An Ontology-based Context Model for Home Health Monitoring and Alerting in Chronic Patient Care Networks

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Abstract

New care models have been defined in order to manage the increasing impact of chronic conditions. These models pose several technology-oriented challenges for home-based continuous care, requiring assistance services based on collaboration among different stakeholders: health operators, patient relatives, as well as social community members. This work describes an ontology-based context model and a related context management middleware providing a reusable and extensible application framework for monitoring and assisting patients at home. It provides flexible instruments for patient health status and social context representation, as well as reasoning mechanisms for alarm situation handling.

1. Introduction

In the last decades, developed countries have experienced an increase of average life-length and, consequently, the impact of chronic conditions on the population. Pervasive and context-aware applications have been widely recognized as promising solutions for improving quality of life of both patients suffering from chronic conditions and their relatives, as well as for providing cost savings in continuous care services provision.

Obviously, efficiency and effectiveness of health services cannot be guaranteed by technology efforts by themselves. New models of care have been proposed, which define guidelines for policy planning, as well as principles for social community and health care systems organization and effort coordination. For instance, the Chronic Care Model (CCM) is a conceptual, evidence-based framework, developed in the USA [1]. The World Health Organization (WHO) has proposed the Innovative Care for chronic conditions (ICCC) framework, which extends the CCM model in order to define a reference model for an international community [2].

Continuous care models promote home-based continuous care of chronic patients. Effectiveness and efficiency of long-term condition care depends on both the capability of patients and their relatives to manage their case (self-management) and the collaboration of all care providers (shared care). Patients, family members, health care teams (e.g. clinicians, general practitioner, nurses, etc.) and social community members (e.g., social workers, volunteers) should be informed, motivated and prepared in order to effectively collaborate together.

These models pose several technology-oriented challenges for home-based continuous care, requiring assistance services based on collaboration among different stakeholders: health operators, patient relatives, as well as social community members.

This work describes a context model and a related context management middleware providing a reusable and extensible application framework for monitoring and handling patients' chronic conditions. It provides flexible instruments for patient health status and social context representation, as well as reasoning mechanisms for alarm situation handling.

The paper is organized as follows: Section 2 discusses related work in the development of context-aware systems for continuous care network support; Section 3 introduces main requirements for a context-aware system for chronic conditions care. Section 4 describes our context model and Section 5 describes the context reasoning approach. In Section 6 we describe the architecture design and Section 7 concludes with a discussion on future work.

2. Related work

There are a number of research projects related to tele-health. Here we will focus on works proposing context-aware systems to support home-based assistance of chronic patients at home.

Most attempts have focused on specific aspects, such as health status monitoring, alert and reminders based on scheduled activities (e.g., medicine taking, training activities, etc.), patient behavior and daily activities modelling. For instance, Vivago® is an alarm system providing long-term monitoring of user's activity profile and automatic alarm notification [3]. It consists of three main components: a wrist unit, a base station and an alarm receiving and routing software. Further systems are: Georgia Tech Aware Home, providing assistance services for the elderly [4]; CareMedia [5], which uses multimedia information to track person activities; MIT's PlaceLab [6], which includes a proactive health care application based on wearable and environmental sensing.

The Freeband Awareness project aims at the development of a context-aware infrastructure architecture [7]. The project focuses on requirements coming from the health care domain. Its reference scenarios include tele-monitoring, tele-assistance and assistance to disabled persons.

More specifically, for what concerns chronic conditions, semantic web technologies have been used to build an ontology-based context model for modeling agitation behavior in persons with dementia [8].

In above works, guidelines and reference models for continuous care are not yet extensively taken into account in the design of pervasive care solutions. Recently, some high-level analysis and conceptual design have been performed. Chronic care model principles have been taken into account in the conception of Pervasive Self Care, a ubiquitous computing service infrastructure conceptual framework [9]. In [10] social network analysis is applied to the study of continuous care networks. First experimentation results have been reported in [11], where a telemedicine system is used for the home care of patients suffering from Chronic Obtrusive Pulmonary Disease; its functionalities include communication facilities between patients and their care team and data sharing among the care team.

