DREAM : Emergency Monitoring System for the Elderly

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***Abstract* — DREAM is in Italian the acronym for Dispositivo di Rilevazione Emergenze per Anziani e Malati (Device of Emergency Rescue for Elderly and ill people). It is a monitoring and rescue system conceived and designed for the elderly. By means of several sensors integrated into a wrist watch it is possible to monitor the every-day activity of the user and support him in an emergency situation. The prototype system was validated in several field trials and in different contexts (Residential and Nursing Houses, Homes and Hospital) with encouraging results. The paper presents the methodology adopted at the different development stages and describes the results obtained, giving also an overview on further developments. The results coming from the field trials and the final users' feedbacks were strongly taken into account in order to move toward a pre-production phase.**

I. INTRODUCTION

In Italy life expectancy has increased more and more in the last decades and the need to provide a good quality and independent life for the elderly has become a mandatory issue. The Piedmont Region and their Municipalities have given in these last years high priority to guarantee Health and Social Services devoted in particular to elderly people. Evaluation and Management Geriatric Units have been established in order to provide best services by means of interdisciplinary teams that follow the elderly with their Social, Health and Psychological frailty in a continuous and coordinated manner.

In this context also ICT and Telecare Services can play a role in order to maintain as long as possible elderly people in their own environment providing a remote monitoring and giving them electronic assistive technologies useful in emergency situations. Technology of course cannot replace social relations with the care-givers, but is an effective complement to the Welfare Organization.

DREAM has been conceived and developed taking into account all these concepts by putting together and involving Health Local Agencies, Doctors, Engineers, Psychologists and all the Care-Givers concerned with the elderly, starting from the early stage of the service development.

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For all these reasons we can say that DREAM is not only a Technological Tool but also a Shared Service Model.

II. METHODOLOGY

The Project has followed in each phase an approach born within Ergonomics, the so-called Human Centered Approach. Ergonomics has the purpose of ensuring a good fit among people, things they do, objects they use and the environment in which they work, travel, play and live. Basic topics of Ergonomics are 'User-Centered Design' (UCD), 'inclusive design' and 'usability'. As Rubin defined it [1], UCD is a pragmatic approach in which the end-user is both the starting point and the centre of the design process.

The method envisages an iterative path, where the end-users are involved in each singular phase: from the user-requirements collection to the final evaluation. Each phase provides feedbacks on the previous one, and suggestions for next ones.

Another UCD characteristic, that has been applied to the Project, is its multi-disciplinary nature. In our case the result was the creation of a team made up of engineers, computer scientists, designers, and psychologists.

The *Design for all*, or the Universal Design, provides important guidelines to shape services, products and environments usable by the widest range of people, in such a way that no further adjustments are requested [2]. This design approach is very important and especially focused on the development of devices and services for impaired and elderly people. In particular, the design of specific solutions for the ageing, defined as *Trans-generational Design* [3], emphasizes requirements of feedback, perceptibility and adaptation, considering the last one as the core-concept. The project must – in synthesis – take into account the plasticity that the human beings have, their latent potentialities, adaptation and learning possibilities, with current skills. [4].

In the great part of Human Sciences the object of study matches with the action field. On the contrary, Ergonomics is focused on the human being operating however with all the world around him (environment, tools, activities, procedures…) in order to adapt it to the psychological, perceptive, cognitive, emotional, social characteristics. In ergonomics, the person is intended not as an object, but as an active subject, in a "sited status" where he/she is understood as a system in relation and interaction with the environment and his/her objectives [5].

The DREAM project implies a great level of complexity due to the application context. Shaping applications and solutions for social services requires to take into account the needs of several actors and final users. The solution is addressed to elderly, frail or alone people, and is managed by different professional operators: the care-givers and

their organizations.

We will now summarize the different process phases, followed for designing our tele-care system; the same phases have been scheduled for the field trials execution too.

A. *The 'Knowledge Phase'*

The user requirements collection was the starting point of each activity concerning design, development and field trials. At the beginning of the research, a large survey was carried out in Italy and France (DANTE Project) in order to collect information about the relations and the expectations of elderly people with respect to the adoption at their homes of new technological services, and in particular tele-monitoring services. This phase was very important to adapt the solution to existing contexts, people, needs and constraints.

B. *The "Preparatory Phase'*

This phase has been very important especially for the field trials conduction. Before starting our trials, we collected information about people and context, through individual meetings with the elderly and collective meetings with the health and social operators; then we provided a first introduction to the experimental service, explaining the technological solution and the aims of the trial. From this activity, functional and interface specifications came out. As a matter of fact, most of the elements of the different service models we experimented were captured in this phase.

