AmIHomCare: AAL system for elderly and disabled people indoor assistance

Stefan Mocanu, Irina Mocanu, Silvia Anton, Calin Munteanu

***Abstract*—**This paper presents a complex ambient intelligent system designed to monitor and assist human subjects at their residence. Unlike other proposed systems, AmIHomCare will monitor the vital signs of the patient or elderly people in attempt to identify a potential dangerous situation and it is also capable to control environmental parameters in order to ensure a personalized environment for the user. The system offers several other functions: access control to some restricted areas based on biometric recognition, gesture and object identification based on image retrieval and processing, mobile robot assistance, real time processing of data gathered from sensors, data logging and archiving, communication with a remote call center, automatic alerts sending capabilities. The system is based on 4 independent modules, each one with it's own specific task. The modules communicate and may cooperate if required by a specific situation. The core of the system is represented by the environment monitoring module where all the data from other modules is gathered and kept in a data base. The core also acts as a relay for alert messages that are being sent by the other modules (when detecting an emergency situation) to a call center. Certain communication redundancy will be implemented in order to make sure that alerts reach the destination and fast reaction is guaranteed. The emergency medical unit that arrives at patient's home can consult his/her medical history by accessing the local database. Some individual components and functionality have already been tested and other just simulated.

***Keywords*—** ambient monitoring, content based retrieval, elderly and disabled assistance, image annotation and retrieval, iris and fingerprint recognition, multi-agent system, wireless body sensors, wearable sensors

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I. INTRODUCTION

Recent statistics [1] reveal a serious ageing trend in European Community's countries. Latest figures show that more than 20% of the population exceeds 65 years (2010) and the prognosis show that in 2025 the percentage will grow up to 35% while in 2060 it will reach 55% or more.

Medical advances nowadays allow a higher life span expectancy. Corroborated with the decrease in birth rate due to social, economical and political factors, it is obvious that the old population will soon face the incapacity of society to offer them decent living conditions and medical care. Less contributors and more consumers will collapse the classical social and health funds as well as medical systems.

According to World Health Organization [2], "Disabilities is an umbrella term, covering impairments, activity limitations, and participation restrictions. An impairment is a problem in body function or structure; an activity limitation is a difficulty encountered by an individual in executing a task or action; while a participation restriction is a problem experienced by an individual in involvement in life situations. Thus disability is a complex phenomenon, reflecting an interaction between features of a person's body and features of the society in which he or she lives". A recent report of World Health Organization states that : "An estimated 10% of the world's population - approximately 650 million people, of which 200 million are children - experience some form of disability. The most common disabilities are associated with chronic conditions such as cardiovascular and chronic respiratory diseases, cancer and diabetes; injuries, such as those due to road traffic crashes, falls, landmines and violence; mental illness; malnutrition; HIV/AIDS and other infectious diseases. The number of people with disabilities is growing as a result of factors such as population growth, ageing and medical advances that preserve and prolong life. These factors are creating considerable demands for health and rehabilitation services". In [3], Morgani and Riva point that existing and future solutions do not match the needs of disabled people unless new concepts emerge.

As a result of the statistics presented above many efforts are currently being redirected towards development of innovatory systems for medical assistance. On March 15, 2010, the Declaration on European Cooperation on e-Health was signed in Barcelona by the Ministers of Health of the EU Member States, proving a strong determination of improving health services at the EU level.

II. AMBIENT ASSISTED LIVING AND HOMECARE

More and more we hear about Ambient Assisted Living (AAL) and Ambient Intelligent Environment [4] (AmI). If 4 or 5 years ago these terms were fairly new, today they are becoming more a reality than they are a concept. Advances in hardware, software, sensors, power supplies and communications allow the development of new environments where people are surrounded by intelligent devices and interfaces that will have the only purpose of making life easier and more comfortable for the users.

According to Information Society Technologies Advisory Group (ISTAG), AmI should be aware of users' personalities and preferences but, yet, should not be obtrusive. Furthermore, the user should not be forced to adapt to such a system nor should need a long time to learn how to use it. Ideally, the interaction between such environments and the user should be limited to natural language commands or gestures.