3. A context-aware service platform for continuous care networks

This work is part of the Kamer Project. Kamer (Knowledge Management in Ambient Intelligence: technologies enabling the innovative development of Emilia Romagna) is an Italian regional project that involves two universities and one industry. The main objective of the Kamer project is to define novel models and technologies of Ambient Intelligence and context-awareness supporting knowledge exchange and collaboration among individuals in mobility. More specifically, one of the project objectives is the design and development of a context-aware service platform architecture for assistance to patients at home.

Emerging care models for chronic conditions suggest that information and communication systems should provide technological instruments in order to effectively support the activity of continuous care networks and coordinate efforts of different members: patients and families, health care teams and community partners [2].

Technology-enabled services for home-based assistance to chronic patients can be classified into the following categories: 1) emergency services; 2) assistance services for patient daily activities (e.g., nutrition, communication, medicine assumption, vital signs monitoring, etc.; 3) services for life quality improvement and self-care support (e.g., education, infotainment, socialization)

In addition to these patient-oriented services, the design of a pervasive system should also offer services supporting shared care teams. We identified the following services that might be provided to caregivers: communication facilities; shared access to patient related data; decision-support services; mutual "social awareness" about role and actions of network members.

This work aims at describing the ontology-based context model and context management middleware that have been developed in order to ease the development of context-aware applications for home-based health care. They are based on the general-purpose context model and context-aware middleware developed in the Kamer Project. Whereas in this paper we focus on the health care domain, a more detailed description of the general-purpose Kamer context model and middleware can be found in [12]. Our reference application scenario is briefly described below.

John is affected by a chronic disease. Her wife Barbara and his daughter Emily live with him and provide daily assistance services. John's home is equipped with a context-aware system, consisting of: monitoring devices (biomedical and environmental sensors), emergency and ordinary call buttons, and a PC which collects and analyses sensed data in order to infer possible critical situations and trigger corresponding alarms. The Home PC is connected (via ADSL) to a server in the Health Center (e.g. a hospital or a nursery home) which is responsible for the implementation of the Patient health plan. When an alarm is activated, the Home PC sends a message to the Health Center containing some relevant data, such as patient identifier, alarm level (e.g. very low, low, *medium, high) and alarm triggering conditions (e.g. out-of-range biomedical parameter values or pressure of an emergency call button). Then, the Health Center notifies some of the care providers which have in charge that patient (e.g., physicians, nurses and relatives. Individuals to be contacted and proper notification channels (e.g. email and sms) are chosen by the system according to their role, their current availability for intervention, and the alarm level. John's general practitioner can receive notification messages on his device (PDA or desktop). He can also access patient records and update some information fields (e.g. new prescriptions, alarm triggering thresholds, vital signs measurement scheduling). Nurses have similar facilities, but different access rights to patient records. Both the general practitioner and nurses can inform the system of their availability for an intervention, by filling a web form on their PDA. In case of an alarm, the system will preferably notify the operators marked as "available".*

Barbara and Emily can receive information about John health status on their mobile phone; they can also inform the system about their travel time to patient home, via a web form; In case of an alarm, the system will preferably notify the patient's closest relative.

4. Ontology-based context model

In this section, we will describe the main concepts of the ontology-based context modeling approach for the Kamer home care assistance scenario. As already mentioned, we extended an ontology-based context model representing main general concepts and relations for context representation.

Our work moves from the widely accepted definition of context, provided by Dey & Abowd in [13]: "Context is any information that can be used to characterize the situation of an entity." Therefore, an entity is a person, place, computational entity, or object which is considered relevant for determining the behavior of an application.

The context of an entity is composed of one or more Context Items. A Context Item describes a specific characteristic of the entity context. Context Items are classified into five general categories: Location, Physical Data, Activity, Instrumental Context, Social Context [12].

The context ontology has been extended in order to represent contextual situations in a home care setting.

In this application scenario, context includes data items describing patient physical conditions and social context. Context reasoning is used mainly for alarm triggering and management. At this stage of development, alarm triggering is based on the analysis of vital sign measurements and home environmental monitoring. Alarm management is here addressed in terms of alert notification planning. We believe that these tools can be easily customized for a wide range of patient cases. Consequently, we do not currently provide support for automatic therapeutic intervention. As a matter of fact, modeling therapeutic intervention options would require deep knowledge of the specific patient case

Hereafter we describe the following ontologies: the Patient Personal Domain Ontology, the Home Domain Ontology, the Alarm Management Ontology and the Social Context Ontology. This latter ontology represent care networks resources coming from different organizations (health teams, social community members, etc.). The Alarm Management Ontology represent care network members that might be engaged in critical situations handling and thus might have to be notified by the system for intervention.

