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An Ontology-based System for Context-aware and Configurable Services to Support Home-based Continuous Care

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***Abstract*— Continuous care models for chronic diseases pose several technology-oriented challenges for home-based care, where assistance services rely on a close collaboration among different stakeholders such as health operators, patient relatives and social community members. This work describes an ontology-based context model and a related context management system providing a configurable and extensible service-oriented framework to ease the development of applications for monitoring and handling patient chronic conditions. The system has been developed in a prototypal version, and integrated with a service platform for supporting operators of home-based care networks in cooperating and sharing patient related information and coordinating mutual interventions for handling critical and alarm situations. Finally, we discuss experimentation results and possible further research directions.**

***Index Terms* — ambient intelligence, chronic disease management, context awareness, continuous care, ontology-based models, telemedicine.**

I. Introduction

IN recent years, novel care models have been proposed in order to improve the quality of care and social assistance services. In the elderly populations of industrialized nations the percentage of people who are affected by disabilities and chronic disease conditions is increasing. Examples of chronic conditions especially affecting the over-65 population are: arthritis, hypertension, pulmonary disease, diabetes, cancer and osteoporosis [1]. Europe and Japan will experience the most pronounced ageing trends until 2050; the share of the above-60 age group will be around 37% in Europe and even more in Japan, and slightly lower in North America (27%). The "Survey of Health, Ageing and Retirement in Europe" [2] provides a clear picture of the problem. This requires a paradigm shift in care management, with respect to "acute-problem" approaches. As a matter of fact, while "acute" problems could have a quick evolution, by requiring intensive but relatively short-term interventions (e.g., medications and/or surgery), chronic conditions tend to come on more slowly. In the latter case, short-term care solutions are not usually effective: rather than the disease itself, the consequences of chronic conditions also greatly affect patient's daily life, involving also personal relationships with, as well as the quality of life of, patient's relatives [3].

Paper subject is a novel context-aware ontology model and system which is part of a service-oriented platform for home-based and continuous care support. The service platform has been implemented as a prototype, called ERMHAN (Emilia Romagna Mobile Health Assistance Network), in the framework of the KAMER research project [4]. The aim of the ERMHAN platform is to facilitate the development and delivery of an easily configurable set of personalized care services for patients at home. Services are to provide support also to family, social assistants and care providers who are involved to a different extent in patient care and assistance.

The paper is structured as follows: Section II introduces chronic care models and Section III discusses related work in context-aware and ontology-based e-health systems. Section IV introduces main objectives of the ERMHAN service platform and our reference application scenario for chronic conditions handling. In Section V we describe the ontology-based context model and reasoning approach for patient status monitoring, alarm detection and handling. Section VI briefly introduces the ERMHAN prototype and describes the Context Management System. Section VII reports on evaluation results of experimentation activities with groups of caregivers and Section VIII concludes the paper.

II. Chronic Care Models

Chronic condition treatment requires continuous and long-term assistance services. To this purpose, continuous care models for chronic disease conditions are recently being discussed, promoted and experimented nationally and internationally. One of the first examples is the Chronic Care Model (CCM), a conceptual evidence-based framework developed in the USA [5]. Recently, the World Health Organisation (WHO) have proposed the Innovative Care for Chronic Conditions (ICCC) framework, which extends CCM to

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an international community [6], [7].

Continuous care models place point-of-care in the community and at patient's home. These models emphasize the fact that effectiveness and efficiency of long-term condition care depend strongly on the capability of both patients and their relatives to manage their case (self-management) and on the collaboration of all involved care providers. These models need an organized care system ("care network") based on the active role and cooperation of the above-mentioned heterogeneous actors. Care network members are, typically, patients, family members, health care teams (e.g., clinicians, general practitioners, nurses, etc.) and social community members (e.g., social workers, volunteers). Even if they play different roles in the care network, they have some common requirements: they should be properly informed, motivated and prepared in order to effectively collaborate together.

Pervasive and context-aware systems represent promising technologies to provide enhanced services to chronic patients [8]: a) emergency detection and management services; b) autonomy enhancement services for primary needs and/or everyday activities assistance; c) comfort services allowing better life quality.

As discussed in [9], the evolution of IT towards an horizontal service platform, supporting anytime and anywhere access to information and knowledge-driven and context-aware decision making, can act as a driver towards the delivery of care services in a health continuum perspective, especially in the care of chronic degenerative diseases. In this framework, the application landscape should be characterized by "3 P's" [9]: "Personalized", as diagnostic and treatment decisions should be tuned to the individual's personal norm; "Pervasive", referring to an interoperable platform to access, communicate, process and store health data and knowledge in an anytime and anywhere perspective; "Personal", referring to services that support the individual by matching his/her personal needs in health management.

Nonetheless, pervasive and context-aware systems targeted to supporting care networks should support extensibility and configurability capabilities in order to meet the variable requirements characterizing this application domain.

