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Aware and smart environments: The Casattenta project

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ABSTRACT

"Casattenta" (Aware home, in Italian) is the demonstrator of a research project on "Ambient Intelligence", "Sensor Fusion" and "Wireless Sensor Networks". The result is a system composed of fixed and wearable sensor nodes, providing elderly people living alone in their house (but also people in other situations and environments) with adequate and non-intrusive monitoring aimed at improving their safety and quality of life. The system consists of fixed smart sensors distributed in the environment and wearable ones monitoring the inhabitants' health and activity. The interaction between fixed and mobile nodes, based on the ZigBee compliant technologies, allows indoor tracking and identification of dangerous events.

1. Introduction

The enormous progress in many scientific fields has significantly expanded life expectation and quality in many countries. In particular, in Europe 16% of the whole population is over 65 y.o. [1] and about 90% of these people live alone at home and has an independent life, in spite of the fact that, in general, they need some assistance, monitoring and companionship. On the other hand, their choice to live alone makes it difficult for their relatives to provide immediate help in case of need. In this context, Ambient Intelligence (AmI) can play a great role in providing adequate (tele-) surveillance aimed at improving their quality of life, without compromising their privacy. In particular, recent developments in wireless communications, miniaturized sensors, intelligent garments [12] and low-power electronics [2–4] make it possible to introduce significant amount of intelligence into the spaces of daily life, while ubiquitous computing and embedded systems for diagnostic and monitoring of both people and environments have been exploited to create assistive spaces [13]. In this context, substantial research effort has been dedicated to the implementation of smart homes [8–10]. In some projects, volunteers lived for some days of the week in a sort of sensorized accommodation, treating it as a temporary home, though it was really a living lab [11]. However, in all these cases the proposed electronic systems required considerable (and undesirable) deployment work.

The work presented here, called "Casattenta", is an AmI system, applying Wireless Sensor Networks (WSN) technology to monitor elderly persons in their house, in order to recognize events (falls, reaction incapacity, immobility) needing immediate assistance. Because of the WSN technology, the system described below does not require substantial installation work; hence it can be easily and economically deployed also in existing and even old houses.

The Casattenta system is conceptually composed of two parts: a fixed one and a mobile one. The former features a number of "Monitoring Nodes" (MNs) powered by the house main supply and implementing all functions normally required for home security and safety (e.g. anti-intrusion, gas leaks, temperature control). This component is able to communicate with the other part, formed by a few "mobile" nodes, here called "Active Keys" (AKs), each worn by one of the house inhabitants. These mobile nodes, of course powered by batteries, contain sensors aimed at capturing the wearer's activity, e.g. accelerometers are used to detect falls, inactivity, still horizontal positions, etc.

To date, the system has been developed as a prototype and only a few "scenarios" have been implemented. However, it will be expanded to cover an increasing number of needs, in order to make houses safer, more comfortable and "aware" of the needs of their inhabitants. Furthermore, the developed system can be suitably adapted to cover other applications, such as, for instance, monitoring of industrial or hospital environments; biomedical; logistics and transport. For these reasons, the interest of this work extends well beyond the limits of the specific, though important, application described in this paper.

2. Related work

Recent advances in technologies enabled the concept of pervasive computing and AmI [15] to become feasible and suitable for real implementations. As described in [16], the

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expectations regarding Smart Environments functionalities depend on individual needs and include such different targets as improved inhabitants safety, higher energy savings and reduced maintenance costs, automatic task execution with attention to user needs and behaviours.

In this scenario, several research projects have aimed at realizing "intelligent" environments. For instance, the Georgia Tech's Aware Home Research Initiative [9,17] exploited advanced technologies and an interdisciplinary approach to turn a house into a living laboratory for ubiquitous computing applications. Similarly, the Philips'AmI project "Home Lab" [18] made use of an actual tow-stock house to demonstrate advanced functionalities of a normal house. The MIT's House_n [10], instead, shows how new technologies, materials, and design strategies can be used to realize dynamic, evolving environments that respond to the complexities of modern life. A list of other significant projects in the field can be found in [19].