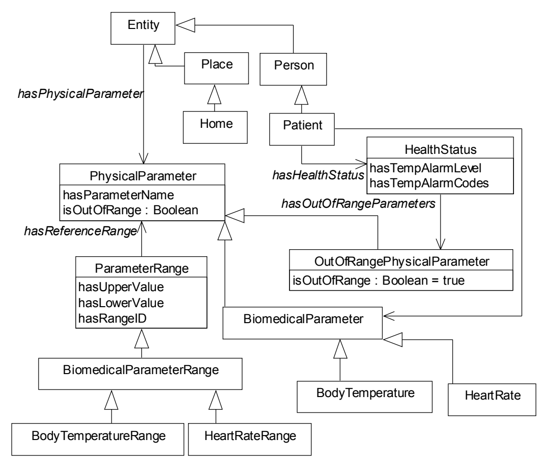

Figure 1: Patient Personal Domain Ontology

In the Patient Personal Domain, relevant context items include patient physical data (i.e. biomedical parameter values), location and activity. These data can be used by the system to automatically infer the patient health status and detect possible alarm situations.

In the Home domain, relevant context data include mainly sensed parameters. Monitoring of environmental parameters, such as temperature and relative humidity, is important in order to maintain a healthy environment and detect possible alarm situations (e.g. by means of gas and fire detectors).

The Context Model has been written in OWL (Web Ontology Language) [14]. OWL ontology fragments are hereafter represented by means of UML class diagrams. UML Classes represent OWL classes, attributes represent OWL Datatype properties and associations among classes are used for OWL Object Properties representation.

Fig. 1 illustrates a fragment of the context ontology specialized for the Patient Personal Domain. A specialization of the BiomedicalParameter class is added for each specific biomedical parameter which is monitored (e.g., Body Temperature). Measurement values are used to determine patient heath status by comparing these values with a set of parameter ranges (ParameterRange class). Each range is specified in terms of upper and lower thresholds and related alarm level; when a measured value falls out of the thresholds, an alarm of the corresponding level is then triggered. We specified four basic alarm levels (very low, low, medium, high), but the model can be easily extended to include further levels.

As detailed in the following section, when one or more measurement values fall out of the thresholds, the Patient Health Status is updated with associations to current OutOfRangeParameters and the corresponding alarm level (hasTempAlarmLevel attribute). An AlarmEvent is also generated by means of rule-based reasoning. An AlarmEvent is characterized in terms of criticity of patient conditions (i.e., hasAlarmLevel attribute) and parameters that have determined abnormal conditions (i.e., hasAlarmCode attribute).

An alarm can be triggered also by abnormal environmental parameters. This situation is modeled by means of the Home Domain Ontology, shown in Fig. 2. The model is similar to the previous one, but it deals with environmental parameters.

When the system has automatically discerned that a critical situation has occurred, due to abnormal biomedical parameter values or non-healthy and/or potentially dangerous environmental conditions, proper intervention actions should be planned.

As previously discussed, such intervention planning should be based on flexible coordination and joint action of different stakeholders: health team, family and social community members. To do this, we need to model alarm notification policies, i.e. policies specifying whom should be alerted, how and when (with respect to other peers) the notification is sent and if acknowledge is required. In Table 1 we define a basic example policy for each alarm level.

In the Alarm Management Ontology, shown in Fig. 3, a Notification Policy is modeled as a set of ContactQueues. A ContactQueue contains a list of contacts (ContactPerson), pointing to care networks members. It also specifies if acknowledge is required (requiresAck attribute) and the notification channel (e.g. email, sms). ContactPersons have a sequence number (hasSequenceNumber attribute) specifying with which priority an individual should be contacted with respect to other peers in the same ContactQueue.