Such variability is of course centered on the specific patient case (i.e. the characteristics of chronic diseases, possible comorbidities and their evolution over time [1]) but should also match with other contextual factors of the care network: type and role of actors involved in the care network; accounting of the heterogeneity of health centers and communities (e.g. hospitals, municipalities, local health authorities, voluntary associations); national and local regulation frameworks.

III. Related Work

In this section, we will discuss other work that is relevant to the ERMHAN Context Management System in the areas of:
- Context-aware pervasive systems;
- Ontology-based e-health systems.

A. Context-aware pervasive systems for health care

A system may be labeled as "context-aware" if it can acquire, interpret and use context information and adapt its behavior to the current context of use [10].

Context aware computing is a research field which considers healthcare a relevant area of application [11].

The application of context-aware and pervasive technology in hospital environments have been experimented in several works [11]. Pervasive and context aware technology may help in improving some aspects of hospital work procedures, such as: improving the management of Electronic Patient Records [12], [13]; supporting the communication among hospital workers via mobile devices and localization techniques [14], [15]; facilitating information sharing and access by embedding context-aware capabilities in patient room equipment [12].

As regards context aware and pervasive systems for home-based care, several works have focused on specific aspects of service provision, such as patient health status monitoring, alert and reminding service, patient behavior modelling. Some examples are: Vivago®, an alarm system providing long-term monitoring of user's activity profile and automatic alarm notification [16]; Georgia Tech Aware Home, providing assistance services for the elderly [17]; CareMedia [18], providing activity tracking services; the sensory-oriented framework in [19], which is evaluated in a health care scenario.

Recently, some works have begun on taking into account requirements coming from guidelines and reference models for continuous care, with the following objectives: building a conceptual framework for a pervasive self-care infrastructure [20]; experimenting the use of pervasive technologies for home-based care of specific chronic conditions, e.g., Chronic Obtrusive Pulmonary Disease [21] and depression [22].

B. Ontology-based e-health system

An ontology may be defined as a formal, explicit specification of a shared conceptualisation [23]. More specifically, it helps modeling a world phenomenon by first identifying its relevant concepts ("Conceptualization") and defining explicitly concepts and related constraints ("explicit"). "Formal" refers to the fact that the ontology should be machine readable, and "Shared" reflects the notion that an ontology should capture consensual knowledge.

Ontologies have been experimented in several context-awareness research domains, including e-health.

The definition and use of ontology in the medical domain is an active research field, as it has been recognized that ontology-based systems can be used to improve the management of complex health systems [24].

Ontologies have been employed as a mean to define a common terminology for the medical domain with an unambiguous meaning, in order to facilitate information sharing among persons or systems. One relevant example is the GALEN ontology, which provides re-usable terminology resources for

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clinical systems [25]. Other works have adopted ontologies for managing organizational knowledge [24] and cooperative work among care networks [26], providing clinical decision support features [27], and supporting continuity of care for specific diseases, such as heart failure [28].

As regards context-aware systems, ontologies have been recognized as a key technology for context modeling [29], [30]. Several works have experimented the use of ontologies in context-aware systems. Examples in the health-care domain are [31], [32] and [33].

Ontology-based languages and tools are considered as a key technology for developing context-aware systems, since they enable a formal analysis of the domain knowledge and promote contextual knowledge sharing and reuse in a ubiquitous computing system [30], [34]. Ontologies may help in: a) specifying contextual knowledge in terms of classes of objects, relationships, and constraints on their properties; b) describing contexts semantically in a way which is independent of programming languages, underlying operating systems or middleware; c) enabling formal analysis of domain knowledge, i.e. context reasoning using first-order logic, temporal logic, etc [35]; d) deriving fresh knowledge and facts through reasoning on context data by using inference engines [36]; e) enabling knowledge reuse, as ontologies of different domains can be composed and extended with new concepts in order to produce new ontologies without starting from scratch. Moreover, reasoning approaches based on Bayesian networks or fuzzy logic [37] have been experimented to handle uncertain context.

With respect to related work, our contribution consists in investigating how context management, semantic and pervasive technologies may help in supporting continuous home-care models for chronic conditions. To the state of our knowledge, this issue seems not to have been extensively investigated by related work. On one side often context-aware system designers have considered e-health just as an application scenario. On the other side, application driven experimentations of ontology and context-aware systems have been typically focused on specific hospital settings or on remote patient monitoring, while not facing requirements of home-based care network members.

IV. Context-Aware Services for Home-Based Continuous Care

Our work aims at designing a context-aware service platform for supporting the main characteristics of emerging chronic care models: (a) home-centered long-term patient follow-up; (b) shared care provided by a network of heterogeneous care providers (named “continuous care network”); (c) adaptation of care plans on a per patient basis.

As discussed in Section II, requirements for home-based long-term care services may vary according to different parameters. In order to match with this complexity, while containing costs of solutions, the service platform should offer the following capabilities:

- re-configurability, referring to the capability of the system to be reconfigured in order to meet requirements depending on parameters that do not often change (e.g., local regulation, number and kind of organizations involved in providing long-term care solutions)
- context-aware service adaptation, referring to the capability of the system to adapt service delivery depending on parameters that can often change over time (e.g. patient health conditions, availability of caregivers).

