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An Ontology and Rule Based Intelligent Information System to Detect and Predict Myocardial Diseases

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Abstract— **Elderly people have a high risk of myocardial diseases. Hence, here we propose an architecture for Ambient Assisted Living (AAL) and telemedicine that supports pre-hospital health emergencies, remote monitoring of patients with chronic conditions and medical collaboration through sharing health-related information resources. Furthermore, it is going to use medical data from vital signs for, on one hand, the detection of symptoms using a rule system based on Jess (tachycardia, arrhythmia …) and, on the other hand, the prediction of illness using chronobiology algorithms. This paper proposes a knowledge base to represent general human information, heart details and electrocardiogram parameters based on ontologies and a Jess' rule system to detect anomalies and patterns from electrocardiogram information. This solution has been tested by the research team's staff, using a wearable electrocardiogram.**

Index Terms— *Telemedicine, Ambient Assisted Living, Architecture, Ontology, Rule-Bases System.*

I. Introduction

NEW problems are arising with aging of the population, as a result of both increased life expectancy and declining birth rate. Today there are around 600 million persons aged 60 in the world. The number will be doubled by 2025 and will reach almost 2000 million by 2050 [1]. Therefore, the demand of healthcare services is increasing in Europe and now we have a problem; we are not able to react to the demand of healthcare services because of the lack of personnel, old people's home and nursing homes.

For this reason, it is well known that the Information and Communication Technology (ICT) must provide an answer to problems arisen in the field of healthcare. Ambient Assisted Living (AAL) is a new technology approach from ICT to support elderly citizens. AAL aims for prolonging the time that elderly people can live independent in decent way in their own home [2]. It can be achieved increasing their autonomy and confidence, knowing that if any problem happens, they are not really alone, doing activities of daily living easier with home automation and ambient intelligence solutions.

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Other problems associated with aging of the population are the issues related to health status. Elderly people have an increased risk of heart disease, diabetes, hypertension etc. They have a tendency to get sick easily. That is why it is very important to carry out an early detection of diseases, because there is ample evidence that an appropriate treatment in the onset of the disease will increase the chance of a positive outcome in these patients. Hence, early identification of these patients is critical to accomplish a successful treatment of the disease [3].

For that purpose, nowadays preventive measures are primarily based on periodically scheduled evaluations at clinic visits that are intended to detect the onset of an illness. Such visits often present an incomplete assessment of the patient's health by providing only an instantaneous patient's state. Hence, it is possible that the patient is in the onset of an illness but symptoms or important events have not manifested in the clinic visit time. For this reason, we have considered that monitoring elderly people at home is as important as monitoring that takes place in hospitals. Thereby, this solution is able to detect symptoms and anomalies at any time.

Our contribution is an architecture which supports both the system installed at home to monitor the wearable systems [4, 5] and the remote systems that will be situated in the health care supervision centrals [6-7]. In section 2 it is shown that this architecture has been endowed with a variety of communication interfaces to provide a great flexibility in connectivity and a mobility protocol that allows patients both to use a wearable system either at their homes or in the hospital and to move from one room to another with a seamless connection [8]. In addition to improve the quality of life in elderly people, this system is equipped with the latest technology in home automation. Over this architecture has been defined an OSGi (Open Services Gateway Initiative) platform for the detection and prediction of illness, it is based on a Jess' rule system [9] and a health ontology that has been developed with Protégé [10]. In section 3, both medical analysis of heart diseases [11-13] and chronobiology-based prediction studies [14] are carried out, for finally in section 4 and 5 explain how they have been implemented with a Jess' rule system and a Protégé's health ontology.

II. An Architecture for AAL

We have developed a modular architecture to be scalable, secure, effective and affordable. Its last feature is very

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important, because we are defining a very complex system, very flexible and with a lot of possibilities. Usually a user is not going to use all the technologies the system provides, so that each client can define an ad-hoc architecture from his needs [16-17].