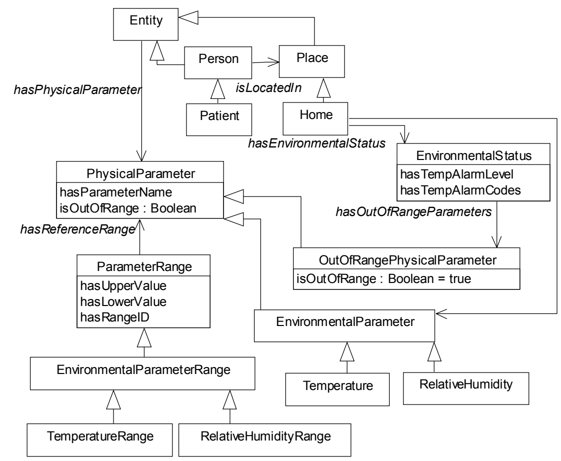

Figure 2. Home Domain Ontology

Table 1: Alarm Notification Policy Examples

ALARM LEVEL	NOTIFICATION POLICIES
VERY LOW	- sms to patient relative, no ack
LOW	- sms and mail to general practitioner, no ack - sms and mail to relative, no ack
MEDIUM	- sms and mail to general practitioner or nurse, ack - send sms and mail to relative, no ack
HIGH	- message to emergency operator, ack - sms to relative, ack

For instance, we suppose that when a "MEDIUM" level alarm occurs, the system should perform the following actions (see also Table 1): a) alerting an health operator via sms or email. For first, a general practitioner is alerted. If he/she does not send the acknowledge within a fixed time interval, other operators (e.g. nurses) are alerted, until one of them sends an acknowledge. At the end, if no acknowledge is received, the system alerts an emergency operator. b) At the same time, at least one of family members should be alerted, but acknowledge is not required. Action a) can be modeled by means of a ContactQueue with "requiresAck" setted to "true" and pointing to individuals qualified as general practitioners and nurses, assigning them incremental sequence numbers. Action b) can be specified by means of a second ContactQueue with "requiresAck" setted to "false" and pointing to one or more relatives.

When an alarm is triggered, notification policies are instantiated by binding contactQueue instances with individuals populating the patient care network. Patient care network is modeled by the Social Context Ontology (see Fig. 4). From the general-purpose Person class the following classes are derived: Patient, Relative, Health Operator and Social Community Member. These classes inherit attributes modeling static information (e.g. identifier and role) as well as by dynamic information (e.g. location and activity).

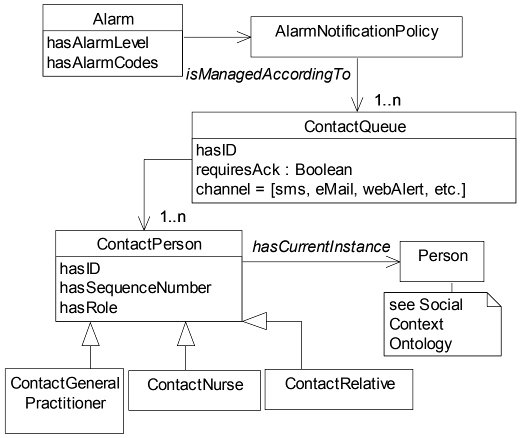

Figure 3. Alarm Management Ontology

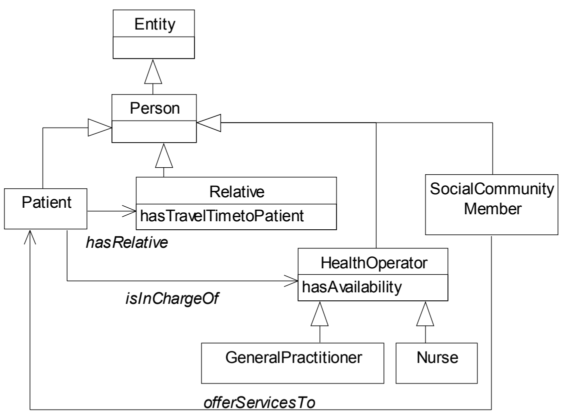

Figure 4.Social Context Ontology

In our application scenario it is also important to model other information, such as the availability of an health operator for an intervention and the distance of a relative from patient location (travel time). Users can provide this information via a web form, by choosing among predefined values (e.g., “available”, “busy”, “notAvailable”). As part of future work, we will investigate the use of context-aware systems that can help in semi-automatically updating and managing such information (e.g. GPS positioning and inference mechanisms).