C. *The 'Experimental Phase'*

On the knowledge basis of the previous phases, the system has been field tested. The focus of the analysis was two-fold, requiring at same time a technical evaluation (mainly based on system performance measurements) and an ergonomics evaluation (based on usability [6] aspects, acceptability, "learnability" of the systems and procedures). Measurements, subjective evaluations, through interviews, diary and observations were the main techniques adopted to collect information. Qualitative techniques were mostly adopted according to the sample of the trials and for methodological reasons. In fact, the qualitative analysis allows one to capture the characteristics of the 'world' we are going to study. Moreover an open research plan offers the flexibility requested from the field and from the prototype we had.

D. *Final Data Sharing and Consolidation*

Upon completion of the above activities, the results have been analyzed, shared and discussed with all participants in a final session.

III. System Description

DREAM, as previously said, is a prototype that has been completely conceived, developed, tested and validated by an interdisciplinary team in tight cooperation with the final users. All the hardware and software components have been designed and realized by engineers of the ISMB Institute and the Politecnico of Turin. This approach has allowed a continuous and progressive improvement of the DREAM system during the development phase, by taking into account the feed-backs coming from the field. So, at the end of this long and sometimes difficult process we were fully aware of what was really necessary and useful.

The DREAM system is basically composed of three items:

A. *Wrist Watch*

The main problem of a tele-alarm system for the elderly is that they do not always bring it with them; so when the elderly person is in an emergency situation and needs to use the tele-alarm, generally the device is out of reach, e.g.: it is on the bedside table, on the clothes-hook, and so on. For this reason we decided to build our system around a wearable device that could be easily accepted by elderly people: an analog wrist watch.

The DREAM watch has several sensors on board that allow the monitoring of some vital parameters like: skin temperature, heart bit rate in a conscious situation, micro and macro wrist movements. On our prototype we have used a two-axis accelerometer for macro-movement and a piezoelectric sensor for micro-movement (fingers level) and radial pulse detection.

We decided to put also a light detector and a near body temperature sensor. All the sensors data are sent regularly (the period is programmable) to a base station installed in a range of 15-20 meters. In order to minimize the power consumption of the wearable device the electronic management has been optimized and a proprietary transmission protocol has been developed. With a transmission period of 4s we obtained an autonomy of several months with a Lithium battery with a capacity of 1Ah. The transceiver used works @ 2.4GHz and to save space and maximize the transmission efficiency an helical antenna was designed.

The wrist watch is provided with a panic button that has to be pressed for at least 3s to trigger a manual alarm: in this condition the period of data transmission is reduced to 1 s, allowing a near real time monitoring of the parameters. A red led, near the panic button, sends different visual feedbacks according to the functionality status of the device.

The battery level is monitored and it is also possible also to know if the wrist watch is being worn or not.

The watch has a diameter of 5 cm, is 18 mm high (see Fig. 1), and very light (less than 60 grams): so, even if it is only a prototype it is small enough to allow us to perform several and successful field trials with the final users.

Fig. 1. The DREAM Wrist Watch: prototype version

B. Base Station

The base station is the second component of the system; it is used as an access gateway for the wrist watch. It must be installed in appropriate environment's position in order to guarantee the area radio coverage. A single base station generally could cover a flat of 50-70 square meters. The coverage area is strongly influenced by the building characteristics and the electromagnetic noise. To extend the coverage one can adopt a base stations star-network topology, where the central node may be represented by a base station gateway or by a local Center Monitor Service. Different network technologies and standards can be used to create a base station backbone, such as: Ethernet, Wi-Fi, Ethernet over Power Line, etc.

The base station master (star centre node) integrates the gateway functionality storage and manages the monitoring data, forwarding periodically the acquired information to the Center Monitoring Service. To this end different kind of telecommunication technologies can be used, such as Ethernet, PSTN, GSM/GPRS/UMTS/HSDPA, Wi-Fi, WI-MAX, ADSL, etc.

C. Tele- monitoring Service Centre

The centre monitoring service is a server application that receives all acquired wrist watch signals through the base station backbone. All the data received are elaborated and stored into a central database for future consultation. A Microsoft Windows application enables the welfare operator to consult history and manage automatic and manual alarm events. For each alarm event the system traces an operator's answer time and the time required to perform the alarm procedure. Furthermore, a centre monitoring plug-in has been developed to manage local alarms system for the activation and deactivation of sounding and flashing devices. A localization system is integrated into the centre monitoring service when it used as a centre local node of the star network topology.