Homecare represents a particular type of ALL. The concept denotes an intelligent environment customized for monitoring and assisting elderly people, disabled people or patients at home. The target of such systems is to allow the user to have a normal life in a friendly environment while making significant financial savings without negative repercussions over the user's safety or integrity. The system addresses the patients that do not require permanent medical surveillance.

The technology is here and, although the efforts and costs for developing and implementing homecare systems are high, all evidence show that they will be received well by the population.

Several assistive systems [23], both for indoor and outdoor environments, have been proposed. Most of them are focused on single tasks such as vital signs monitoring, fall detection, environment customization or person localization. Some less complex systems, actually the simplest of all, are represented by a radio transmitter which acts like an alert beacon when a button is pushed by the user. This system has many inconveniences because, for example, during a heart attack or a stroke the patient may not be able to push the panic button. Another philosophy is based on public/mobile telephony or proprietary pager-like devices. A human operator calls the patient (subscriber) according to a pre-determined schedule to check if the patient is well or to remind him to take the appropriate medication. This category of systems is called "tele-medicine systems". Unfortunately it is not very reliable since it is pretty much based on subjective description of the patient (which, most likely, has no medical background). Moreover, a critical event may occur immediately after the phone call in which case it will only be detected at the next call. Since the interval between phone calls is usually long (this way, annoying the patient is avoided) unwanted events or even death may occur.

More complex homecare systems were proposed [3][5][6][7] during the last few years but none of them covers all the specific needs of a dedicated system for assisting elderly or disabled persons. Such systems have some particularities that require special attention during development, implementation and utilization. The most important aspect is the awareness of the system or, better yet, the lack of awareness for it's user. The typical user is an elderly person that usually rejects new technologies and intrusions, has some physical constraints and presents a limited or no desire to learn new things.

III. PROPOSED SYSTEM ARCHITECTURE

We propose an ambient intelligent system (Fig. 1) for home medical assistance of elderly or disabled people, codename AmIHomCare. The system covers most of the requirements mentioned above and offers the following functions:

- most important vital signs monitoring: temperature, respiratory rate, heart rate, oxygenation
- movement monitoring;
- access control and restriction;
- object recognition;
- ambient monitoring and control
- data logging
- call center notification
- others.

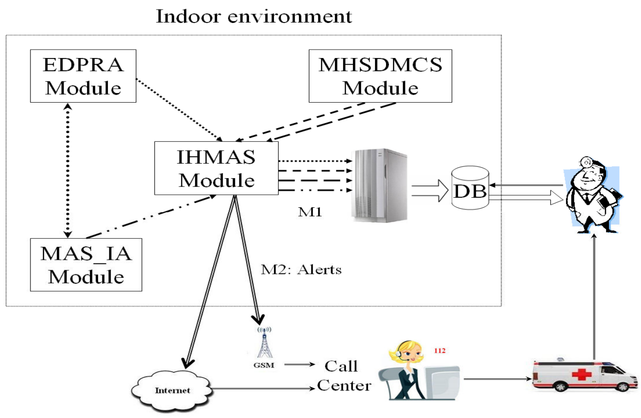

Fig. 1 AmIHomCare system architecture

As one can see in Fig. 1, AmIHomCare is based on four independent modules (subsystems) which cooperate to achieve the following goals:

- environment monitoring and control – this will ensure permanent optimum parameters (established by a doctor or based on user's preferences) and will detect dangerous situations (gas leaks, high levels of CO and CO2)
- home monitoring and assistance for elderly or disabled people with low level risk factors that do not require permanent medical attention in a hospital or clinic;
- medical emergencies detection and notification to a call center that will send medical assistance to the patient's home;
- events logging – this will be very useful in case of a medical emergency, the doctor can see the patient's history and evolution
- user localization and identification
- user assistance
- access control and restriction to some potential hazardous areas or devices (such as a gas oven)

Details regarding each module and how they communicate are given in the following subsections.

A. IHMAS Module

The Intelligent Home Monitoring and Assistance System (IHMAS) module may be considered the core of AmIHomCare. Although, as previously stated, all modules are independent and can be implemented and used separately, besides it's specific tasks, IHMAS module acts like a message relay for other components.