One of the most important parts of a system that works with human beings is the user interface. We can find a lot of literature about Human Machine Interface (HMI) and the need of simple and intuitive interfaces, especially in this case, where a very simple interface is needed because it works with elder people who are not fully adapted to the world of new technologies (ICT), have vision problems or cannot learn to use the system (Alzheimer patients). That is why the proposal is that the user does not need to communicate with the system. However, we offer an intuitive LCD touch and Web interface with a 3D (360 degree cylindrical panoramas) home/hospital representation to access and control the system for hospital staff, old people's home personnel, management personnel or patients if they are able to use it. It is shown in figure 1 where, in the left picture, is shown a control panel with touch screen and touchpad interfaces. In the middle picture is shown a screenshot of the house setting-up software. Finally, in the right picture is shown the Flash application with 3D HMI for local and remote management.

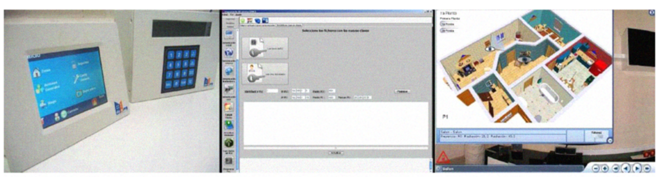

Fig. 1. Users interface of the system

The communication layer provides privacy, integrity and authentication during the process of exchanging information between agents. This system ciphers all the communications with AES cryptography to get privacy and security. It uses hashing with MD5 to get integrity, and user and password to get authentication.

This system has been designed to work with sensors for medical purpose from different vendors. Therefore, this system has a very flexible and open connectivity support.

The system has the next communication interfaces:

1) External communications: Ethernet connection for UDP/IP communications (Internet), modem GPRS (Internet) and Contact ID using PSTN.

2) Local communications: X10 home automation protocol, EIB/KNX (European Installation Bus), 6LowPAN (ZigBee), Bluetooth, Serial, CAN (Control Area Network) and Wire communications using digital or analogy input/output.

In the figure 2 are shown the connections that are available and where they are located.

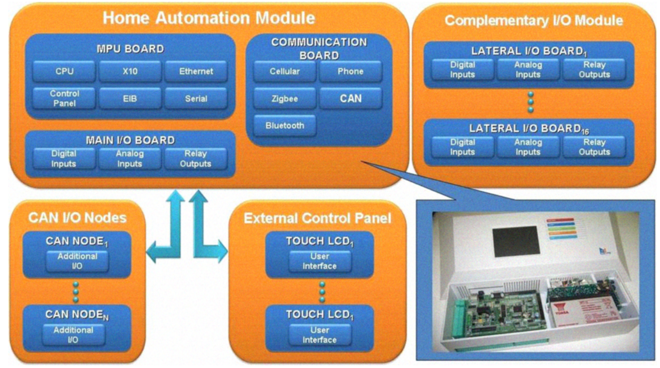

Fig. 2. Communications diagram.

Hence, this architecture serves as a framework to deliver telecare services to elderly and people in dependant situations. This framework is used as a basis to deploy specialized services, coverings aspects such as:

1) Home automation: This service is going to facilitate access to home facilities. Our system was originally conceived as a system that integrates multiple technologies for home automation, adding a high-capacity and heterogeneous communications to interact with other local or remote systems.

2) Security: It is very usual to find security solutions together with home automation ones. For this reason, it is able to be used like a security system too, and for that purpose, it implements the standard protocol used nowadays in security systems to send alarms to a central security, i.e. contact ID over Public Switched Telephone Network (PSTN).

3) Ambient Intelligence: Ambient Intelligence is used both to increase the ease of use of home facilities provided by the home automation and to adapt the home to the Activities of Daily Living (ADL). ADL refers to the basic task of everyday life, such as eating, bathing, dressing, toileting and transferring [15]. If a person can do his ADL, then we can talk of independence. These kinds of tasks are very difficult in elderly people. So by learning behaviors and habits using Ambient Intelligence, the environment is going to facilitate ADL.