IV. Field Trials

The DREAM System has been tested in different service's scenarios and deployed using different kinds of network: Nursing House (Wi-Fi), Home (PSTN and Wireless Wide Band), Hospital (Wired).

A. Nursing House Trial

The first trial started at the beginning of 2005 and lasted six months; the location was the "Casa di Riposo della Città di Asti" and the project was partially funded by the Welfare Councillorship of Piedmont Region (ADITECH Project). In this trial, 10 self –sufficient elderly people (74-89 years old), 5 professional care-givers and one ward sister were involved.

After the knowledge phase we adapted the laboratory prototype in order to satisfy the requirements coming from interviews with the nursing house operators. The area radio-coverage was guaranteed by 13 base stations connected to the Service Center computer by means a Wi-Fi network. The computer with the tele-monitoring application was installed in the ward sister office, and an ADSL connection to the ISMB laboratory in Turin was activated to make the technical remote assistance easier. Fig.2 shows the map of the area monitored and the position of the 13 base stations.

In order to give prompt information to the operators in case of emergency, all the base stations were equipped with big flashing lights, two sounding alarms were installed in the corridors and a big display was installed in the main corridor.

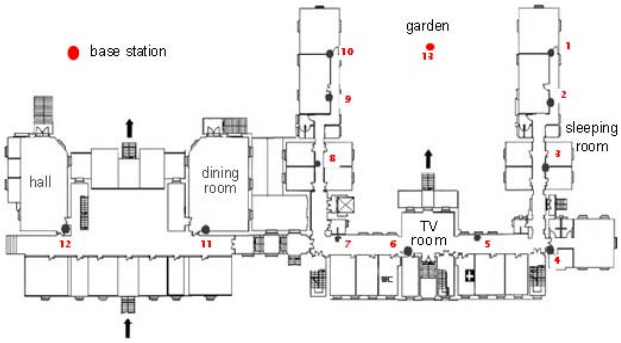

Fig. 2. The Nursing House Plan: the 13 base stations location.

The field experiment lasted two months and in this period ten wrist watches were worn simultaneously by the users involved in the trial. In fig.3 the emergency protocol adopted is described: in an emergency situation a broadcast signal is sent by the wrist watch to the base stations and a localization algorithm running on the tele-monitoring centre activates a flashing light on the base station near the patient; in the meantime the sounding alarms are activated and then the information about the patient, kind of alarm, base station position are shown on the monitor of Service Centre and displayed on the corridor panel. So the nursing people alerted can easily locate the elderly caller and give him a prompt and efficient assistance by resetting the emergency alarm directly on to the wrist watch.

Fig. 3. Emergency protocol adopted in the Nursing House Trial

In this trial the wrist watches were programmed to send data every 4 s: in this manner it was always possible to know the location of the nursing house guests with an adequate timing and spatial accuracy.

Another very useful application of localization is that it allows the study of every-day behavior and the level of activity of people wearing the watch. In Fig. 4 the graph with one-day location pattern is shown: the horizontal axis

reports hours, whereas the vertical axis indicates the base station number. In this particular case we can say that our guest stayed in his bed-room (Base Station 2) till 6 o'clock in the morning, then he spent some time in the TV room (Base Station 6), afterwards he moved to the hall (Base Station 12) and went to the dining room (Base Station 11) for breakfast and so on…

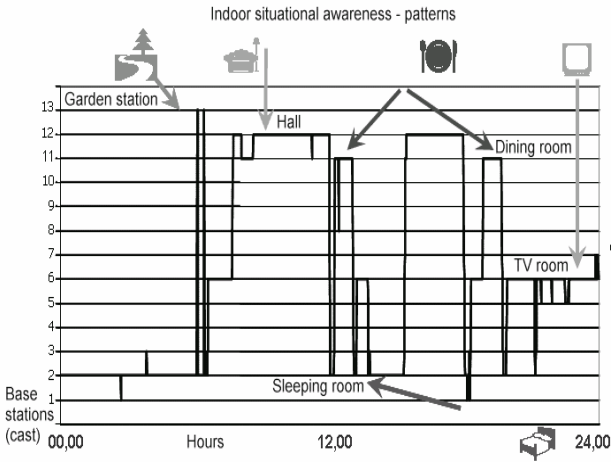

Fig. 4. Indoor situational awareness-patterns.

