Deployment of a Smart Telecare System to Carry out an Intelligent Health Monitoring at Home

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***Abstract*—Information and Communication Technologies together appropriate reasoning tools can add value to current telecare systems, including smart tele-monitoring solutions to enhance the capability for identifying risk situations at home. Cooperation between Home Area Networks (HAN) and Body Area Networks (BAN) at home can provide smart systems to support effective health solutions for ageing people living alone, improving service quality and security to the users and relatives. This paper details the development of a reasoning platform to monitor situations of the person at home, and react in risk situations that demanding care support of remote careers. The system integrates BAN and HAN with intelligent agents, whose behavior is defined by ontologies and rules. The system manages environmental and user data to proactively detect risk situations, and dynamically adjust its behavior to trigger the adequate problem solve mechanisms. A development methodology was also adapted to sustain knowledge acquisition process from experts in all stages of the development process and to create the reasoning logic adapted to the users in telecare scenario. Thus, the platform is flexible and easily customizable, according hardware conditions and user profile.**

***Index Terms*—telecare, smart home, health monitoring, ontology, context-aware**

I. Introduction

The ageing population is having a great growth in last years in developed countries. According United Nations, the number of older persons with more than 60 years, that growth is projected to accelerate in the coming decades, reaching nearly 2.1 billion by 2050, assuming a growing of approximately the double regarding the ageing population in 2015 [1].

This scenario supposes new economic and social challenges in the provision and management of health resources. New strategies and advancements in public health services and telecare/healthcare systems will be required to address this situation. The role of Information and Communication Technologies can play an important position in the development of cost effective high quality services, specialized and accessible to the ageing population and more adapted to their needs.

Smart home technologies and biomedical devices in Body Area Networks together adequate monitoring and reasoning mechanism can offer significant benefits in the creation of intelligent healthcare environment that detect and prevent risk situations at home, in the support of appropriate treatment of chronic diseases or in the disease prevention or detection of possible pathologies in early stages [2]-[5].

Common wearable devices and environmental sensors are not capability to carry out sophisticated reasoning by themselves. Monitoring platforms are required to capture and integrate data in the system for its processing. Multiagent systems have been widely tested in dynamic environments where the response time, efficiency and precision in data management is a key matter [6]-[8]. However, it is not enough include an efficient platform to manage the information flow. This information collected must be processed according previously defined context-aware procurements dependents of measurements of sensors, and user profile. The use of ontologies as a tool for context definition has been widely validated in last years. Nevertheless, published solutions aim at solving specific healthcare scenarios mainly. Decision-support-systems based in ontologies usually focus on medical monitoring in concrete medical conditions [9], or they are centered in activities of daily life recognition, such as Wongpatikaseree *et al.* that shown as an ontology can model each activity using location, human posture and sensors [10] or Bae [11] that proposed an ontology to discover and monitoring daily life activities based on OWL.

The system presented in this paper (called ANGEL) includes sensors, actuators and biomedical devices, managed by a sophisticated monitoring platform context-aware to detect and classify situations at home, identifying abnormal status that require external attention, avoiding invasive elements such as cameras. The aim of the ANGEL system is to enhance the personal autonomy by improving the quality of life of ageing people, extend their stay at home in secure conditions, by attending the user when a risk situation is happening and detecting early disease symptoms and given the health condition of the person historically and detect through biomedical devices. Reasoning procurements are based on ontologies

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that define the context of the system and relationships between elements and situations.

II. Matherials and Methods

The construction of a monitoring system context-aware for smart telecare requires a potent methodology which allows to design and to define the distribution of functionality among software entities with own characteristics, and the knowledge of the expert system to understand the environment and take decisions according each detected situation. Traditional methodologies cannot be optimized to manage key features of context-aware healthcare systems, with quick changing capabilities in time, and they are not focused in context-modeling and reasoning, and focused on user needs. However, methodologies oriented to construct expert system are rude and harder. Agile methodologies provide an efficient and flexible process to software development very user oriented.

The used methodology, based in MAS-CommonKADS and agile software development process, has been applied satisfactorily in the construction of the ANGEL system.

The first stage of this methodology was the knowledge acquisition phase. The goal of this phase consisted on the extraction of relevant information about health monitoring at home, identifying market solutions, keys of I&R projects more relevant, stakeholder’s definition and needs, and finally opportunities and barriers. Information sources was relevant publications of the healthcare monitoring area; more specific studies and recommendations in healthcare and telecare for ageing people (i.e. World Health Organization, Spanish Institute for Elderly and Social Services (IMSERSO); and technologies acceptation models more known and applied to obtain relevant information of stakeholders’ needs, use intention and satisfaction).