Many of the projects in this fields made use of a rich infrastructure of networks, sensors, actuators and processing capabilities and aimed at identifying and experimenting the technologies, both hardware and software, most suitable to realize smart environments. Some of them also enabled to collect useful data on the behaviour and habits of the persons involved in the experiments [20,21].

However, in the real world, particularly in Europe, the vast majority of buildings are neither new nor equipped with the infrastructure required to support the set of technologies (e.g. Internet, Wi-Fi) used in many research projects.

Thus, a different kind of solution is required and our aim is to integrate existing technologies into a system suitable to be used also in houses poor in communication infrastructures, such as those typically hosting elderly persons living alone.

3. System's general description

The Casattenta system implements the concept of an indoor environment aware of significant events related to the ambient and/or its inhabitants and capable of communicating remotely with interested observers. The system is mainly based on WSN technologies, which can be easily deployed in existing and even historical buildings without major renovations or the need of advanced infrastructures. Furthermore, WSNs offer the advantages of self-organization, scalability, low power consumption and relative low cost.

The system of this work is flexible and easily adaptable to different requirements in terms of sensors' type, number and functionality. In addition, it makes use of low-cost standard heterogeneous technologies.

The Casattenta system makes the domestic environment interactive and safer for its "interactive guests", i.e. people particularly exposed to risk of domestic accidents (such as elderly, but also impaired people, children). Each of such "guests" is furnished with an AK, based on commercial components able to communicate wirelessly. We exploited both a ZigBee based solution (Texas Instruments Platform) and a TinyOS alternative (TmoteSky Platform).

The AKs are provided with some sensors and actuators, allowing the interaction between the user and the Casattenta system fixed component, which is able to recognize the occurrence of particular events and react with appropriate responses. Such a fixed part is composed of MNs, implemented with devices similar to the AKs but featuring different sensors.

Furthermore, the system features a central control and communication unit, hereafter denoted as "Home Gateway" (HG). The AKs and the MNs form the Casattenta's sensorial system, while the HG is the centre for data collection and processing, constituted by a Java application that manages the graphic and sound interfaces and controls the whole system.

Fig. 1 illustrates the main elements of the system: the user wearing the AK, the MNs distributed in the environment and the HG. The latter is interfaced via standard communication interfaces (Wi-Fi or GPRS) to the external world. Therefore, information from the house and its inhabitants can be shared with relatives, caregivers or call centre services.

As far as data treatment is concerned, when no help is needed, no information is stored or sent outside to preserve persons' privacy. However, if needed for medical treatment, continuous collection of data on the activity and habits of the monitored persons is possible.

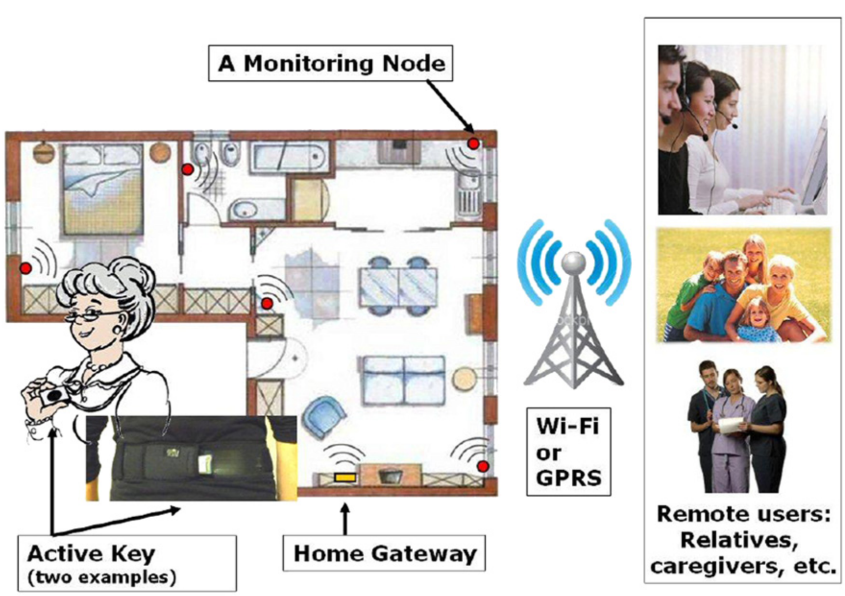

Fig. 1. Casattenta's general architecture concept.