Network members are related each other by means of relations (i.e. OWL object properties). In Fig. 4 we point out only a few relations which directly involve the patient: a Patient may have some Relatives; patient care is in charge of some Health Operators (in most cases a general practitioner and one or more nurses); Social Community organizations and their Members can offer some assistance services (e.g., transport and companion services).

5. Context reasoning

We adopted a rule-based approach based on first-order logic for context reasoning. We used two kinds of reasoning: ontology-based reasoning and user-defined rule-based reasoning. Both have been implemented using a rule-based reasoning engine.

Ontology-based reasoning can be used in order to determine concept satisfiability, class subsumption, consistency and instance checking.

User-defined rules provide flexible mechanisms to make inferences over the ontology base. We have defined a set of first-order rules in order to determine if an alarm has to be triggered and which alarm level should be activated, according to measurement values and corresponding thresholds. For instance, the following example shows a rule activating an alarm when both following conditions occur: hearth rate frequency is less than 40 beat/minute and systolic blood pressure is higher than 160mm/Hg:

(?par1 rdf:type HeartRateFreq) (?par1 hasMeasResult ?v1) le(?v1, 40) (?par2 rdf:type SystBloodPressure) (?par2 hasMeasResult ?v2) ge(?v2,160) -> (?healthstatus hasAlarmLevel ‘HIGH’)

When the alarm has been activated, rule-based reasoning is used to determine the notification policy that should be actuated in order to manage the alarm. For instance, when an alarm of ‘MEDIUM’ level has been activated, an on-site intervention of a health operator is required (see Table 1). In this case, it is convenient to contact operators which are ‘AVAILABLE’ in that moment (see example below).

(?nurse rdf:type Nurse) (?nurse hasAvailability 'AVAILABLE') (?a rdf:type Alarm) -> (?q rdf:type ContactNurse) (?q contactIndividual ?nurse)

6. Architecture overview

This section describes the context management middleware architecture that we have developed to ease the implementation of assistance services for chronic patients.

According to a widely accepted logical abstraction [15], a context-aware system is made of three types of components: context providers (distributed sensors that gather context data), a context management middleware (i.e. context data distributed management), and context consumers (e.g. software applications which adapt their behavior according to context information).

The Kamer Context management middleware is composed of context management nodes, named

Context Managers (CM). Fig. 5 shows the CM logical architecture. A Context Manager collects data from heterogeneous context providers. The Context Data Acquisition module receive context data from context providers via SOAP messages (e.g. web service-enabled sensor networks [16]), or via sensor adapters. The Ontology Manager manages the knowledge base, composed of a database (for context model and instances storage), a rule-based reasoner and rules files. A Context Broker component makes context information available to external applications, by managing queries from applications and/or notifying interested applications when the context has changed. Communication among distributed components is provided via SOAP Web Services and HTTP Notification of XML messages.

The Context Manager has been implemented as a J2EE application. The Ontology Manager and the reasoner are based on Jena [17], a Java framework for building Semantic Web applications. Ontology-based context model and instances are stored in a relational database (MySQL).

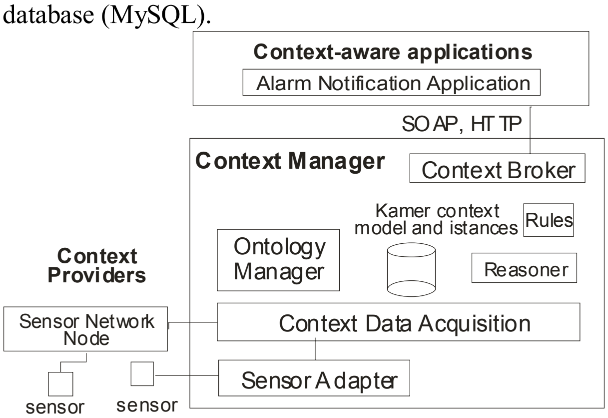

Figure 5. Context Manager Architecture

6.1. Deployment in a real application scenario

Based on the Context Model and Context management middleware, we are developing a context-aware prototype system for home-based care and care network support for chronic patients (see Fig. 6).

