used for evaluating the quality of sensed information. Thus, errors on data acquisition and processing are taken into account.
- Reasoning functionality: an intelligent system analyses the features (health indicators) obtained by monitoring and concludes three different types of situations which are passed to the alerting module:
  - Assessment 1: Baby recovers normally: The intelligent system does not show any alert (everything is fine with the baby).
  - Assessment 2: Baby recovers abnormally: The baby's parameters are out of ordinary.
  - Assessment 3: Baby recovers abnormally and an emergency actuation is required. The baby's parameters are extremely out of ordinary.
- Alerting functionality: alerts are raised whenever critical states (assessments 2 and 3) are detected based on the data processed by either the monitor or the reasoning functionality, or when an improper operation in any part of the system is identified (i.e. a sensor malfunction or server crash). Also, if no critical alert was triggered, the parents receive an acknowledgment from the doctor to assure the correct evolution of the baby.
  - Alert 1: malfunction of an element in the system.

Table 1. Input variables. There are three types of variables according to whether they have been assisted by the mobile (M), a sensor (S) or provided by caregivers (C).

Parameter	Description	Assisted
Date and hour	Date and time of day when the baby is assessed.	M
General aspect	Normal colour and breathing normally.	C
Weight	Weight of undressed infant in gr.	S
Heart rate	Heart beats per minute.	S
Respiratory rate	Respirations per minute.	C
Hemoglobin saturation	Percentage of oxygen saturated haemoglobin.	S
Axillary temperature	Skin temperature taken in the axilla in Celsius degrees.	S
Bilirubin	Concentration of total bilirubin	S
Feedings a day	Number of feeds per day.	C
Daily stools	YES, or NO, depending on whether the baby passes daily stools or not.	C
Weekly stools	Number of stools in a week, in case they are not passed on a daily basis.	C
Sleeping	Whenever the baby sleep mostly during the day, at night, or at any time during the day and night.	C
Taking vitamins	Whether the baby receives vitamins or not.	C
Taking iron	Whether the baby receives iron supplements or not.	C
Taking medication	Whether the baby receives other medications or not.	C
Other aspects	Hygiene, ambient temperature, intercurrent illnesses.	C

- Alert 2: Baby recovers abnormally: The baby's parameters are out of ordinary. A warning notifies this situation to the parents through the smartphone. The parents contact the hospital and get new instructions. Doctor requests a data update and examines the data.
- Alert 3: Baby recovers abnormally and an emergency actuation is required. An emergency alarm is shown to both, the parents and doctors smartphone. Parents should take the baby to hospital. Doctor requests a data update and examines the data.
- Ack: The doctor has examined the data and everything is fine with the baby.

4 CBR

CBR is a methodology for developing knowledge-based systems that attempts to solve a given problem within a specific domain by adapting established solutions to similar problems [10, 11].

CBR has been formalized for purposes of reasoning and learning based on the exploitation of existing similar historical records as humans do. It has been argued that CBR is not only a powerful method for computer reasoning, but also a pervasive behaviour in every day human problem-solving; or, more radically, that all reasoning is

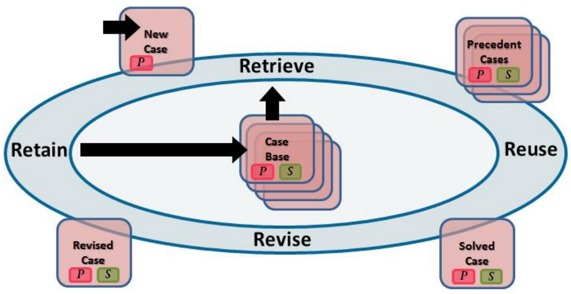

Fig. 1. Four-step process (4R) of Case-Based Reasoning (based on [10])

based on past cases personally experienced. These features make CBR a good contender for any decision support system [12].

The CBR process is divided in four main steps known as the four Rs: retrieve, reuse, revise and retain (Figure1). It basically consists in retaining experiences as cases for a further reuse. Cases are registers containing a description of a problem and its solution. The input of the cycle is a new case of a problem to be solved, and a case base with instances of problems that have already been solved. First of all, the most similar cases are retrieved of the case base. Then, the solution of these past cases is reused to solve the new case. Reuse implies an adaptation procedure of the retrieved solutions that is finished with a revision. After validation, the cycle is completed by retaining the solved situation (problem + new solution) in the case base for future usages.