In this context, our approach is based on the exploitation of an ontology-based context model and a related context management system for pervasive care systems (see Fig.1). The proposed context model aims at easing the provision of configurable and extensible care services.

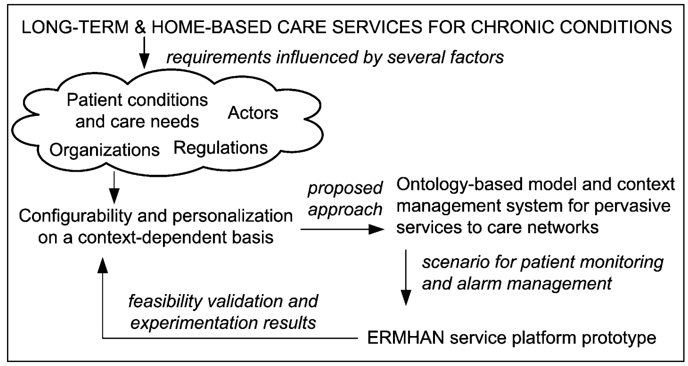

Fig. 1. Approach for context-aware services for home-based care networks

In order to validate the feasibility of such approach we have developed a prototype of a context-aware service platform, named ERMHAN. It provides pervasive and customizable services for supporting the activities of care network actors. The ERMHAN case study is based on a general reference scenario for home-based chronic conditions handling. According to this scenario, the context ontology and context management system specifically address the objective of supporting the provision of general-purpose services for patient and home environment monitoring, alarm detection and policy-based alarm handling. We do not focus on a specific chronic disease from the very beginning, but our approach can be extended and specialized in order to match specific requirements of real cases.

In the following subsections, we describe possible actors in a care network and our reference application scenario.

A. Care Network Actors and Requirements

With the term “(continuous) care network” we refer to the broad range of people involved to a different extent in the care of a chronic patient. The complexity of care network management is usually due to the fact that members typically have more than one work place, do not belong to the same organization and do not have frequent physical contacts.

Here we consider a basic care network populated by the following actors: the patient, family members, doctors, nurses, social assistance operators, the care centre, and other community members.

Patient: general patient requirements include the capability

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of monitoring health and environmental conditions, easily communicating with relatives or health operators, notifying an emergency situation and requesting an intervention. He/she might also require assistance for implementing his/her care plan (for instance, reminding services for regular medicine taking and vital sign monitoring). Requirements depending on specific patient conditions have not been taken into account in this work.

Family members: providing care can have a different impact on patient relatives' life. In [3] three main categories have been identified: those who make drastic life changes to support the elder (e.g. quitting job or neglecting hobbies and social activities); those who make significant contributions to care for the elder (without making important changes on their lives), those who have peripheral involvement in the elder's care. Relatives belonging to the first category are critical network members, as their contribution is relevant for the patient quality of life. As these relatives are often involved in implementing the care plan, they should be informed of patient conditions and care plan implementation status. They also should be made capable of expressing their availability for an intervention.

Doctors: Doctors (especially general practitioners) are responsible for defining the patient care plan. Accordingly to emerging continuous care models, they should cooperate with nurses and social assistance operators in order to define and implement an integrated care plan. Main requirements include the capability of accessing complete and accurate patient records and timely updating patient data (for instance during home visits). Doctors also need not be overwhelmed by intervention requests, especially when the situation is not extremely critical and could be handled by other operators (nurses, social assistance operators), or when they are already involved in other critical interventions.

Nurses: They are relevant care providers and, analogously to doctors, need efficient scheduling management. They also require access to patient records as well as information support for timely interventions.

Social assistance operators: They provide support for daily activities and social communication. They can also gather information that might be useful for evaluating health plan implementation results but could not be automatically measured (e.g., patient attitudes and emotive states).

Care center: with this term we refer to the center which has the responsibility of handling the patient care plan. For this purpose, it can coordinate/be participated of different health care organizations. Although these organizations may have different goals, while being located in different places and providing different assistance services and resources, they are actually required to cooperate towards the common goal of implementing the patient care plan. Here, we consider the Care Center as the virtual point of contact for the involved users. Consequently, it should manage incoming calls, alerts and planning interventions. In real cases, it can be implemented in different locations (e.g., hospitals, municipality offices), depending on the specific models adopted in the target territory.

Other community members: community members can be involved to a different extent in providing their contribution. They may include volunteers, special transportation service providers, shops, chemistries, etc. Their service provision can improve the quality of life of both patients and relatives.

B. Reference Application Scenario

John is affected by a chronic disease. His wife Barbara and daughter Emily live with him and provide him with 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. The PC hosts context-aware services which collect and analyze 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 Care Center (e.g. a hospital or a nursery home) which is responsible for implementing the Patient health plan.