4) Telemedicine: The last service consists of monitoring and care of elderly or ill person with telemedicine solutions. For vital signs and health condition monitoring, a set of biometric sensors can be located in the preferred environment of the elderly, and transmit, via the central module, information about his/her health status to the EHR central, so that it could be used by qualified professionals to evaluate their general health conditions with a big amount of information. Hence, Doctors could do a better diagnosis. Furthermore, these sensors are able to fire alarms in case an emergency occurs. We will see this in the rest of the paper.

Our system used for telemedicine (with medical sensors) is shown in the figure 3 and a description of these elements in table 1.

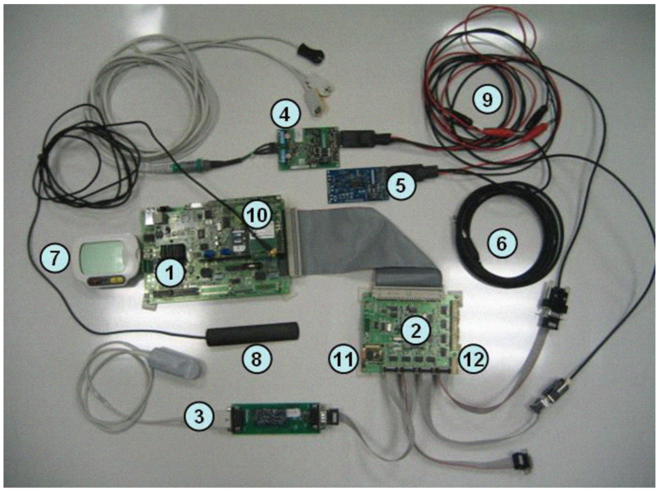

Fig. 3. Medical sensors connected to central node.

TABLE I
DESCRIPTION OF ELEMENTS FROM FIGURE 3

ID	Description
1	Control unit with GPRS and Ethernet communication interfaces
2	Medical extension with Serial and Bluetooth communication interfaces
3	Test Kit Mini pulsoximeter OEM Board. EG0352 of Medlab
4	**Test Kit EKG OEM Board, EG01000 of Medlab**
5	Test Kit Temperature OEM EG00700 (2 channel YSI 401 input) of Medlab
6	YSI Temperature Sensor 401 of Medlab for core and peripheral temperature
7	Bluetooth glucometer of OMRON
8	GPRS Antenna
9	Power supply
10	GPRS Modem
11	Bluetooth Modem
12	Serial ports (RS-232)

Particularly, the EKG module is used in the next sections to evaluate heart state. The EKG curve is measured in the physical unit "cm/mV" for the y-axis and "mm/sec" for the x-axis. This reminds from times when the amplified signal was written down directly on paper using strip recorders. Since it is not defined what kind of display is connected by the user to the EG01000, this offers a value between 0 and 255 for the y-axis. The numbers of sample points sent per second for the x-axis (s^{-1},Hz) is equal to 300.

The zero line is always in the middle of the range, e.g. 128 or 0x80. A usual EKG signal has amplitude of 1mV, which is equal to 75 steps, exactly the signal swings between 90 and 165.

This system connects the EKG module to the OSGi platform, which receives the data of the curve. In the next section is explained the EKG curve and how illness can be detected.

III. ELECTROCARDIOGRAM ANALYSIS AND CHRONOBIOLOGY

In order to determine the patient's medical condition, several wearable systems focus on monitoring a single dominant physiologic feature as a symptom of a medical condition by performing a simple rule-based classification on individual sensor data to generate alerts [20]. With this kind of solution we get a first approximation of the health status, but we know that it may not lead to an accurate medical diagnosis. That is the reason why we are defining all the base elements to get a capture of several vital signs, so that in future works it will be possible to build temporal-based models for diagnosis using different physiologic features.

In the actual state of the solution, we are defining the detection of myocardial diseases using a rule based system and a health ontology.