IHMAS aims to provide users the tools they need in achieving a pleasant and safe environment in their home [27] and to predict (as much as possible) the user's needs. This is an important component in AmI (a very comprehensive state of the art in AmI is presented in [8]) and represents one of the main research directions for next generation buildings [9].

The system was designed in a modular and scalable way, with components that can be added at any time, each one handling a specific task. The module's architecture consists of three layers (Fig. 2).

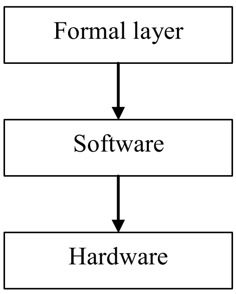

Fig.2. Functional architecture of ambient monitoring system

The first layer is represented by the modelling tool, which is Interpreted Petri Nets. This tool is used because it has the ability of modelling systems which are synchronized on external events, have associated timings to different activities and can also handle variables.

The second layer is represented by the software component. This component will be a multi-agent system [20] which consists of four main components:

- interface agent
- temperature control agent
- lighting control agent
-important events agent

The interface agent has the following tasks:

- establish the reference values for temperature and lighting control agents. The reference values are either computed by the interface agent, either received from the other components of the AmIHomCare system (according to medical prescriptions)
- send the reference values to corresponding agents,
- send to the exterior (a call centre or an emergency situation centre) the information from the important events agent.

Temperature control agent is designed to have the following functions:

- follows the reference received from the interface agent;
- notify the interface agent regarding the impossibility of following the received reference;
- use a temperature sensor and an actuator in order to control the ambient temperature.

Lighting control agent has the following functions:

- follows the reference received from the interface agent;
- notifies the interface agent regarding the impossibility of following the received reference;
- uses a light sensor and two actuators (for both window blinds and artificial light control).

The fourth agent is monitoring the occurrence of important events, such as: gas leaks (CO, CO_2 and combustion gases), fire, overflow, smoke presence. It will be linked with multiple sensors, each one monitoring a specific event. Apart from monitoring, this agent is notifying the interface agent about each occurrence.

The third layer is represented by the hardware equipment: sensors and actuators for monitoring and controlling different environment parameters (all mentioned above).

In respect to the information that will be transmitted, two message classes were set:

- inter-component messages (messages from one component of AmIHomCare module to another). Two main classes have been identified: M1 – log or information exchange messages and M2 – alert messages;
- intra-component messages (messages from one component to another, both corresponding to the same AmIHomCare module)

The intra-component messages related to the intelligent ambient monitoring system are structured in three categories:

- basic messages (data acquired by the sensors and sent to different agents and commands to the actuator). Not all the information is logged.
- logging messages (some important messages from the first category).
- high risk messages (messages from important events agent or important patient health/state messages from other AmIHomCare components; eg: health parameters, fall detection, etc).

During the next step, the ambient monitoring component will become intelligent by learning the user behaviour and trying to predict his/her actions and preferences (regarding ambient parameters).

B. MHSDMCS Module

The Medical Home Surveillance Devices Monitoring and Coordination System (MHSDMCS) module is responsible with the vital signs monitoring. Based on their evolution and instant values critical situations can be detected and transmitted to the call center via IHMAS module. The module can monitor other non-vital parameters such as patient's movement (from a quantitative perspective) so that sedentary bad habits can be prevented.

MHSDMCS is based on the concept of Body Sensor Network (BSN) [10][11]. In our approach, sensors (also known in literature as Body Sensor Units – BSU [12]) are wirelessly connected to a mobile central unit (also known in literature as Body Central Unit – BCU [12]) where all data from sensor is gathered and processed. The results are passed (also wirelessly) as messages to a Home Area Network (HAN) implemented at IHMAS level. The categories of messages (logging messages and alert messages) were previously described.