4. Hardware and software architecture

4.1. Fixed and mobile networks

The Casattenta MNs are installed in the house and allow all the monitoring functions of an advanced home system (e.g. access control, gas leaks, lightings, noises, opened windows, humidity, temperature, etc.). The system is easy expandable, re-configurable and programmable to cover necessities that can emerge after installation.

The AKs worn (unobtrusively in the pocket, on the belt, around one's neck) enable one to track the interactive guests, their physiological parameters and activity.

4.2. Hardware basic characteristics

The first implementation of the Casattenta system was based on the commercial wireless modules TmoteSky [5], equipped with a Chipcon Wireless Transceiver (250 kbp, 2.4 GHz IEEE 802.15.4), an integrated antenna and a low-power microcontroller (TI MSP430). Moreover, these modules feature standard on-board sensors for humidity, temperature and light, while other kinds of sensors and actuators can discretionally be added. In particular, we provided each AK with a MEMS tri-axial digital accelerometer (fabricated by ST Microelectronics) and a vibro-motor, similar to those mounted on mobile phones (Fig. 2). Finally, a gyroscope (by Analog Devices) has also been added to implement a step counter.

Instead, in the TmoteSky modules used as MNs microphones (to capture unusual sounds and shouts for help) and Passive InfraRed (PIR) sensors for presence detection (Fig. 2) have been added to the standard ones (for temperature, humidity and light). Some MNs can also host other specific sensors, such as, for instance, those for gas leakage in the kitchen and bathroom.

In a further development, in order to use a standard communication protocol, providing significant advantages in terms of flexibility, self-re-configurability, number of nodes and low-power characteristics, the system was realized by means of a Zigbee WSN. The hardware chosen for this purpose was the TI CC2430-based hardware modules bundled with the Z-Stack$^{\text{TM}}$ [7] (Fig. 3).

Naturally, the use of a standard protocol also helps in extending the system to other applications.

4.3. Software main features

The TmoteSky modules adopt the TinyOS operating system and the programming language nesC [6]. Instead, the Zigbee nodes are equipped with Z-Stack$^{\text{TM}}$ and can be programmed in C. Casattenta's software is composed of the firmware running on each system node/module and executed by the HG. The modules are programmed according to their roles (AKs, MNs and data Collection Points CPs), and each one is identified by an unambiguous address. Finally, the HG acquires and processes the packets collected from each end-node.

The HG is a Java application designed to present a user-friendly graphical user interface (Fig. 4), while making the interfacing with the WSN transparent to the user. Several plug-ins enable the user to display real-time data collected from the sensors on each node. Furthermore, the HG enables to track all AKs by means of a dynamic map. Other plug-ins provide graphical feedback on the main system functionalities, related to user-safety (e.g. fall detection), home surveillance (e.g. access control), environmental monitoring (e.g. temperature, humidity and lighting), social interaction (e.g. video-conferencing, activity recognition), setup of personal alarms, reminder of agenda events.

Additionally, the HG enables the user to configure the system, for example setting the alarms to identify abnormal parameter behaviour (e.g. high temperature, gas leaks) and provide appropriate responses (e.g. activation of webcams, sound alarm, AKs' vibration).

Two different versions of the HG have been developed. The most advanced and complete one uses a PC, allowing remote Internet connection and dynamical personalization of the system functionality and services. Of course this solution offers a number of important advantages, in particular as far as further expansions and developments are concerned. On the other hand, it is rather expensive and possibly difficult to be operated and accepted by elderly persons.