On one hand, in this section it is going to be explained how to analyze the electrocardiogram curve in order to find out any heart anomaly, on the other hand, it is going to be explained how to predict myocardial infarction using an algorithm from chronobiology.

1) *Electrocardiogram analysis*

As it is known, the EKG test is written down in a graph paper in which x axis represents time and y axis voltage. Due to the velocity of the paper, each horizontal millimeter is equivalent to 0.04 seconds. From now on it will be used, for example, the number 12 instead of 0.12 (seconds). Another issue is that it is going to be used only the V2 precordial lead (The signal from V2 is got from the EKG module explained in the section II). With V2 it is enough in order to compile the required information.

The EKG curve looks usually as follows:

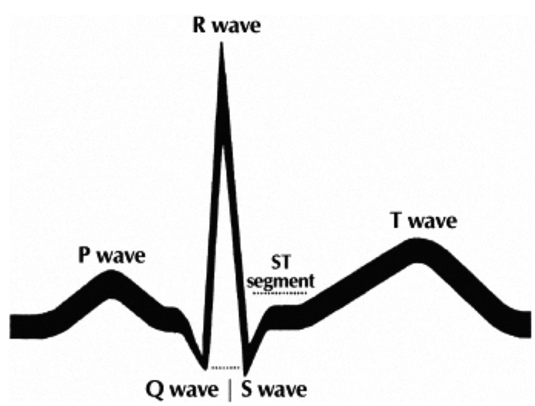

Fig. 4. EKG Curve [21].

In this figure six waves can be distinguished, their names are, as it can be seen, P, Q, R, S, T and U. They are caused by the movements of the heart. Studying the relationships between them it is possible to find out some anomalies. Each of these anomalies can be caused by a set of myocardial diseases. For example, if the width of the QRS segment is less than 12 it could be expected necrosis or ventricular hypertrophy, among others.

As can be observed, it is not possible to talk about a direct mapping between an anomaly and a disease. What it is intended with it is to alarm the patient that something wrong could be happening.

Particularly the most relevant information from this curve is the periods between the six waves and polarity of signals U and T.

In the table 2 are defined some rules to infer the causes of such anomalies from the electrocardiogram [11-13].

TABLE 2
RULES FROM ELECTROCARDIOGRAM

Anomaly	Possible Causes
Segment QRS > 0.12 secs	Ventricular hypertrophy, necrosis, BCRD, BCRI, pacemakers, cardiomyopathies, electrolyte abnormalities
Sign U <> Sign T	Ischemic heart disease, hypokalaemia
Segment PR > 0.20 secs	First-degree AV block
Segment PR < 0.12 secs	Tachycardia, WPW, manners or headphones low rates
Segment QT > 0.45 secs	Antiarrhythmic medicines, ischemic heart disease, cardiomyopathies, hypocalcemia, mixedema, long QT syndrome
Segment QT < 0.35 secs	hypercalcemia, hyperkalemia, early repolarization, digoxin

2) Chronobiology

The prediction of illness can be carried out with results from chronobiology, which is ancillary to the medicine results.

Chronobiology is a field science that studies the temporal structure (periodic and cyclic phenomena) of living beings, the mechanism which control them and their alterations. These cycles are known as biological rhythms. The variations of the timing and duration of biological activity in living organisms occur for many essential biological processes. These occur in animals (eating, sleeping, mating, etc), and also in plants. The most important rhythm in chronobiology is the circadian rhythm, a period of time between 20 and 28 hours [4].

According to some chronobiological studies [14], the myocardial infarction could be predicted until eight days before it happens. This algorithm is based on the assumption that the beat rate of a patient is very variable from a moment to other (it is chaotic in a normal patient). This is very usual because a person can make an effort, move, go upstairs and even without conscious activity as digestion the heart is working.

In the figure 5 is shown the variability of the heart beat rate in a normal situation and days before to a myocardial infarction.