In this paper we show that the success of a technology is directed linked with user experiences and previous uses of this technology by users, and satisfaction with the use (understanding, usability, usefulness perception and capability of empathize with users and perception of security, efficiency, reliability and information quality showed by the system in a noninvasive way).

Together user experiences and perceptions, the most important knowledge is obtained of telecare experts, through guided interviews carry out by a sociologist in Red Cross telecare Center to telecare professionals and social workers. This extraction of information is a continuous process of this methodology. Functionality is developed in an incremental way, in small software deliverables guided by user requirements obtained in knowledge acquisition phase in each iteration. Each deliverable adding and increase the functionality of the system.

Each iteration finalize with an evaluation process with users to verify and validate the correct functionality of the system, and evaluation of the user satisfaction, including drivers and barriers to use the system. In this evaluation new functionalities or variations to implement are detected and planning in next iterations.

To evaluate this factor with the different stakeholders that will use the system, specific questionnaires oriented to each kind of stakeholder are planning, attending to special features of each one.

Decisions about what kind of sensors to use in this system have been taken during the process of construction the system. However, the presented system tries to wean the logic development and the hardware of detection/actuation. Thus, same logical system can acts with different hardware with similar functionality in different scenarios and homes. Hardware devices are classified according their actuation with the environment and integrated in the knowledge of the system. In the section 3.3, we describe the elements of the system context, and their relationship.

III. System Results

The implementation of the healthcare monitoring system showed in this paper, is based in a JADE multiagent platform. Inside the system, each system agent has its own specific tasks, and they work together with the common aim of detecting risks situations. This architecture improves considerably the efficiency of the system and the decision capability. Agent’s functionality is divided in the phases of monitoring and processing of a context-aware system, such is shown in the Fig. 1. These parts are: detection, preprocessing, reasoning, storage and communication. As result, the system can deduce activities carry out by the user and normal of abnormal situations at home. When a risk situation is detected, it can propose actions oriented to solve this problem. Actions can be divided in two great groups: inside home and outside home. Inside home actions manages actuators at home (e.g. notice user some message, regulate temperature, close open taps, turn on or off some light, etc.). Outside home actions are destined to facilitate decision making for professionals of telecare center when they receive the notice.

This system is a platform independent and it could be installed on a laptop or any device running a Java Virtual Machine. This feature is critical to prevent installation problems in every user's home. Furthermore, its basic software requirements allow their use in low-cost machines with low processing requirements, such as raspberry Pi.

A. Detection

This stage is composed by two differenced parts: devices and Detection Agents. Devices can change in the development of the platform, adapting their use according the market and the requirements of the detection platform.

Nowadays, three kinds of devices are used by ANGEL system:

X10 devices: composed mainly by movement sensors X10-RF and contact sensor as detectors, and lamp and machine modules as actuators. As controller, we use de CM15 module connected to Raspberry PI. Mochad is a Linux TCP daemon for X10 devices- CM15 controller. The selection of X10 have been based in the price compared with others smart home protocols, their plug &

play capability and their simplicity of use and configuration.

Telecare devices in 869Mhz: Tunstall sensors, such as smoke detector, dioxide carbon detector, flood detector, fall detector and bed and chair occupancy together Tunstall Lifeline CONNECT+. More reliable and accurate devices to detect risk situations at home. This element can be traduced to X10 signals through a device called MyLife and an interface XM10. X10 signals can be detected by the ANGEL system, and they can be incorporate in the monitoring and reasoning process.

Body Area Network: This sensors monitor person's physiological parameters. BAN is composed by glucometer sensor, electrocardiogram sensor, pulse and oxygen in blood sensor, body temperature sensor and airflow sensor. These elements establishes communication with raspberry PI through a Bluetooth module connected with an Arduino eHealth Sensor Platform linked to an Arduino UNO board.

Detection agents collect measures and events of these devices and they traduce them to obtain relevant and understanding information for the system. This information takes part of the common knowledge shared by all agents of the system. There is an agent per communication protocol with devices.