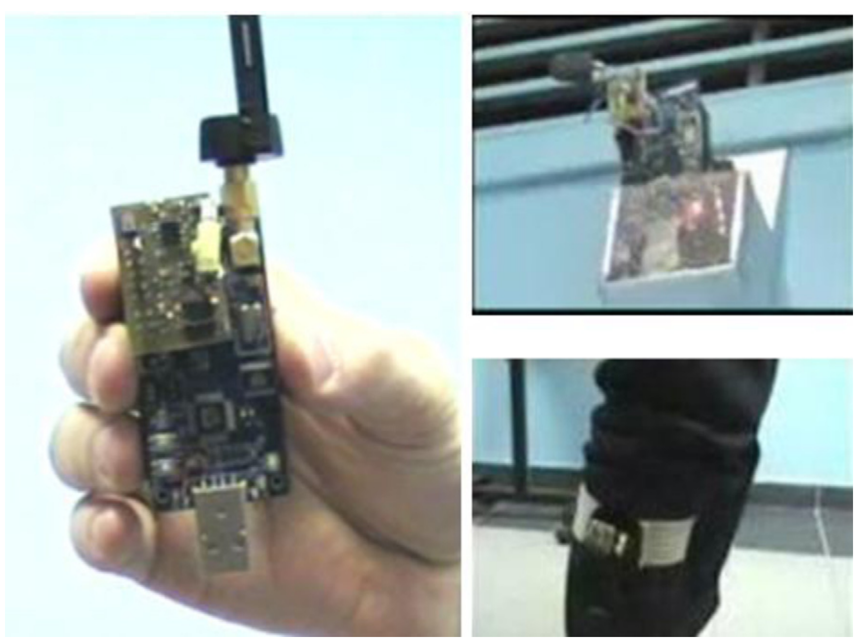

Fig. 2. On the left: A TmoteSky module equipped with vibro-motor and tri-axes accelerometer used as AK. On the right: up: MN with PIR sensor and microphone, down: AK with gyros fixed on the user leg.

For these reasons, a second, simpler version of the HG has also been realized by means of a (cheap) GPRS gateway, allowing remote control by means of SMS or simple multimedia messages.

5. Applications

Hereafter we describe briefly some of the main services implemented for demonstration purposes in the Casattenta system.

5.1. User indoor tracking

Localization is a typical function required from smart environments and can be implemented in many ways [22]. In the Casattenta system, user tracking has been realized using the Received Signal Strength Indicator (RSSI) measurements relative to the communication between the user's AK and the fixed nodes distributed in the surroundings. The main advantages of this technique are that it can be applied to all radiofrequency devices; thus other devices already deployed in the house for other purposes (gas leak detection, user activity monitoring, light control, etc.) can also be exploited for AKs tracking. As known, RSSI is a rather noisy parameter, affected by problems of multipath fading and attenuation due to obstacles (e.g. furniture, walls, people, user body absorption); thus, in order to be exploited it needs rather complex and robust algorithms and the achievable accuracy is only of some square meters (however, it is suitable for our purposes).

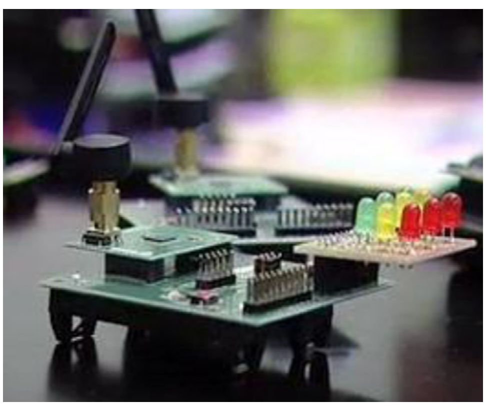

Fig. 3. A pair of TI CC2430 modules in the evaluation kit provided by Texas Instrument.

In Casattenta, the tracking algorithm is a Java application included in the HG. It has a modular structure dividing the whole environment of interest in sub-areas, each covered by at least one MN, for tracking purposes acting as a beacon. The beacons are placed at about 2 m above ground level, one every 20 m^2 in larger space or at least one for each smaller room. The RSSI signal has been discretized to identify 6 ranges or levels, from which the distance from the nearest beacons is derived: the lower level (0) corresponds to the largest distance from the monitoring point (no communication is established from beacon and AK is established), while the higher one (5) indicates the presence of the AK near the beacon.