On the left column appear some graphs which show the cardiac frequency (i.e. the variation of the cardiac rhythm over time). On the second appear the spectral analysis (i.e. the variation of pulses' amplitude over time) and on the third one we see the trajectories in a space of phases (the cardiac rhythm at a given moment over the cardiac rhythm at a time immediately preceding). These phase diagrams show the presence of an attractor (An attractor is the pattern we see if we observe the behavior of a system for a while and found something like a magnet that "attracts" the system towards such behavior).

The individual represented in the top row shows an almost constant heart beat, suffered a heart attack three hours later. We can observe that the variability is less of 10 beats. The central row, showing a rhythm with periodic variations, was obtained eight days before sudden death. We can observe that 8 days before the variability it is between 10 and 20 beats. The bottom row corresponds with a heart beat of a healthy individual. We can observe that in a normal situation the variability is between 30 and 40 beats.

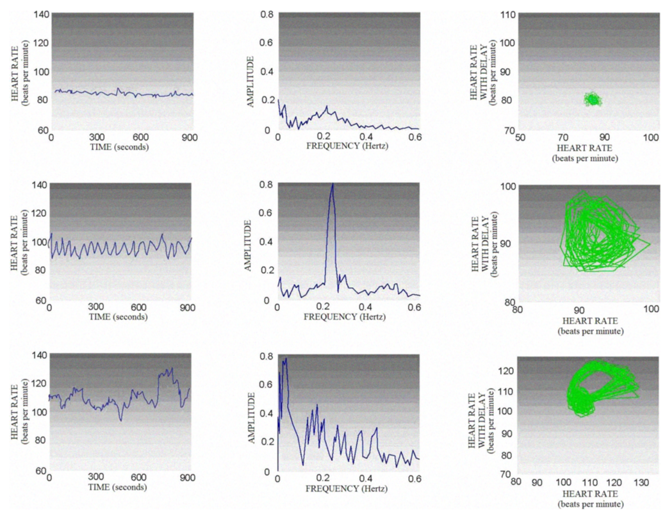

Fig. 5. Heart rate days before a myocardial infarction [14].

Hence, we can analyze this variability in heart beat rates in circadian periods to detect the risk of myocardial infarction.

IV. HEALTH ONTOLOGY

In this section it is going to be explained which is the knowledge base and how it has been developed.

To accomplish the goal it is needed a knowledge base that compiles all the required information in order to infer the set of diseases.

In this case, the ontology has been developed using Protégé [10]. The classes in the ontology show a semantic relationship, e.g. *Human* is the super class of the rest.

Fig. 6. Ontology tree.

Each of these classes has certain numerical properties, e.g. a human has weight or the heart has some properties related to the EKG curve (see section III). The data compiled in real time by the sensor will be mapped to these properties; hence the ontology will be updated with the last reading. Besides, it is also possible to save the readings in a file in order to create a health record.

With regard to the information for the prediction of myocardial infarction, since it is based on a chronobiology algorithm, we need to save a 24 hours history, because it is the circadian rhythm. For that purpose, in the ontology has been defined an instance for each hour, so each one of them saves the minimum and maximum heart rate frequency, thereby, the rule system can get the minimum and maximum value from the last 24 hours and if the difference is less than 20 bpm, then a alarm is fired.

In the figure 7 is shown how the 24 instances for each hour and one for calculating the absolute values are saved.

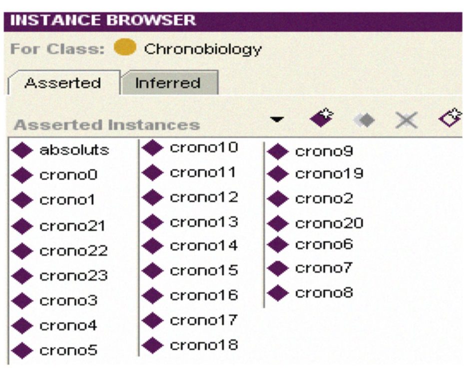

Fig. 7. Chronobiology's instances in Protégé.