A key factor in constructing a good CBR engine is defining a model containing the variables needed to decide which decision of a set should be taken. In this proposal the set described above (Table 1) have been used. Then, a case consists in two parts: the baby measurements listed in (Table 1), and the solution or baby state assessment.

5 Intelligent system for e-Health

This section describes the architecture and the components of the medical system designed for the premature baby care use case. The general scheme (Figure 2) is composed by three main components: a mobile capable of gathering data from sensors, an external server, and the Hospital Information System (HIS). It is based on the general framework agreed in the Moshca consortium and can be consulted in [13]. Proper sensors are attached to the baby to start monitoring according to hospital protocol. Most of these medical parameters can be automatically read by a smartphone via WIFI or Bluetooth. Then, recommendation is performed by case-based reasoning algorithms in two stages: first at the mobile using a reduced version (CBR lite) due to mobile limitations in terms of memory and/or processing power, and later, a more complex processing is carried out at the server. Basically, a recommendation consists of an output saying whether there is a risk for baby's health or not. Moreover, CBR can be applied in two phases of the application life cycle: configuration set-up and exploitation. In the configuration set-up CBR is used to tailor the general medical information to the particular patient data (personalized medicine). On the other hand, in the exploitation phase, CBR is used for monitoring and reasoning.

On the other hand, medical professional can access to all the information from his/her personal device (mobile, tablet or PC) through a Hospital Information System (HIS) service. This service provides the communication with HIS databases and an external server containing baby's parameters and the recommendation obtained by the CBR system. If some alert was triggered the doctor can accept it or discard it, and finally the doctor performs a diagnosis. Then he/she sets the data as revised and servers are updated. The parents can see the result of this evaluation on their mobile device. In addition to the data, patients and doctors can establish a real time video conference call.

5.1 Mobile component

Data fetched by the sensors are collected and stored in a mobile, along with other data introduced by caregivers. This information is processed by a CBR Lite obtaining a recommendation which is transmitted immediately to caregivers. Then, the recommendation and the parameters used in the processing are sent to a data server. Figure 3 shows a block diagram with the internal modules of this component. Next, the modules in the figure are described. They have been classified in functional modules and intelligent modules.

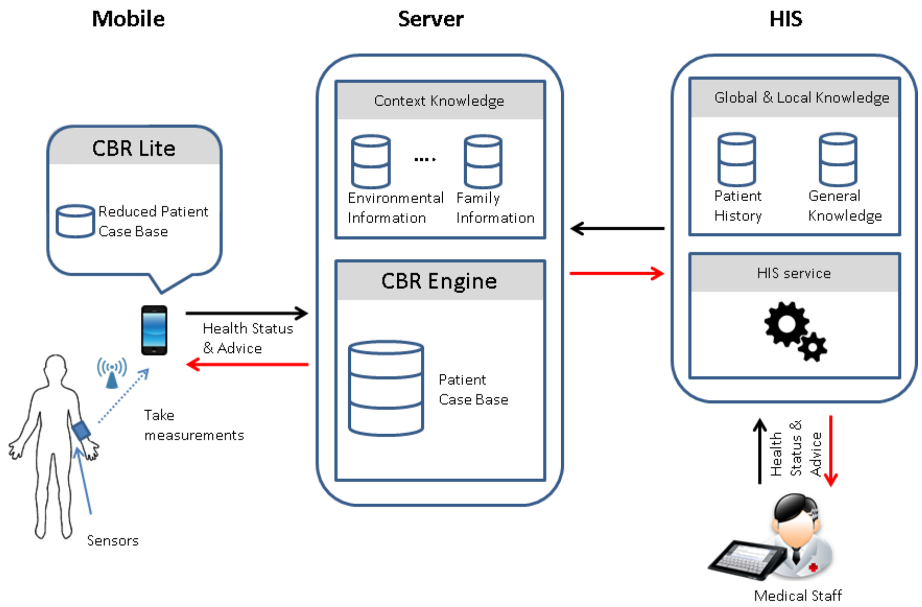

Fig. 2. Architecture overview.

Functional modules are those modules that meet functional requirements of the overall architecture:

- **WS Client Interface**: Is the access point to the internet in the client side (i.e. mobile) and is used to interchange information with the server.
- **Sensor Interface**: Gathers the data of vital signs and other baby's attributes from sensors.
- **Application GUI**: Gathers other valuable information of the baby and shows the recommendations and alerts obtained by the reasoning engine.
- **Data Access Layer**: provides access to the data bases for reading/writing.
- **Local Database:** it stores locally the sensor data, the patient's profile and context data.