When an alarm is activated, the Home PC sends a message to the Care Center containing some important data, such as the patient identifier, alarm level and alarm triggering conditions (e.g. out-of-range biomedical parameter values or pressure of an emergency call button). Then, the Care Center notifies some of the care providers who are in charge of 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 general practitioners and nurses can inform the system of their availability for an intervention by filling out 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's health status on their mobile phone; they can also inform the system about their distance from the patient home through a web form. In case of an alarm, the system will preferably notify the patient's closest relative.

V. Ontology-based Context Model for Care Networks

This section describes the main concepts grounding the design of the ontology-based context model adopted in the ERMHAN platform according to the requirements of the home-based care scenario.

The context model and context management system provide configurable and extensible services for: a) acquiring data from heterogeneous context sources (e.g., biomedical and environmental sensors); b) representing knowledge about patient's situation by means of ontology-based formalisms; c) reasoning over knowledge using rule-based and ontology-based

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engines; d) applying reasoning techniques in order to specify personalized health-care plans.

Our work moves from the widely accepted definition of context provided by Dey & Abowd in [38]: "Context is any information that can be used to characterize the situation of an entity." An entity is a person, place, computational entity, or object which is considered relevant for determining the behavior of an application.

With reference to the methodology for context-ontology modeling proposed in [29], we extended a general-purpose ontology-based context model with concepts characterizing basic aspects of a home-based continuous care scenario.

In the general context model, described in [39], the context of an entity is characterized by one or more Context Items. We defined five general categories for Context Items: Location, Physical Data, Activity, Instrumental and Social Context.

According to our reference scenario for patient health status monitoring and alarm detection and handling, the model represents information needed for inferring the patient health status, detecting possible critical conditions and speeding up appropriate alert notifications and/or interventions. The context entities thus include: Person entities modeling care network members (i.e. Patient, General Practitioner, Nurse, Relatives, Community Members); Place entities representing symbolic locations (i.e. the patient's home and the Care Center).

Related context items include information on patient biomedical parameters (e.g., vital signs) and home living environment (e.g., temperature and relative humidity at the patient's home). The social context (i.e. information regarding members of the care network) is considered a relevant contextual information to be exploited for context-aware assistance service delivery.

Patient status is derived from context data by applying reasoning rules on measurements of biomedical and/or environmental parameters. In case of an alarm, the system exploits contextual knowledge in order to specify and execute personalized intervention policies.

In order to characterize such situation, the context model is made of four sub-ontologies: the Patient Personal Domain Ontology, including entities and relationships for representing monitored biomedical parameters and related evaluation conditions for estimating patient's health status; the Home Domain Ontology, representing monitored environmental parameters and related evaluation conditions; the Alarm Management Ontology, specifying policies for handling alarm situations by exploiting available resources in the care network; the Social Context Ontology, representing persons involved with different roles in the patient's care network.

The ontologies are connected by a set of context reasoning rules, as explained in subsection E.

The Context Model has been written in OWL [40]. In the following figures, OWL ontology-based context fragments are represented by means of UML (Unified Modeling Language) class diagrams. UML Classes represent OWL classes, attributes represent OWL Datatype properties and associations among classes are used for representing OWL Object Properties.

A. Patient Personal Domain Ontology

The Patient Personal Domain Ontology includes context items that can be used to monitor patient conditions, activity, and position and to infer possible alarm conditions or abnormal situations. Fig. 2 illustrates a fragment of this model. A specialization of the *BiomedicalParameter* class is added for each monitored biomedical parameter (e.g., *BodyTemperature*, *HeartRate*). Measurement values (*MeasurementResult*) are used to determine patient heath status by comparing such values with a set of pre-defined parameter ranges (*ParameterRange*). Each range is specified in terms of upper and lower thresholds and related alarm level; when a measured value falls out of the thresholds, a rule-based reasoning process is activated and an alarm is triggered once needed. We have specified four basic alarm levels (very low, low, medium, high), but the model can be easily extended to include further levels and annotations.

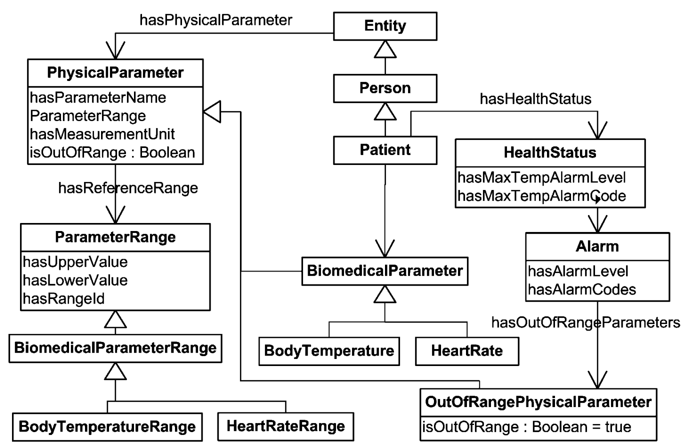

Fig. 2. Patient Personal Domain Ontology

Each Alarm is characterized in terms of the critical level of patient conditions (*hasAlarmLevel* attribute) and the measurement event triggering the alarm (*hasAlarmCode* attribute and *hasOutOfRangeParameters* association). The Patient *HealthStatus* is characterized by a Maximum Temporary Alarm Level (*MaxTempAlarmLevel*), and the corresponding Alarm Code (*MaxTempAlarmCode*). This information represents the most critical alarm condition among possible concurrent active alarm instances triggered by other types of out-of-range measurements.