The algorithm used to analyze the received signals identifies impossible sequences of tracked positions (for any specific user), retaining only those with a real possibility of movement from one to another. Moreover, in the case of particularly noisy signal, the algorithm "slows down" enlarging the windows of consecutive samples on which determining the user location. The consequent delay is usually not higher than 500 ms.

5.2. Environmental monitoring, access control and fall detection

As already mentioned, the Casattenta system can monitor environmental parameters because of sensors on each MN. Plug-ins dedicated to such sensors allow HG to: (i) display raw data in a separate window; (ii) store data for further use and analysis; (iii) use data to identify with high reactivity critical events and generate alarms.

Thanks to the integration of PIR sensors and Wi-Fi cameras, the system detects and signals the presence of a non-authorized person (i.e. not wearing AKs). When the presence of a person near an MN is detected, this information is cross-checked with data

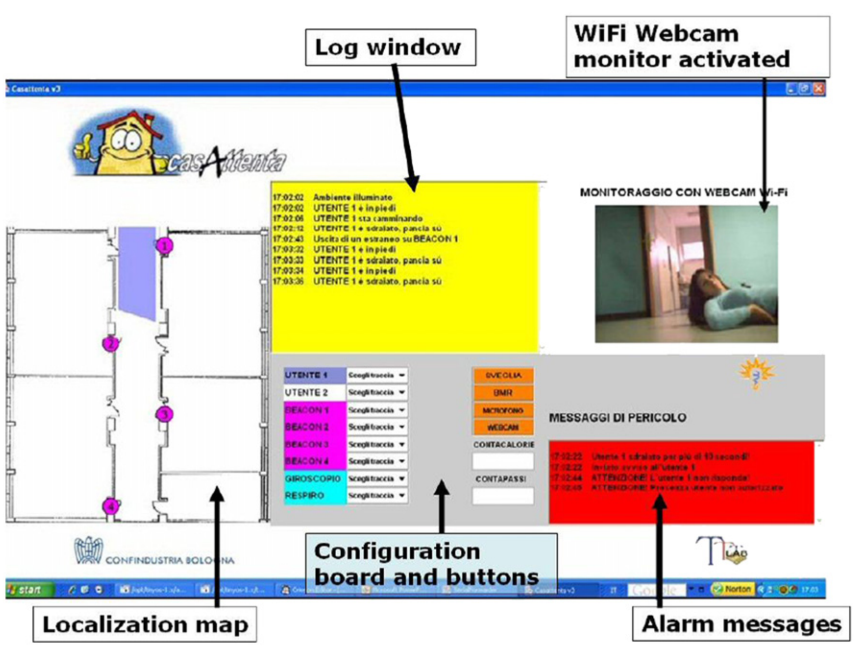

Fig. 4. A snapshot of the Home Gateway screen.

from the user tracking software. The check will fail if no person with an AK is nearby the PIR sensor. If this situation occurs a set of alarms with different levels of importance can be generated upon configuration: blinking messages displayed on the HG GUI, acoustic alarms, vibration to user AK, etc. If needed also web cameras in the relevant sub-area can be activated to advise relatives or a call center.

As mentioned, one of the most important events to be detected is a fall. To this purpose, the system combines the use of accelerometers integrated in the AK with the tracking system to lower the number of false positive. In particular, the accelerometer data are used to monitor the tilt of the user. If the user is found to lie down, this information is integrated with the knowledge of the area where the user is localized. In case this is not the bedroom the alerting system is activated starting with a vibration on the user AK to ask for reaction. If the user is aware and well, further actions can be stopped by simply pressing a button on his key. Otherwise an alarm is sent out through the HG, and a webcam can be switched on in the area of interest to be seen by a remote user. Moreover, other sensors present in the area of interest (e.g. microphones to identify the user crying) can also be used to fuse information for improved recognition and comprehension.