The deployment configuration includes at least two Context Manager nodes: a CM node, deployed on a PC at patient home, named PatientCM; another CM node, named CentralCM, which is deployed on a server, named Central Application Server, in the domain of the organization which is responsible for the integration and delivery of care services (for instance, hospitals, nursing homes or municipalities).

The HomePC (a HP Tablet PC) hosts the PatientCM and communicates with the Central Application Server via ADSL. The Central Application Server hosts the CentralCM and other assistance and information service applications. These services include: an alert notification service, which notify care team members and relatives according to the notification policy specified by the CentralCM; a patient record data management and a web application which offers web-based access to health operators via mobile device (PDA) or PC; a web-based medicine assumption reminder for the patient [18].

The HomePC initiates the communication with the Central Application Server in order to send periodical status messages and up-to-date measurement values, as well as to notify alarms.

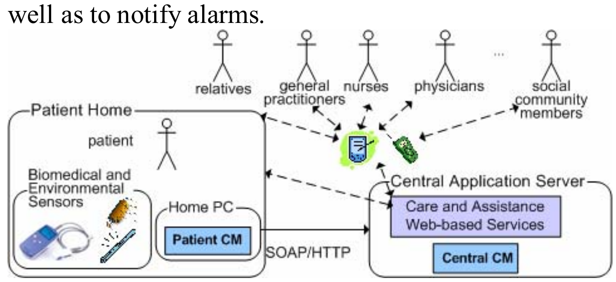

Figure 6. Kamer Prototype System Architecture

The Patient Context Manager acquires data coming from biomedical and environmental sensors and performs context data analysis in order to detect possible alarms. Sensor data are injected into the knowledge base in order to update system knowledge about patient context (Patient Domain and Home Domain ontologies). Rule-based reasoning is applied in order to detect out-of-range measured values and thus a possible alarm situation. If an alarm has been detected, the PatientCM sends a message to the CentralCM containing the following information: patient identifier, out-of-range measured values, and the alarm gravity level. The CentralCM thus instantiates a suitable alarm notification policy, by applying rule-based reasoning to Alarm Management and Social Context ontology instances. The alarm notification is then actuated by the alert notification service.

Use-case testing is underway with a trial in a nursing home in the near future. This testing stage will be focused on evaluating health operators acceptance of implemented features. For this test stage, biomedical and environmental sensing will be simulated by a web application. Biomedical parameters currently taken into account in the model are: heart rate frequency, pulse oxymetry, systolic and diastolic blood pressure, body temperature, and glycemia. The web application provides services for manual input or pre-defined scenario simulation for context data acquisition. A testing stage with chronic condition patients will be planned in the near future. For these tests, a sensing system for vital signs and environmental monitoring will be deployed.

9. Conclusions

In this paper, we have presented an ontology-based context model for health monitoring and alert management for a system supporting patient care at home. An ontology-based context model has been developed for modeling health and home environmental conditions, alarm management policy and patient social context.

This work has focused on rule-based reasoning for analysis of measurement values at specific time instances. Further work will be focused on: 1) analyzing more complex patterns for discerning alarm conditions, for instance by means of long-term observation. For this, we will evaluate further reasoning mechanisms, such as neural networks and fuzzy logic; 2) implementing services for privacy policy specification and enforcement.

Future research activities will be also devoted to analyze engineering issues about system dependability.

A strong motivation for research in pervasive care applications is that benefits might outweigh the risks, as continuous care is not affordable with traditional approaches, which are instead conceived for treatment of acute problems. Nonetheless, successfulness of pervasive care systems will strongly rely on the degree of system dependability, reflecting the user's degree of trust in that system.

Pervasive applications for homecare are likely to create privacy, security and safety concerns [19]. This is due to several factors, including: distributed management of sensitive data which are directly related to patient health and safety; domestic context characterization as a complex socio-technical system with requirements different from those of organizational contexts.

An extended risk analysis should be performed in order to identify the most probable threats and to provide corresponding solutions. In addition to the technological perspective, also proper user training methodologies for system use in ordinary and emergency situations will be analysed. System training should be conceived as part of the self management educational plans for patient and relatives promoted in the framework of continuous care programs.

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