Hereafter we provide a snapshot of the "Alarm" entity definition in OWL syntax:

```
<owl:Class rdf:ID="Alarm"/>
<owl:ObjectProperty rdf:ID="hasOutOfRangeParameter">
   <rdfs:range rdf:resource="#PhysicalParameter"/>
   <rdfs:domain rdf:resource="#Alarm"/>
</owl:ObjectProperty>

<owl:ObjectProperty rdf:ID="hasAlarms">
   <rdfs:domain rdf:resource="#HealthStatus"/>
   <rdfs:range rdf:resource="#Alarm"/>
  </owl:ObjectProperty>
```

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```
<owl:DatatypeProperty rdf:ID="hasAlarmCode">
   <rdfs:domain rdf:resource="#Alarm"/>
   <rdfs:range
rdf:resource="http://www.w3.org/2001/XMLSchema#int" />
   <rdf:type
rdf:resource="http://www.w3.org/2002/07/owl#FunctionalP
roperty"/>
  </owl:DatatypeProperty>

<owl:DatatypeProperty rdf:ID="hasAlarmLevel">
   <rdfs:domain rdf:resource="#Alarm"/>
   <rdfs:range
rdf:resource="http://www.w3.org/2001/XMLSchema#int"/>
   <rdf:type
rdf:resource="http://www.w3.org/2002/07/owl#FunctionalP
roperty"/>
</owl:DatatypeProperty>
```

B. Patient Home Domain Ontology

An alarm can be triggered also by abnormal environmental parameters. This situation is modeled by means of the Home Domain Ontology, shown in Fig. 3. In the Home domain, environmental parameters, such as temperature and relative humidity, should be monitored in order to maintain a healthy environment and detect possible alarm situations (e.g. by means of gas and fire detectors). The model is similar to the previous one, and therefore not further described hereafter.

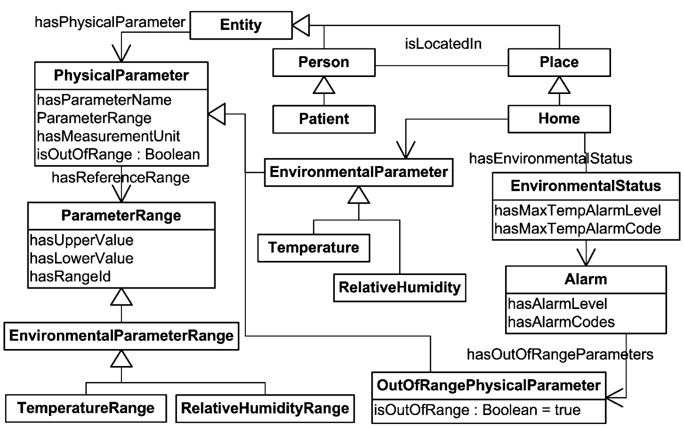

Fig. 3. Home Domain Ontology

C. Alarm Management Ontology

When the system has automatically discerned that a critical situation has occurred, due to abnormal biomedical parameter values or non-healthy and potentially dangerous environmental conditions, proper intervention actions should be decided and implemented. Such intervention planning should be based on flexible coordination and joint actions of different stakeholders: health team, family and social community members.

The Alarm Management ontology represents possible intervention plans for handling critical situations. As an example of possible plans we modeled policies for alerting and requesting intervention to caregivers. More specifically, an alarm notification policy specifies who should be alerted, how and when (with respect to other peers) the notification is sent and if an acknowledgement ("ack") is required. In Table 1 we define a basic example of a policy for each alarm level.

TABLE I
ALARM NOTIFICATION POLICIES - EXAMPLE

Alarm Level	Notification Policies
VERY LOW	SMS to patient relative, no ack required
LOW	SMS and mail to general practitioner, no ack required; SMS and mail to relative, no ack required
MEDIUM	SMS and mail to general practitioner or nurse, ack required; send SMS and mail to relative, no ack required
HIGH	- Message to emergency operator, ack required; SMS to relative, ack required

In the Alarm Management Ontology, shown in Fig. 4, a Notification Policy is modeled as a set of ContactQueues. A ContactQueue contains a list of contacts (ContactPerson) representing care networks members. It also specifies the notification channel (e.g. email, SMS) and whether an acknowledgement is required from the health operator in order to communicate that he/she has read the message and has taken in charge the intervention request (ack required/no ack required in Table 1). ContactPersons have a sequence number attribute specifying with which priority an individual should be contacted with respect to other peers in the same ContactQueue.

For instance, we suppose that when a "MEDIUM" level alarm occurs, the system should perform the following actions:

a) alerting an operator via sms or email. First, a general practitioner is alerted. If he/she does not send the acknowledgement within a fixed time interval, other operators (e.g. nurses) are alerted until one of them sends an acknowledgement. At the end, if no acknowledgement is received, the system alerts an emergency operator, available 24/24 and 7/7. The list of operators to be contacted is dynamically created by selecting the caregivers which are assigned to that patient and are "available" for intervention.

b) At the same time at least one family member should be alerted via SMS, but acknowledgement is not required.

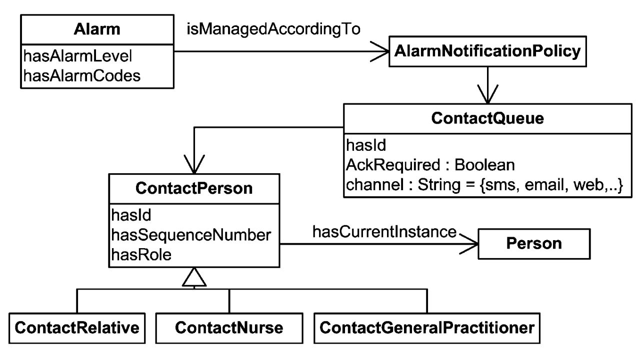

Fig. 4.Alarm Management Ontology

Action a) can be modeled by means of a ContactQueue with AckRequired set to true and pointing at individuals qualified as general practitioners and nurses. Action b) can be specified by means of a second ContactQueue with AckRequired set to false, while pointing at one or more relatives. When an alarm is triggered, notification policies are instantiated by binding contactQueue instances with individuals populating the patient care network and represented in the Social Context Ontology.

D.Social Context Ontology

Patient care network members are modeled in the Social Context Ontology (see Fig. 5). From the general-purpose Person class the following classes are derived: Patient, Relative,

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HealthOperator and SocialCommunityMember. These classes include attributes modeling static information (i.e. identifier and role) as well as dynamic information (i.e. location and activity).

In our application scenario it is also important to model other information, such as the availability of a 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 on the integration of context information sources that can help in semi-automatically updating and managing such information (e.g. GPS positioning and inference mechanisms).

Network members are linked through associations. In Fig. 5 we show only a few associations, which directly involve the patient: a Patient may have some Relatives (*hasRelative*); some Health Operators (*GeneralPractitioners* and *Nurses*) are in charge of patient care (*isInChargeOf*); Social Community Members can offer assistance services, such as transportation services (*offerServicesTo*).

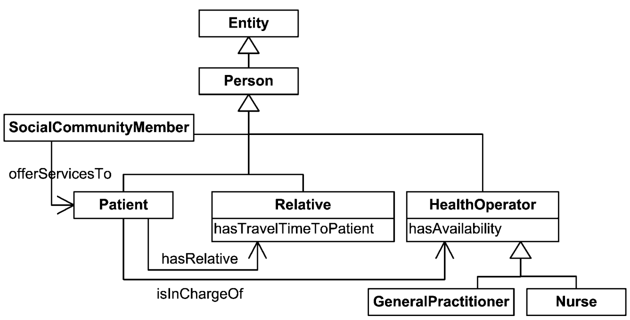

Fig. 5. Social Context Ontology

E. Reasoning over Context

Reasoning over context is triggered for every context data update in order to infer further information on the care network situation (i.e. the patient health status, the most appropriate alarm level to be triggered, the availability of care network members for intervention).

We adopted two kinds of reasoning: ontology-based reasoning and user-defined rule-based reasoning.

Ontology-based reasoning is used in order to determine class subsumption, consistency of new information added to the context knowledge base and instance checking.

User-defined rules provide flexible application-dependent 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, according to measurement values and thresholds represented in the Patient and Home Domain Ontologies. The following example shows a rule activating an alarm when the following conditions occur: “IF systolic blood pressure is higher than 200mm/Hg, diastolic blood pressure is higher than 110mm/Hg and heart rate frequency is higher than 95 beats/minute THEN the patient health status has a HIGH alarm level”

```
(?par1 rdf:type SystBloodPressure) (?par1 hasMeasResult
?v1) ge(?v1,200) (?par2 rdf:type DiastBloodPressure)
(?par2 hasMeasResult ?v2) ge(?v2,110) (?par3 rdf:type
HeartRateFreq) (?par3 hasMeasResult ?v3) ge(?v3, 95) ->
(?healthstatus hasAlarmLevel ‘HIGH’)
```

When the alarm has been activated, rule-based reasoning is applied to Alarm Management and Social Context Ontologies instances in order to determine the notification policy that should be actuated for managing 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).