This trial allowed us also to collect a lot of data (more than two million records) in order to ascertain the possibility of building some automatic emergency scenario. In Fig.5 an hypothetical automatic scenario usable at night is shown; it matches data coming from light and accelerometers sensors with localization information. This scenario has been validated by the data coming from the trial and was considered very useful by nursing people involved in the night shift.

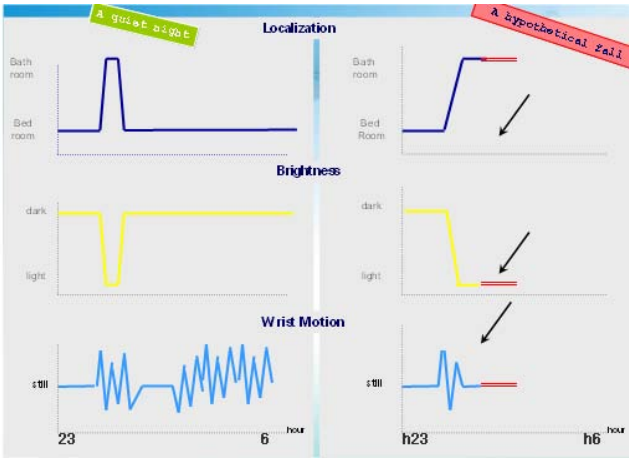

Fig. 5. Automatic alert hypotesis

The wrist watch and the DREAM system was very well appreciated by both the elderly and the nursing people (the ward sisters said "it is easy to use and useful"). Some users wore the wrist watch, also at night (especially men users), whereas some women declared that the watch was a little bit thick to be worn also at night. The security perception of the elderly increased significantly and in some case they acquired more self confidence in their every day behavior (e.g.: an old woman with some walking problems started to go again into the garden after receiving her wrist watch).

B. Home Trial (PSTN connection)

The second trial was performed in the 2005-2006 period, lasted 6 months, and was a part of the DANTE Interreg Project. The location was Dogliani, a beautiful country village famous for its wine. In this trial six self–sufficient elderly people (60-80 years old) living at their own homes were involved. The tele-monitoring Centre was installed at Dogliani Country Hospital, where doctors and nurses of ASL16 (Health Local Agency 16) took a very active role in the service model elaboration and provided also the tele-care support during the field trial.

The base stations installed in the elderly homes were linked to the tele-monitoring centre using a conventional telephone line (PSTN) and a dial-up connection to Internet; whereas for the computer installed at the Dogliani Hospital an ADSL connection was provided. The monitoring data coming from the wrist watch were stored into the base station and then automatically sent to the tele-monitoring centre once a day. In case of emergency the alarm and the data were sent by means of the dial up connection immediately to tele-monitoring centre, where nurses were alerted by the sounding alarm installed in the corridors of the hospital. Then the emergency was managed following a standardized protocol with an escalation procedure.

Also in this trial we collected a lot of data in order to study the feasibility study of automatic alerts. Fig. 6 shows data monitored from midnight to 6:30 in the morning: the first graph reports the trend of the skin temperature, the two graphs below give information regarding movements, and the last graph shows the signal detected by the light sensor. It may be assumed that the elderly went out of his bed at midnight, at 3:30 and at 6:20 (in all these cases the skin temperature decreases, a movement is detected and the light sensor shows a change). In our view these data are not enough to build a strong automatic alert scenario. By adding some indoor localization information (see paragraph VI: Further Development) to these data it will be possible in the future to reinforce it.

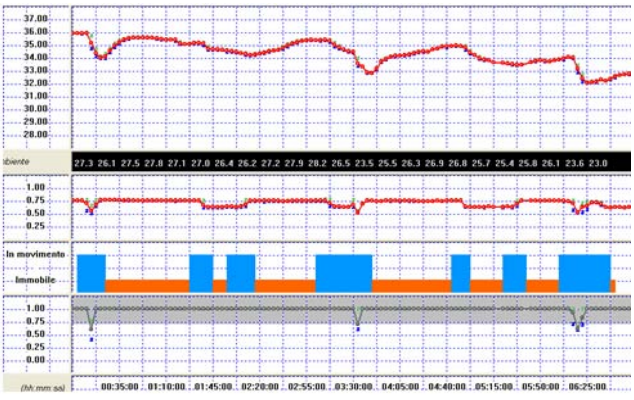

Fig. 6. Data monitored at night.