Considering the communication channels between BSU and BCU [26] and, also, between BCU and HAN, MHSDMCS module is, in fact, a Wireless BSN with external communication facilities (sending messages only) implemented at BCU level. Specific requirements of the application such as: low power consumption, low range (<1m for intra-communication and <10m for inter-communication), low transmission rate led as to IEEE 802.15.4 standard both for intra and inter communication. This standard covers all the requirements of the proposed system (range up to 10m, transfer rate up to 250kb/s) which recommends it for a typical home use where rooms rarely exceed 30m2. So far, similar monitoring systems were only tested in hospitals or clinics where the saloons' area is considerably smaller.

The proposed architecture for MHSDMCS module is depicted in Fig. 3.

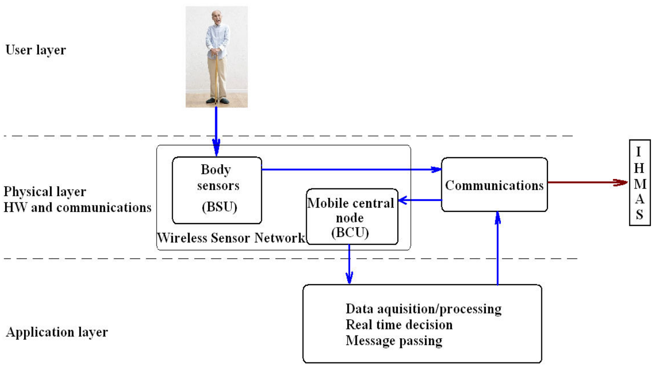

Fig. 3 Functional architecture for MHSDMCS

Based on IEEE 802.15.4 specifications, for the wireless sensor network a star architecture was chosen. Only the central node (the BCU) can communicate with the exterior (IHMAS module) by sending messages. Sensor data fusion and decision will be made at the BCU level. This way, minimum power consumption will be achieved at the wireless body sensor units.

MHSDMCS monitors following vital signs in attempt to determine a medical danger or crisis:

temperature, respiratory rate, heart rate, oxygenation – they are used to determine if an inflammatory syndrome occurs;

movement monitoring – it is used to determine the subject's physical condition and to prevent sedentary states;

falls – it is well known that elderly present high risk of falling which may lead to medical complications.

Another new concept introduced by AmiHomCare at MHSDMCS level is patient profiling. This is achieved by grouping diseases into clusters and monitoring specific parameters. This is also very important for determining and setting optimum environment parameters for the patient/user in IHMAS module.

During design and experiment stage, only temperature monitoring and raw data transmission kits were used as shown in Fig. 4.

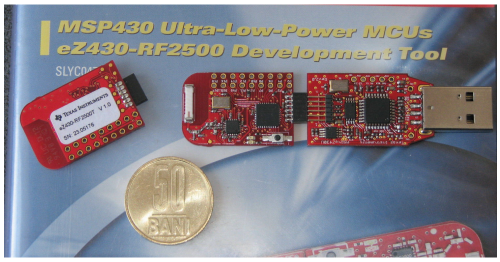

Fig. 4 Texas Instruments development kits

Since the other sensors have similar behavior so they will be easily integrated into the system.

Critical situations' detection will be made at the BCU level. In this case, alert messages will be sent to IHMAS module which will route them to the call centre. In order to avoid any possible disputes, these alert messages will be stored in the DB along with the normal medical history. Special attention will be granted to delicate situations when abnormal vital sign reading may indicate a possible critical state (for example, the user takes a hot shower which will determine a serious temperature raise and, also, an increase of heart rate; with all these, the person's health is not at all in any danger)

C. MAS_IA Module

Based on pictures received from the cameras, the Multi-Agent System for Information Access (MAS_IA) module will identify the position of the monitored person inside the house. Using the extracted information from the analyzed images, the system will send alert data to the surveillance factors of the person. Also the supervised person can use the system for retrieving different medical products based on images.

MAS_IA captures and stores images from the supervised person's house. These images will be constantly analyzed and interpreted either by a human operator or automatically. The result gives the person's position relative to objects in the room. For this purpose the images will be annotated with the component objects. After that, the person's position will be obtained. The system will also detect an emergency situation and send alert messages to the call-center via IHMAS.

The supervised person may need to seek a medical product in a simple form: he will provide to the system an image of the product and it will obtain a list of similar products. For this, content based image retrieval techniques [25] will be used.