Intelligent are those modules with a capacity of reasoning over some part of the process:

- **Recommendation engine (control):** it manages the flux control of data and processes related with reasoning and assessments, allowing the writing/reading of local data, access to the reasoning module (CBR Lite) and validation engine, and alert management.
- **CBR Lite:** this module is in charge of assessing the baby health state according to the last measurements of her vital signs and other attributes, and on data stored in the local database.
- **Validation Engine:** it incorporates a logical reasoning to decide whether the gathered values are valid, otherwise it recommends an action.
- **Alerting engine:** this component is used to alert the user for events, warn the user, etc.

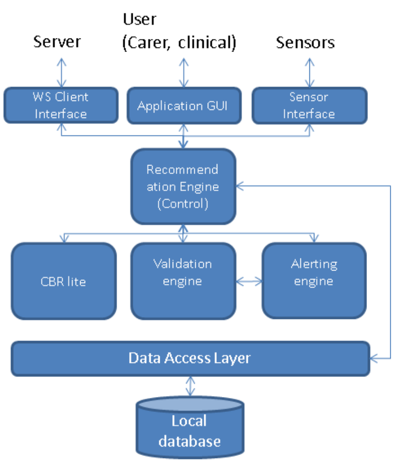

Fig. 3. Mobile component (based on [13]).

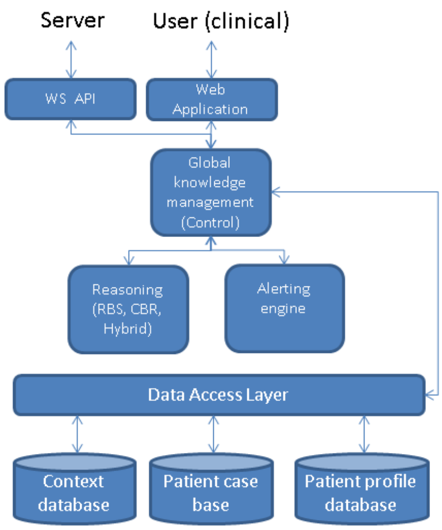

Fig. 4. Server component (based on [13])

5.2 Server component

An external server receives the information gathered by the mobile. Then, this information is classified and stored in the server data bases. Here, received data is reprocessed by a more complex CBR engine and a new recommendation is proposed. The new result is communicated to caregivers if it is different to the first recommendation obtained by the CBR Lite. All of the information handled in the process (inputs and outputs) is stored and available to the medical staff, which can access it for consultation, and rectification or validation of results. Next the internal modules of this component are described (Figure 4). As above, they have been classified in functional modules and intelligent modules.

Functional modules meet functional requirements of the overall architecture. They are the following:

- **WS API:** Is the access point to the internet in the server side (i.e. data center) and is used to interchange information with the clients (i.e. mobile and HIS applications).
- **Web Application:** it allows identify clinical users to access their patient's data and plot them in graphical charts.
- **Data Access Layer:** provides access to the data bases for reading/writing.
- **Context database:** it stores information regarding context.
- **Patient case base:** it stores the babies' medical information.
- **Patient profile data base:** it stores data related with the user identification and other personal information.

Intelligent modules include artificial intelligent techniques to add smartness to the reasoning process. They are the following:

- **Global knowledge management:** it manages the flux control of data and processes, allowing the writing/reading of server data, access to the reasoning module (CBR) and alert management.
- **Reasoning:** an evolving complex CBR engine allows refining the first recommendation obtained by the CBR Lite on the mobile. Thus, it makes a second assessment of the baby health state according to the last measurements of her vital signs and other attributes, and on data stored in the backend database. In addition to the CBR, some other techniques as rule-based systems (RBS), or hybrid approaches could be used.
- **Alerting engine:** this component is used to alert the user for events, warn the user, etc.

5.3 HIS component

The HIS component refers to the system which manage the information that health professionals need to perform their jobs effectively and efficiently. The main modules (Figure 5) in this last component are described below:

- **HIS Service:** this service provides the communication among the internal hospital information system and an external data server.
- **Data access layer:** provides access to the HIS data.
- **Patient history (EHR):** it stores all the existing information about the patients. It contains the patient's medical history, diagnoses, medications, treatment plans, images, laboratory results, etc.