5.3. User daily life support

To investigate activity recognition service, one of the TmoteSky modules has been equipped with a MEMS gyroscope (ADXRS300 by Analog Devices) and exploited as a step counter. This (extra) module has been positioned on the user leg, in addition to the AK, while the number of steps is displayed on the PC screen used as HG. The number of steps can be indicative of the level of activity of a person while at home, together with complementary information such as the time spent in front of television or in bed. As a demonstrative service, calculation of the calories spent walking (by means of a standard model) has been implemented, together with calculation of BMR (Basal Metabolic Rate) and recommended daily calories intake, according to the equations and principle of Harris and Benedict [14]. From this data, at any time of the day the user can have a rough idea of her/his level of activity and need of calories.

Furthermore, in the perspective of system supporting users in their daily routines, the Casattenta HG enables the activation of alarms to remember meaningful events and to update personal calendars. This application, for instance, enables to set time and date of reminders, number of repetitions, periodicity (e.g. daily, weekly, etc.), kind of alarm (vibration, sound, blinking led) as well, of course, the AK to which each alarm must be sent.

6. On-going work

At present, further functionality is being added to the Casattenta system, in particular in order to increase the user's ability to communicate with the external world. To this purpose, the use of a set top box as HG is explored, in order to exploit the TV set, a very popular terminal among elderly. The Digital Video Broadcasting-Terrestrial (DVB-T) set-top-box is a commercial device featuring an IBM Power PC and several standard communication interfaces (e.g. USB, Ethernet, serial ports). Therefore, it can support a Java-based environment suitable to implement interactive applications, such as the collection of sensor data and the interaction with the Casattenta WSN. Additionally, exploiting the connections between digital TV cable and the Internet (via Ethernet port), the TV set can perform as a very user-friendly terminal for the interaction with the external world.

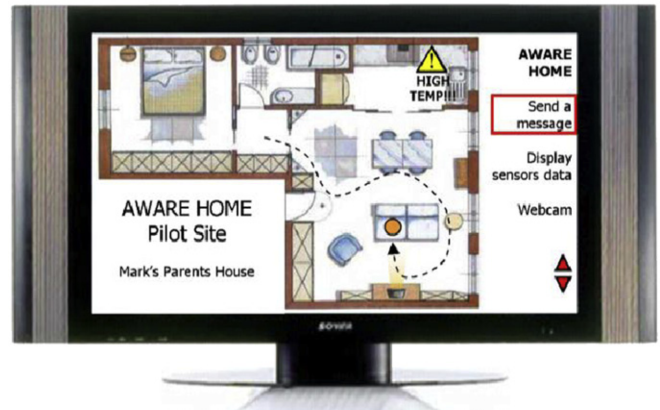

Fig. 5. The actual interface of the set-top-box implementation of Casattenta's "Home Gateway".

In this context, our work aims at implementing a service to chat, exchange files and multimedia documents with friends and relatives using the television as user interface, thus significantly improving the social inclusion of elderly persons living alone.

7. Conclusions

The Casattenta system presented in this paper is a comprehensive "Ambient Intelligence" application making use of advanced Wireless Sensor Networks technology to make houses safer and more comfortable, particularly for elderly people (and similar type of persons) who like to live independently also when needing occasional, but essential, attention and help.

The system has been realized as a prototype implementing only a partial set of all conceivable functions, particularly aimed at recognizing events that require immediate medical assistance (e.g. falls, immobility, and shouts for help).

Although the Casattenta system has been primarily conceived for the application described above, it can easily be adapted for other interesting cases (museums, hospitals, industrial plants, etc.), where indoor tracking, seamless interaction among people and a smart environment are desired.

Looking at the future, new developments are planned in different directions, namely expand the system to include further functions, use more standard and easily available hardware, validation with "field trials" (i.e. the houses of target people) and exploit the potential of digital TV now accessible via the set-top-box that we are exploring as user-friendly Home Gateway for communication with the external world (Fig. 5).

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