Thus the MAS_IA can be viewed as: i) a supervising system, or as ii) a retrieval system. In both cases we have a semantic image retrieval system which will use annotated images, will retrieve similar images based on their content and the system architecture will be based on the multi-agent architecture. The main components of the MAS_IA module are presented in Fig. 5.

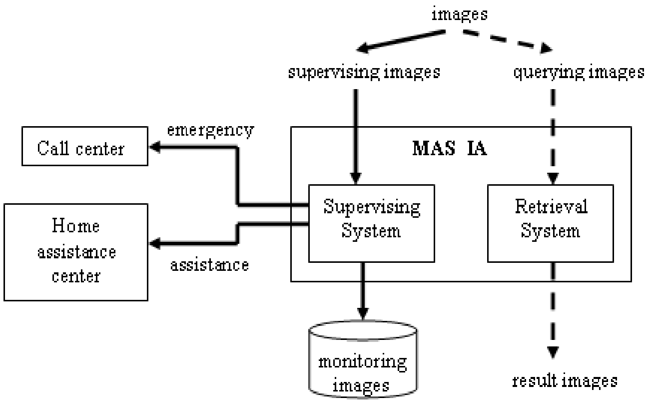

Fig.5 The MAS_IA structure

For the image annotation, a method based on a genetic algorithm [13] has been proposed. The training images are clustered using K-means algorithm based on the contents' similarities. These similarities are computed using the shape low level feature. Annotation is performed using a genetic algorithm, which determines the best match between each region from the image and the corresponding regions of the cluster to which it belongs. To reduce the execution time, a parallel version of the annotation genetic algorithm [14] was proposed.

The person position in the room will be obtained in two steps, as described in Fig. 6. First, the image will be annotated using the genetic algorithm, obtaining the set of the objects in the room. These objects will be grouped in a semantic net which will be the room representation. Second, the body components will be detected using the method described in [15] and the person position will be modeled using a set of rules grouped as a context free grammar.

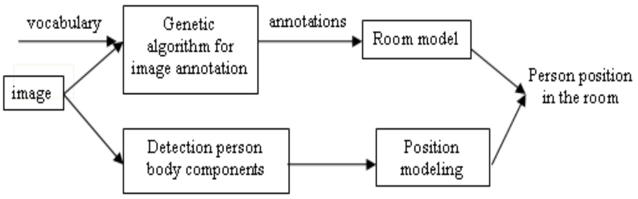

Fig. 6 Person position modeling

At this moment the supervising system knows the position of the person in the room. Using the information obtained from a set of consecutive images, the supervising system can learn the activity of the person. Thus the main parts of the supervising system are: image annotation, person detection, detection of the person position and activity recognition. Also the person can be analyzed based on its emotions. Fig. 7 describe the steps for obtaining the medical images together with the monitoring information.

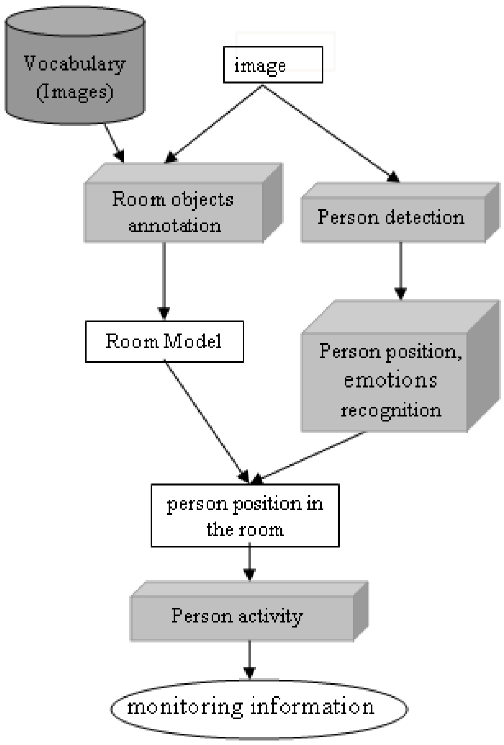

Fig. 7. Obtaining the medical information

The main component of the MAS_IA - semantic image retrieval component – will be organized as a multi-agent system, as depicted in Fig. 87. The user will provide a query which will be analyzed by a set agents; each agent will retrieve similar images using individual methods. A collecting agent will negotiate with the image retrieval agents and will provide only the best relevant images with the query. The image retrieval agents will use annotated images and domain (home medical care) ontology to select the similar images so that they are as close as possible to the human perception.