V. RULES SYSTEM

In this section it is going to be explained the inferences system. When the knowledge base is created it is possible to infer the set of diseases that could cause the anomalies. As it can be observed, it is a backward search. What it is intended is to find out the causes.

The rule system has been created with Jess, which can communicate with Protégé using JessTab Plug-in. This allows us to load an OWL file and map the ontology instances to facts. To load and map the ontology the next commands must be executed.

```
(load-project file:///C:/monere.pprj)
(mapclass http://monere.owl#Human)
```

Remark that the mapclass command only needs to indicate the superclass human.

TABLE 3
RULES FOR JESS

Anomaly	Possible Causes
Segment QRS* > *0.12 secs	(defrule rule1 (object (is-a http://monere.owl#Heart) (http://monere.owl#_tS ?s) (http://monere.owl#_tQ ?q)) (test (> (- ?s ?q) 0.12)) => (printout t " Ventricular hypertrophy, necrosis, BCRD, BCRI, pacemakers, cardiomyopathies, electrolyte abnormalities " crlf))
Sign U <> Sign T	(defrule rule2 (object (is-a http://monere.owl#Heart) (http://monere.owl#_vU ?u) (http://monere.owl#_vT ?t)) (test (or (and (> ?u 0) (< ?t 0)) (and (< ?u 0) (> ?t 0)))) => (printout t " Ischemic heart disease, hypokalaemia " crlf))
Segment PR > 0.20 secs	(defrule rule3 (object (is-a http://monere.owl#Heart) (http://monere.owl#_tP ?p) (http://monere.owl#_tQ ?q)) (test (> (- ?q ?p) 0.20)) => (printout t " First-degree AV block " crlf))
Segment PR < 0.12 secs	(defrule rule4 (object (is-a http://monere.owl#Heart) (http://monere.owl#_tP ?p) (http://monere.owl#_tQ ?q)) (test (< (- ?q ?p) 0.12)) => (printout t " Tachycardia, WPW, manners or headphones low rates " crlf))
Segment QT > 0.45 secs	(defrule rule5 (object (is-a http://monere.owl#Heart) (http://monere.owl#_tT ?t) (http://monere.owl#_tQ ?q)) (test (> (- ?t ?q) 0.45)) => (printout t " Antiarrhythmic medicines, ischemic heart disease, cardiomyopathies, hypocalcemia, mixedema, long QT syndrome " crlf))
Segment QT < 0.35 secs	(defrule rule6 (object (is-a http://monere.owl#Heart) (http://monere.owl#_tT ?t) (http://monere.owl#_tQ ?q)) (test (< (- ?t ?q) 0.35)) => (printout t " hypercalcemia, hyperkalemia, early repolarization, digoxin " crlf))

In the table 3 are shown the rules, as were defined in the table 2, but now using Jess and the ontology defined in the section IV.

VI. CONCLUSION AND FUTURE WORK

We have built an architecture [6-8] to give support to care-delivering environments, such as patients home, i.e., self-care. This architecture provides a set of services that can be used autonomously by elderly people. The set of care-delivering environments is very wide, that is the main reason that we provide an architecture very flexible and with a lot of different options of configuration, so that the final user can define an ad-hoc solution to his needs.

In the actual status, it can detect anomalies in vital signs that show myocardial diseases [11-13], as well as detect myocardial infarction using a chronobiology algorithm [14]. But it does not offer an accurate base of diagnosis, for this reason, as future work, we want to improve the artificial intelligence layer, so we can detect diseases using temporal-based models too. Furthermore until the moment, this system has just been tested by the members of our team. Hence, we want to test it with elderly people and real patients, and together with them and their experiences, implement ambient intelligence algorithms to detect patterns in the user behavior.

Finally, in a monitoring system is very important to keep a register with the information from patient over time. For this purpose we want to save information in CEN/ISO 13606 format, so it can be deliver to other medical information systems as HISA at hospitals. Thereby, when either a symptom or disease is detected, the information that shows the anomalies can be sent to the hospital, avoiding observation periods in the hospital.

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