Also in this trial the wrist watch was very well accepted: Fig.7 shows, how long the users wore their watches during a week (green bar means that the watch is worn, yellow bar that the watch is not worn, gray bar that

the watch is outside of the coverage area): there is a wearing average greater than 85%. This success mostly depends, in our view, on the fact that the device was introduced and explained to the users directly by their own doctor, i.e. the main actor in the home care process. During the trial more than 30 emergency calls were simulated and we had only one false positive call due to a unintentional pressure of panic button. This trial has shown additionally that, even with some limitation, one can deliver a service based on the DREAM system in a very poor connectivity context using a PSTN line and an analog modem.

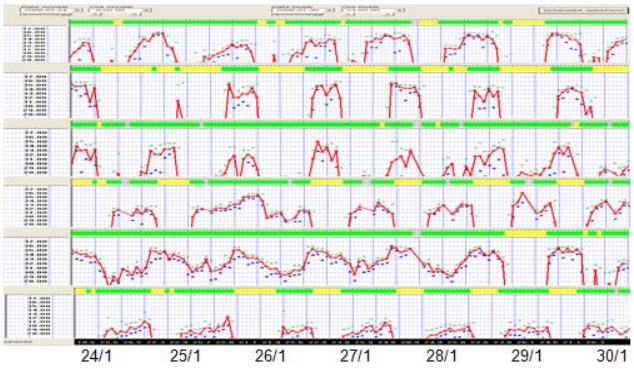

Fig. 7. Data monitored in a week: the green bar shows how much the wrist watch was worn in this period time

C. Hospital Trial

This trial was conducted in 2006 for a three-month time period at the San Giovanni Battista Hospital Antica Sede of Turin, where recently ISMB, Politecnico of Turin and Molinette Hospital have jointly established an e-Health Laboratory.

In this case the main trial objective was to test sensors behavior with ill users (we would like in any case to stress that DREAM is not to be considered a medical device). This trial was performed in a hospital only because we had the opportunity to test our sensors in a more controlled context with the cooperation of health professional operators. In particular we have emphasized the use of the piezoelectric sensor for the heart pulse waveform acquisition and the study of and micro-movement at fingers level; the skin temperature also was used to monitor patients in a fever status. Some results of this trial, that involved more than ten users for few days each one, are shown in Fig. 8 and 9. Fig.8 shows the signal detected by the piezoelectric sensor fitted in the watch wristband and aligned to the radial artery. This signal was sampled and streamed from the watch electronics to the tele-monitoring centre in real time, where the signal was displayed, stored and analyzed.

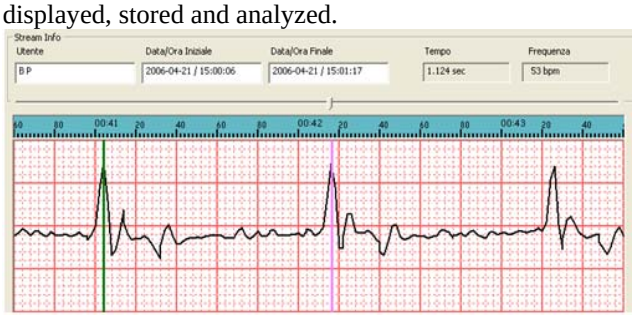

Fig. 8. Radial pulse signal detected with the piezoelectric sensor

The graph reports a best case situation: a good alignment of sensor and a patient with strong pulse. Unfortunately only in the 50 % of tested cases it was possible to detect signals like that. On the other hand the piezoelectric sensor showed a very good sensitivity to detect micro movement at fingers level. Fig. 9 reports data collected in a 24-hour time window, with the micro and macro movement trend; skin and near body temperatures waveforms are shown denoting a constant fever status, around 38°C, on the monitored patient.

Fig. 9. Hospital Scenario: data monitored in 24-hour time window.

D. Home Trial (Wireless Wide Band Connection)

This was the last DREAM trial, it was conducted in the second half of 2007 at Cantalupa, a little and pleasant village 50 km far from Turin near the mountains. To overcome the digital divide and to guarantee a good Internet access to their citizens, the Cantalupa Council decided to install a Wireless Wide Band Network using a Wi-Max-like technology access.

Additionally, the Cantalupa Municipality is the main owner of the local Nursing House and for this reason they proposed us to test the DREAM System in this very interesting context. This was probably the first time that in Italy a tele-monitoring service was deployed using a wireless hot spot. In this trial, 5 elderly people were involved for a 6 month-time period. The tele-monitoring System was installed in the local Nursing House and the service was managed by nursing house caregivers with the collaboration of some volunteers. The main objective of the trial was to validate the service with a high bandwidth wireless connection between homes and the Tele-monitoring Centre. In this way we were able to test all the different scenarios and service protocols previously described in an always-on configuration. It was very exciting for us for us to implement successfully real time monitoring of the elderly living at their home, in a very easy and safe way.