5.4 Case study

To illustrate the different uses of the CBR in the system, let us suppose the baby data provided in Table 2 (baby3). The first column of the data of the figure corresponds to the data when the patient leaves the hospital. This is known as basal data. CBR personalizes recommendation based on this information and the historical data of the patient. Since at the beginning there is no history but the basal information, CBR at the backend plays an important role to perform recommendations based on information about similar patients. For example, in Table 3 the information coming from another baby (baby 2) is used to assess the state of baby3 when performing the first measurement at home (case 1 of Table 2). As long as new measurements and assessments (cases) are obtained for a patient, then, the recommendations performed at the CBR backend could rarely change the decisions performed at the mobile side. The history of cases during a treatment for a patient is enough to be stored in the mobile phone, and CBR lite could manage that.

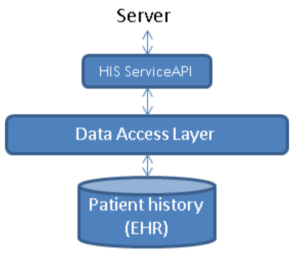

Fig. 5. HIS component

The key issue in the integration of CBR in the proposed system involves the relationship of the patient information as represented in some standards, as coming from the Hospital Information System or other healthcare provider: Electronic Health Records (EHRs) [14], the standard HL7 (Health Level 7) [15], and SNOMED-CT (Systematized Nomenclature of Medicine - Clinical Term)[16]. The former are related to how clinical documents should be structured, while the latter are needed to understand the particular data being sent in such clinical documents. The semantic interoperability ensures that different systems understand the data in the same way. In this approach SNOMED-CT is proposed as clinical terminology to record clinical details of individuals in the electronic patient (Figure 6). As limitations arising from the use of these standards, the complexity in data management and the amount of data increases significantly. Moreover, the identification of the concepts used in SNOMED and creating subsets [16] implies an initial extra workload . On the other hand, SNOMED-CT is offering the possibility to improve cases similarity. All this issues should be addressed in future research.

Table 2. Case base for a patient.

	Basal	***At home***				
	Case 0	Case1	Case2	Case3	Case 4	Case 3
General	Good	Good	Good	Good	Good	Good
Weight	1620g	1600g	1680g	1730g	1840g	2160g
Heart rate	125	155	125	130	128	125
Respiratory	37	42	37	32	35	30
Haemogrlob.	99	99	99	98	97	99
Temperature	36,5	37,8	36,5	36,2	37	36,5
Bilirubin	12	13,8	12	11	10,5	10
Feedings a day	8	6	8	8	8	8
Daily stools	Yes	No	Yes	Yes	Yes	Yes
Weekly stools	-	-	-	-	-	-
Sleeping	Same	Mornings	Same	Nights	Nights	Nights
Vitamines	Yes	Yes	Yes	Yes	Yes	Yes
Iron	Yes	Yes	Yes	Yes	Yes	Yes
Other medication	-	-	-	-	-	-
Other		Dehidr.				
Assessment	Normal	Warning	Normal	Warning	Warning	Warning

Table 3. Assessment of baby 3 through Baby2.

	Baby3	*Baby2*
General aspect	Good	Good
Weight	1600g	1600g
Heart rate	155	125
Respiratory rate	42	35
Haemoglobin saturation	99	99
Axillary temperature	37,8	36,3
Bilirubin	13,8	1,8
Feedings a day	6	6
Daily stools	No	No
Weekly stools		
Sleeping	Mornings	Mornings
Vitamin	Yes	Yes
Iron	Yes	Yes
Other medication		Yes
Other	Dehidr.	Irritab.
State	**?**	Warning

6 Conclusions and future work

There are an increase number of premature babies that, once they achieve some degree of maturity, can be moved at home when their parents can take care of them in a loving environment which most of the times fasten the babies' recovery. For this end, a home based solution is provided, which supports parents in the baby care while keeping babies under the control of clinical staff. The architecture contains two case-based reasoning modules that assess the baby state. Then, the recommendations and alerts obtained are shown in parents' mobile as well as in doctor's device. The proposal of a general and modular architecture enables that this solution can be applied to other use cases within the Moshca platform. Even the reasoning module can be replaced by other module using different artificial intelligent methods according to the current necessities. Moreover, the use of recognized standards worldwide ensures the interoperability of the proposed architecture.

Our future work involves further experimentation including the testing in a real environment and the comparison of results obtained by other techniques. In addition, the influence of context awareness on obtained recommendations should be studied.

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Fig. 6. Example of a parameter measured (weight) codified with SNOMED-CT within a clinical document HL7 CDA (Clinical Document Architecture).

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