```
(?a rdf:type Alarm) (?a hasLevel ‘MEDIUM’)(?nurse1
rdf:type Nurse) (?nurse1 hasAvailability 'AVAILABLE') ->
(?q rdf:type ContactNurse) (?q contactIndividual ?nurse1)
```

The specifications presented above can be properly configured in order to facilitate the delivery of personal, personalized and pervasive services for implementing patient assistance plans.

Configurability involves the following aspects:

- According to the specific patient case study and the availability of sensor devices, the type of parameters to be monitored may change. Specific biomedical and environmental parameters can be added as specialization of the Biomedical and Environmental Parameter class.
- Threshold values for biomedical and environmental parameters change from patient to patient and may vary along time for a single patient. These values should be configured and modified when needed by physicians. The ERMHAN system provides a graphical interface allowing authorized users to modify such values.
- Alarm detection and management strategies may be modified on a patient basis by updating the context model (e.g. by adding further alarm levels and/or contact persons) and specifying new reasoning rules.

VI. ERMHAN SERVICE PLATFORM ARCHITECTURE

ERMHAN is a service platform supporting care teams in providing long-term assistance services.

The ERMHAN prototype provides services for information sharing, distributed and multi-channel personalized access to patient data, patient health-status real-time monitoring and alarm management. The prototype is made of the following main components (see Fig. 6):

- A Multi-channel Health-care Services Manager (MHSM), deployed in the care centre domain. It delivers a set of services to care network members (via PC or PDA): Patient Record Management, Alert Management, User Profile Management and Patient Assistance Services. Data concerning patient status, monitoring and alarm management are stored in a patient record database for home-based assistance.
- A Context Management System, providing back-end services for context data acquisition, modeling and reasoning.

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- A wireless sensor system, to collect biomedical and environmental data.

Extensibility and configurability of the ERMHAN service platform are mainly achieved by means of a modular and service-oriented design, the adoption of open and standardized data formats and communication protocols, the exploitation of the above described ontology-based context model.

The next subsection describes the Context Management System architecture, while more details of the overall ERMHAN prototype may be found in [4].

A. ERMHAN Context Management System

The ERMHAN Context Management System is made of distributed nodes, named Context Managers (CM). The architecture of a CM node consists of:

- A Data Acquisition component acquiring raw data from heterogeneous context providers (e.g., sensors).
- An OntologyManager, processing raw context data according to a predefined context model and reasoning rules. It manages a knowledge base, structured according to the above described OWL context models, and uses a rule-based reasoner for context reasoning.
- A Context Broker, which makes context information available to external applications, by managing queries and/or notifying interested applications when the context has changed.

The Context Manager node has been implemented as a J2EE application, and communicates with external components via XML over HTTP and SOAP messages [41]. The communication among internal components has been implemented according to the Observer design pattern [42]: when an event is fired, all its registered listeners are notified. The OntologyManager is based on the open-source Jena Semantic Web Framework [43] and a MySQL database is used to store context models and instances.

With reference to the application scenario, we distinguish two types of CM nodes: a Patient Context Manager (Patient CM) and a Central Context Manager (Central CM).

The Patient CM has to be located at patient site (i.e. the patient's home). It acquires data coming from biomedical and environmental sensors (e.g. via web service-enabled sensor networks or sensor adapters [44]). Sensor data are injected into the knowledge base in order to update system knowledge about patient context (i.e. Patient Domain and Home Domain ontologies). Rule-based reasoning is applied in order to evaluate patient health status and to possible alarm situations. Context changes are notified to interested applications: incoming alarms are sent to the Central CM and new measurement values are periodically sent to the Care Centre MHSM to update the patient record.

The Central Context Manager can be located at the Care Centre site. It receives alarm notifications generated by Patient Context Managers and specifies proper alert notification policy. The Central CM keeps the Social Context base up-to-date by collecting context data about caregivers and patient relatives (e.g. availability and distance from patient home). In case of an alarm, it instantiates the Alarm Management ontology with current alarm information (e.g., patient identifier, out-of-range measured values, alarm level). Reasoning rules are then applied to specify the proper alert notification policy.

Performance characteristics of the Context management system in alarm-handling scenarios have been evaluated in [4].

VII. Experiment and Evaluation

We conducted some experiments focused on evaluating caregivers' acceptance of implemented features.

The prototype has been tested in a nursing home in Piacenza, whose personnel is involved in both hospital and home-based assistance services. Three groups of users have been chosen: general practitioners, nurses and assistance personnel.

A. Methodology