V. Engineering and Pilot

After the exam of the encouraging trial results it was decided to pass from the prototyping to the engineering phase. Torino Wireless Foundation [7] is the project leader, in tight cooperation with ISMB Researchers, of engineering activity of the DREAM system. This project is funded by the Piedmont Region (DOCUP 2000-2006 initiative). A Cluster of three companies (PRIMA ELECTRONICS, CONSOFT SISTEMI and ETICA) was selected to realize a first engineered version of the system that collects all the feedbacks coming from the field trial experiences. Fig.9 shows the new version of the wrist

watch that is compliant with Social Alarm Systems Standards [8].

A pilot with 100 elderly users will be done by the end of 2008 in cooperation with Municipality of Turin, three Local Health Agencies (ASL Torino 1, ASL Torino 2, ASL Cuneo 1), the above mentioned Industrial Partners and the Local tele-alarms Operators Companies (CILTE, CPE).

Fig. 9. The DREAM Wrist Watch: engineered version

VI. Further Development

We decided to use ZigBee protocol for further development of DREAM system: the ZigBee is a low-cost, low-power, wireless mesh networking standard used to control and to monitor applications for the Home Automation market [9].

ZigBee devices are based on the IEEE 802.15.4-2003 Low-Rate Wireless Personal Area Network (WPAN) standard. The standard specifies the lower protocol layers, the physical layer (PHY), and the medium access control (MAC) portion of the data link layer (DLL). This standard specifies operation in the unlicensed 2.4 GHz, 915 MHz and 868 MHz ISM bands. Most ZigBee transceivers operate in the 2.4-GHz ISM band, the same band as the one used by 802.11b and Bluetooth. It can connect up to 255 devices per network. The specification supports data-transmission rates of up to 250 kbits/s at a range of 10 to 30m depending upon the environment (in a Light-of-Sight condition we measure the coverage range of our new prototypes in about 75m). The ZigBee Alliance, the standards body which defines ZigBee, also publishes application profiles that allow multiple OEM vendors to create interoperable products. Personal, Home and Hospital Care (PHHC) represents a new ZigBee profile that enables mobile devices, such as DREAM, to operate easily into local area network. The ZigBee standard has three different types of nodes with different network functionality: coordinator, router and end-device. The DREAM watch is an end device with reduced functions (RFD), while the Base Station can be a coordinator or a router node. Each domestic device operating as a router extends the DREAM's radio coverage area without additional cost. Furthermore the ZigBee network allows to implement an efficient indoor localization of the mobile watch node. The accuracy of the localization system grows with the number of fix router nodes.

Nowadays the DREAM system and its evolution Z-DREAM (we have developed some prototypes for testing) only work into its own home network (indoor). The service might be extended in the future to an outdoor scenario as a further improvement. For this reason we are considering the new generation of mobile phones as the best devices to implement the Base Station role. The mobile phone will become the gateway between a PAN (or a Body Area Network) and the mobile communication protocols (such as UMTS, HSDPA, GPRS, etc.). An ubiquitous use of the DREAM watch will require of course the definition of handover mechanisms to switch between indoor and outdoor network.

VII. Conclusion

The DREAM System after several trials is now becoming a reality. The experience gained on the field and the results collected were encouraging and the system is nowadays moving on to the pre-production phase.

Dream was conceived using a User Centered Design Methodology and adopts the new technology paradigms (wearable devices, wireless communication, Internet, etc.) in order to provide an easy and useful service to elderly people.

Acknowledgment

The work here described is the result of the activity conducted by an enthusiastic multi-disciplinary team in several years.

First of all we would like to express our gratitude to all the elderly people (more than 30) who participated in the trials in a very active and cheerful way, giving us precious feedbacks.

Special thanks go to Renato Dogliotti and prof. Rodolfo Zich who were the first to have the idea of developing this Service for the Elderly. Many thanks to Antonio Strumia, ISMB director, who provided part of resources necessary for the development of the project and to Antonio Sciarappa who with prof. Pierluigi Civera conceived and developed the first laboratory prototype.

We would like also to thank the Dogliani and Cantalupa Municipalities, the Casa di Riposo di Asti, the San Giovanni Antica Sede Hospital, the doctors and the health and social operators working there for the very useful support and suggestion provided during the trials.

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