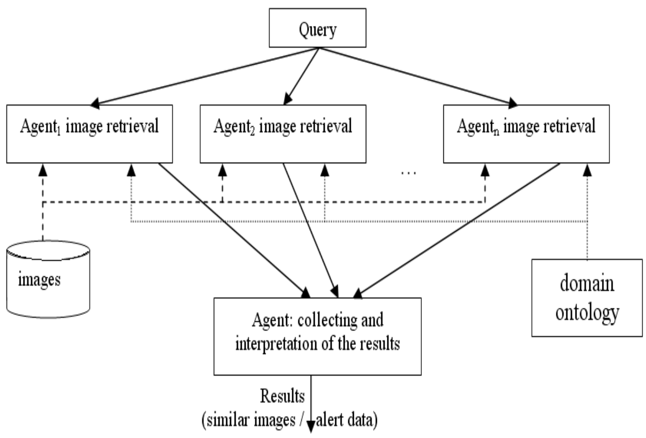

Fig.8: The multi-agent architecture of the semantic image retrieval component

D. EDPRA Module

The Elderly or Disabled People Recognition and Assistance (EDPRA) module integrates a set of intelligent information processing techniques for elderly or disabled people recognition and assistance. The module allows person's recognition and identification based on biometric information but also will monitor the assisted person position and movement. The gestures will be recognized and interpreted in order to create a communication session with a personal assistant robot.

The main purpose of this module is to recognize the assisted person in order to monitor its activity and restrict access to some facilities which can be dangerous for the assisted person (depending on the disease that the person suffers). In order to initiate the monitoring, the person must authenticate using a fingerprint scanner or an iris camera. Those devices are placed in a position monitored by a ceiling mounted camera. When the person authenticate the camera will recognize the person position and from now will follow this person. In this way the system can monitor the target in a multiple rooms environment (cameras will be placed in all rooms) and with multiple persons.

The authentication method (fingerprint or iris) will highly depend on the quality of the biometric data of the person. The fingerprints deteriorate over time, so an old or disabled person may have low quality fingerprints. Similar, a person that suffers from a disease that affects the eyes (for example cataract) may raise problems in using the iris method.

The investigated literature [16][24] points to a considerable advantage of using the iris as a biometric verification and recognition method from the accuracy and reliability perspective. The method is estimated to be ten times more accurate than methods using fingerprint, iris-based methods produce a false acceptance rate (FAR) of 1/1-2 million samples, while fingerprint-based methods produce a false match rate close to 1/100.000 samples [17][18][21]. However, there are cases, as mentioned above, when iris identification is not possible [22]. That is why both methods were taken into consideration for the EDPRA module development; so far, only the fingerprint recognition method was implemented.

When discussing about fingerprint recognition for elderly people, we have to take into consideration the problems that arise due to deteriorated fingerprint. During the person's lifetime, the fingerprints are exposed and directly interact with external, mechanical factors which inevitably produce physical, geometrical modifications to the fingerprints. We will have to deal with cuts that will interrupt the ridges and will create valleys and new minutia points that will significantly affect the recognition process. In Fig. 9 two fingerprints are presented. The left fingerprint is a normal unaltered fingerprint, on the right a fingerprint with multiple cuts is presented.

Fig. 9 A normal fingerprint and a fingerprint with multiple cuts.

When processing the fingerprints, in order to obtain the fingerprint descriptors (minutia points), a set of operations must be performed:

- First, the fingerprint image is acquired and filtered (depending on the type of the acquisition sensor, a set of filters must be applied in order to eliminate the noise added by the acquisition process)
- Then the image is binarized and using morphological operations the holes inside the ridges are filled in order to eliminate false minutia points.
- After the image binarization the skeletonizing algorithm can be applied and the minutia points can be extracted.
- In the last step the minutia points can be verified against a database and the identity of the person can be extracted.