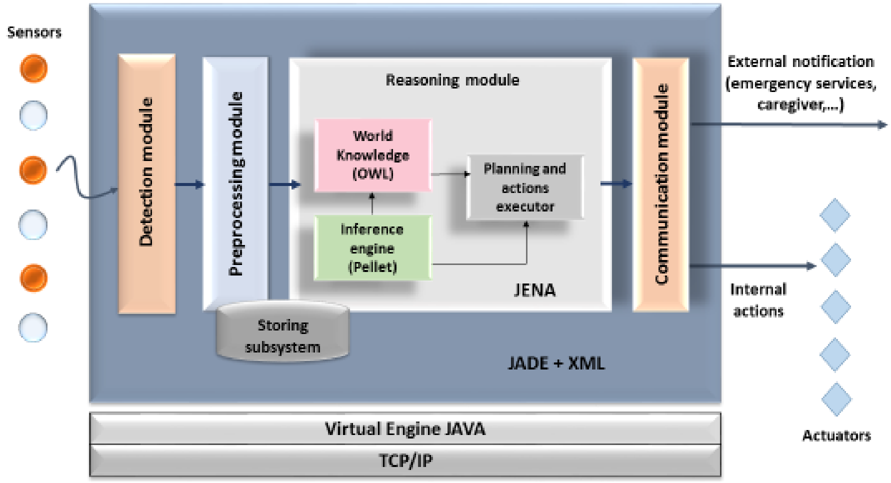

Figure 1. Implementation scenario

B. *Preprocessing and Registry*

When a change of the environment or user is detected, this event is sent to Preprocessing Agent. Preprocessing Agent includes this information in a snapshot with the status of the system in each moment. These snapshots are implemented as XML messages. For each sensor of the system, the xml shows their value, timestamp of activation and time from the activation. Fig. 2 shows a fragment of a XML message generated by Preprocessing Agent.

```
<?xml version="1.0" encoding="UTF-8"?>
<!DOCTYPE TramasSensores SYSTEM "agentes.dtd">
- <TramasSensores idAgente="a1">
  - <trama hora="09:50:00" fecha="01/02/2016">
    - <sensor idSensor="1">
        <valor>1</valor>
        <fechaComienzo>01/02/2016</fechaComienzo>
        <horaComienzo>09:49:00</horaComienzo>
        <tiempoActivo>00:01:00</tiempoActivo>
      </sensor>
    - <sensor idSensor="2">
        <valor>0</valor>
        <fechaComienzo>0</fechaComienzo>
        <horaComienzo>0</horaComienzo>
        <tiempoActivo>0</tiempoActivo>
      </sensor>
    - <sensor idSensor="3">
        <valor>1</valor>
        <fechaComienzo>01/02/2016</fechaComienzo>
        <horaComienzo>09:50:00</horaComienzo>
        <tiempoActivo>0</tiempoActivo>
      </sensor>
    - <sensor idSensor="4">
```

Figure 2. XML message generated by preprocessing agent

Registration Agent records XML Log Files with events triggered by sensors to permit subsequent conclusions from data stored over time, to obtain behavior patterns of the person and detect possible risk situations as deviations of these patterns. Furthermore, this facility allows experts to check the system in post-event inspection through analysis algorithms of logs.

C. *Reasoning*

The Reasoning Agent receives the complete situation of the context in each moment by Preprocessing Agent. It infers new knowledge based in this information and its domain model and knowledge rules of the world. The domain model is defined through an OWL-DL ontology. This ontology defines each situation as a joint of sensors states and profile variables. It allows to detect risk situations for the user (e.g. fall and immobility). The ontology details particular events and activities at home, as well as particular problem solving tasks by specific risk situation. Thus, reasoning is defined by patterns, which can be easily identified by the reasoning engine. Jena API and Protégé-OWL API provide functions to identify tasks and rules in the ontology based on information collected by sensors to include new information and deduct new knowledge by means of the inference. Pellet is the inference engine used in ANGEL system.

Reasoning functionalities of ANGEL system includes: Detection and inference of person's location at time;

Inference of activities to the person according sensors activations, location and time; Inference of Risk activities, normal and abnormal status of the system based in location, activities, environmental condition, behavior patterns of the person and medical conditions; and detecting possible early signs of pathologies, such as Alzheimer, or other health problems.