The study had the objective of evaluating the degree of acceptance of implemented features when used by first-time users simulating the performance of tasks relevant to their working activity. The aim of the experimentation was to:

- evaluate the effectiveness of ERMHAN features when performing daily activities and the advantages and/or disadvantages with respect to current practices;
- analyze potential disadvantages and qualify them (e.g. usability problems, technical bugs);
- gather subjective user satisfaction evaluation.

The trial session was conducted with 11 test users (including both general practitioners and nurses).

A first phase was dedicated to present the system to the users by illustrating the purposes of the ERMHAN system and how it could be used in practice in a home-based assistance situation.

In the second phase the users were asked to use the system by

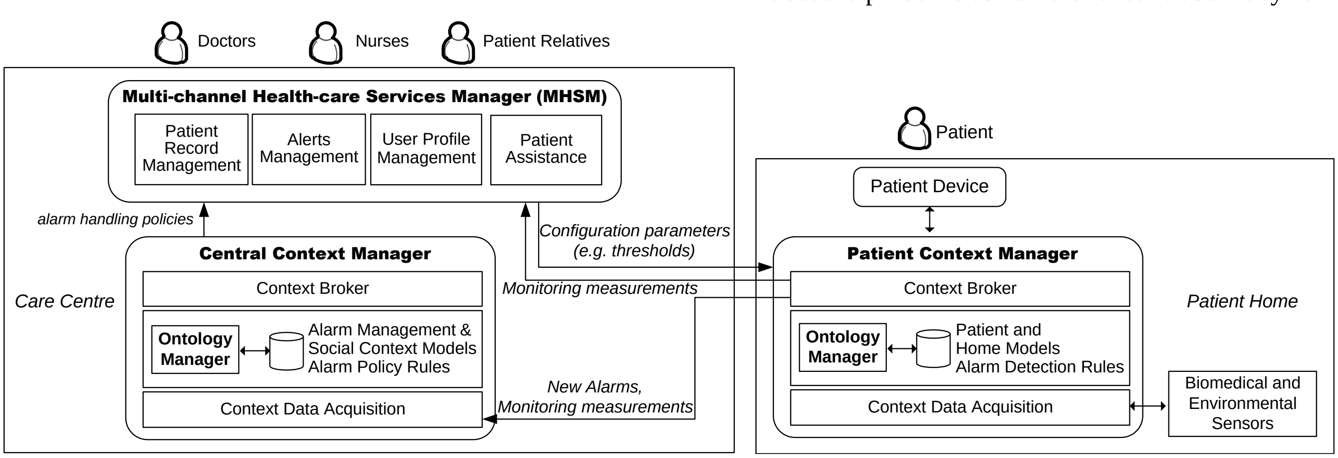

Fig. 6. ERMHAN Platform functional architecture.

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accessing the ERMHAN services via a Desktop PC and a PDA following scenarios simulating possible real-world activities.

Biomedical and environmental sensing of patient health status has been simulated by a web application generating values for some biomedical parameters (i.e. heart rate frequency, pulse oxymetry, systolic and diastolic blood pressure, body temperature, and glycemia). The web application provides services for manual input of values or pre-defined scenario simulations for context data acquisition. Several scenarios were proposed, with the aim of testing the behavior of the system in different alarm level situations.

User feedbacks have been collected through interviews and questionnaires at the end of the trial session.

B. Results

After using the prototype in performing scenario-based activities, users expressed their opinion in a satisfaction questionnaire. The questionnaire included 18 statements to be rated using a 5-point Likert scale [45].

A large majority of users were quite satisfied by the system's overall features (more than 60%). The capability of accessing patient health records has been judged useful and easy to use (but some users had already tested similar features in other experimental systems). The capability of specifying the own profile and availability for intervention were judged very useful (27% of users) and useful (64% of users).

Most users appreciated the capability of remotely modifying the alarm thresholds and data acquisition scheduling on a per-patient basis (18% expressed high appreciation, 73% good appreciation, 9% were neutral). The enforcement of differentiated notification policies depending on alarm levels and the capability of specifying different alarm policies on a patient's basis were evaluated very useful (55%) and useful (40%,). A group of users (30%) complained about some misalignment between MHSM patient record presentation and paper-based records in use in their nursing home (especially in terms of use, information organization and classification). This aspect will be further investigated in future testing activities and properly analyzed when defining a methodology for customized deployment if ERMHAN is applied industrially.

As highlighted in Section IV, the main focus of this work has been to design and implement a service platform addressing configurability and extensibility requirements. These requirements play a primary role for implementing personalized solutions while containing costs by promoting system reuse and re-configuration. This work has thus proposed and experimented a technological and architectural approach based on an ontology context model for coping with these requirements in a general reference scenario. Testing activities have provided a first positive feedback on caregivers' acceptance of services prototyped through the ERMHAN service platform.

These achievements allow to go further on experimentation activities on specific patient cases. Future activities are planned to demonstrate specific improvements of patient assistance and monitoring services at home.

VIII. Conclusions

In this paper we have presented an ontology-based context model and context management system for health monitoring and alarm management of chronic conditions in a home-based care scenario. The main distinguishing features of this work are: a) the attempt to systematically take into account the requirements of novel continuous care models to drive system design; b) the design of an extensible ontology-based context model for modeling health and home environmental conditions, alarm management policy and social context; c) the design and implementation of a context management system and a context-aware service platform for patient assistance and continuous care network support.

We adopted a rule-based reasoning approach for analysing measurement values at specific time instances in order to infer risks related to patient abnormal conditions. Extensibility and configurability of the context-aware adaptive system behavior may be achieved by extending the context model with new concepts or specializations of existing ones and by adding/modifying reasoning rules and alarm threshold values.

Specialization of the ontology context model and related context management system for addressing real case specific needs is not costless, since it requires a system configuration activity by application domain experts. To limit such overhead by easing the reuse and extension of existing specifications, we have designed the ERMHAN context model by adopting a modular approach. In this concern, it appears feasible to extend the graphical configuration interface of the ERMHAN prototype in order to ease system re-configuration by hiding technical details.

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