The problem processing such images is when the image is skeletonized, because any noise created by the cuts in the finger will create false minutia which must be filtered. In Fig 10a, a fingerprint is skeletonized and the minutia points are marked on the image.

As one can see, the image contains a high number of false minutia points which will negatively affect the recognition process. In order to prevent that, the minutia points must be filtered by using a set of filters of which the most important is the pruning operation [19].

The pruning operation will successively erode the skeleton branches eliminating the spurs (small branches created by the noise) and allow only the good minutia points to be used in the recognition process

a. after skeletonization b. after pruning.

Fig. 10. The minutia points

Fig. 10b depicts the results of applying an improved pruning algorithm that dramatically reduces the number of minutia points which allows the recognition algorithm to obtain good results.

After the image has been processed and the minutia points have been localized, the next step is to detect the fingerprint centre. The fingerprint centre is not the centre of the fingerprint image, as many people misunderstand; the fingerprint centre is located in the point of the maximum curvature of the concave ridges in a fingerprint. This is done by searching pixel by pixel following the ridges and computing the curvature. The innermost ridge, which will contain only a valley inside the curvature (or two valleys and one ridge), will be the ridge of which tip is the centre of the fingerprint CP. The CP has the orientation given by the line which separates the valley(s) included the innermost ridge and has the same direction as the divergence direction of the ridge branches.

After the location and orientation of the CP point has been determined, the features for each minutia point are extracted:

- Type (ridge ending - RE or bifurcation - BI)
- Location (measured from the CP)
- Orientation (ridge direction for RE, or bisector direction for BI), measured by using the orientation of the CP as reference (the origin)

For the fingerprint is also computed a minimum distance graph which connect the nearest minutia points and the CP.

These information (CP features, minutiae features and the graph) are stored in the enrolled fingerprints database with the personal data (identification data like name, surname, etc) and the access rights of the person.

When the identification process is started the scanned fingerprint is processed in the same way and the graphs are compared. If the graphs match in a proportion which can be defined by the user accordingly with the desired FAR (False Acceptance Rate), then the person is identified and its access rights are verified. Fig. 11 presents an identified fingerprint. Only the skeletonized image is displayed, the minutia points and their orientations are marked in the image. The same data is marked for the CP of which location is in the centre of the red square. The presented graph is only the part of the entire minutia graph and connects the minutia points which match the enrolled fingerprint.

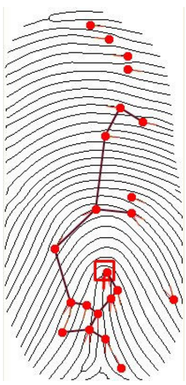

Fig. 11. An identified fingerprint

The biometric identification procedure will be used not only to restrict the access of a person to potential dangerous area (for example, an Alzheimer patient may have restricted access to a gas oven or stove) but to grant fast access of a medical team inside of the patient's house in case of an emergency. The system may be remotely programmed so adding biometric data of a new person (doctor, nurse) can be easily performed .

IV. RESULTS AND CONCLUSIONS

This paper presents an original ambient intelligent system for home medical assistance. In addition to "classic" functions of a medical monitoring system (human subject's vital and non-vital signs monitoring), AmiHomCare integrates new functions such as:

- biometric identification;
- access control and restriction;
- object recognition;
- contend based image retrieval;
- customized environment;
- medical parameters logging
- complex medical alerts

The proposed system provides ergonomic interactions both with the targeted users (disabled or old people) and medical teams. For example, access based on biometric identification saves the medical personnel of carrying other identification devices (such as RF IDs, magnetic badges, etc) which can be easily lost. In case of an emergency, this may turn into a dangerous if not fatal situation.

So far, only independent modules were tested but the obtained results allow us to believe that the final platform will achieve it's goals. The work will continue with further optimizations of each module prior to final integration into a unitary system.

For the design and simulation stage heterogeneous hardware components were used with good results. For the following stages, dedicated and optimized devices will be used at development at integration level.

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