The knowledge definition requires the definition of the system context and the formalization of reasoning mechanisms according to the acquired information. Three key aspects are involved in health monitoring: input information to be analyzed (user profile, location, ADL behavior patterns and sensors), monitoring and reasoning procedures to detect situations and to infer normal/abnormal status, and outputs according inputs and reasoning mechanisms (detected situations and problems solving actions). Table I shows relevant elements included in the context definition of the ANGEL system. ANGEL Ontology and behavior rules are used to formalize the context of the system, defining all relevant elements and their relationships between them, with the aim of define the knowledge of the system. Context includes all relevant elements known by the system and useful for the detection of the risks situations at home.

TABLE I. ANGEL CONTEXT DEFINITION

Element	Information
Sensors	Environmental: lights, temperature, humidity, flood, smoke, fire, sound, etc. User control: movement, open doors/ windows/ closets/ microwave…, chair/bed carpet, use control an electrodomestic. As attributes, this elements should have: location and time
User characterization	User profile: name, gender, age, social and health context situation, such as medical risk factors already detected by a professional (e.g. depression, high tension, etc.), prescribed medications Emotional status of the person User location User activities characterization: normality behavior patterns
Situations	Activities carry out by the person (physical activities, sleeping, eating, cooking, watching TV) according sensors status Risk situations (user is fall, inactivity, …) Health problems symptoms (lack of alimentation, hours of sleeping, oversights, lack of activity, lack of cleanliness, etc.)
Problem solving actions	Action proposals inside home (turn off a light, regulate temperature, notice the user for an alarm, etc.) and outside home (notice a relative or emergency services)

D. Deployment and Validation

Validation of ANGEL system has been carried out in successive phases. During the first phase of validation, a simple interface was created to construct possible uses cases and validate them in an iterative agile process. Datasets with possible input data ware created in these iterations, to check velocity of processing, quality of reasoning and behavior of multiagent platform, and system usefulness for telecare professionals. Validation test included 12 kinds of sensors to detect location, and risk situations such as inactivity, fall detection, intoxication and lack of normal behavior (lack of cleanliness, lack of alimentation, and change in sleeping habits). Mean time of inference in simulations with around twenty followed changes of context are around 30ms in an Intel Core i7, around 200ms in a Pentium 4, and around 600ms in a raspberry PI. Tests cases were specified by Cross Red telecare professionals as sets of inputs variables that define a specific context situation in the system. Outputs of the system, according this input were observed and compared with the expected behavior previously specified by the experts. This test has allowed to validate the correct operation of the ANGEL reasoning in each iteration, to detect behavior problems and to correct them in next phases.

Although the behavior of the reasoning in a controlled lab has been satisfactory, two main problems have been detected by telecare professionals. The first of them is the identification of the person in the case of the person doesn't life alone. ANGEL system is based in non-intrusive sensors that the user has not wear continuously. The problem of identification of the person not is easily to solve without include a smartwatch element or a wearable. Other detected problem by professionals was that it is complicate know 100% the situation at home without the use of cameras. This fact is evident in some situations such as lack of alimentation, where this activity is detect through contact sensors, location of the user and use of electrodomestics. It is possible that the person simulate this behavior without eat. The same case occurs in the case of take medication, only is possible known 100% that the user takes the medication, observing this fact with a camera. However, the use of cameras is intrusive in a telecare system like ANGEL, and telecare experts and users refuse to use it.

Next test cases will be carried out at 15 real users homes. This test will provide information more realistic about the system precision in each case.

IV. CONCLUSION

The presented solution is based on detection and classification of situations at home. It has provided good results in lab tests carried out with test cases provided by telecare professionals. JADE multiagent platform and OWL ontology to define reasoning, together Pellet reasoner provided a powerful solution in the construction of efficient context aware telecare systems. Hence, the system deployment may help to increase the personal security of the user and his relatives, increasing their autonomy and time of staying at home.

Although the system demonstrates a significant processing speed to respond when a new change has happened and to detect and respond in serious situations. Further tests with larger experts groups and users should be done in order to ensure multidisciplinary view. The ontology and reasoning validation process showed the difficulty to have in mind all the rules to be considered when a combination of n elements from m sensors should be correctly associated to another combination of x tasks from y potential actions. Furthermore, new more precise sensors can be required to define more precisely some activities without the use of cameras.

Finally, the applied methodology has provided an easily way to advance in the construction to the system more agile and precise, defining and amplifying functionality in each iteration guided during each iteration by telecare professionals. The main result has been a solution more adapted to the user and professional's functionality, and a more flexible way of implement needed changes.

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