Ambient Intelligence, Smart Objects and Sensor Networks: practical experiences

Elisabetta Farella
Department of Electronics, Computer Science and Systems
DEIS - University of Bologna
Italy
e-mail: elisabetta.farella@unibo.it

***Abstract*—The recent advances in microelectronics and related fields have made the dream of intelligent spaces and objects come true. Reduction of technology costs, power consumption and form factor is enabling to exploit increased processing capabilities of sensor nodes and to distribute the intelligence in the environment. In this paper, significant examples of on-going research on smart environments, sensorized tangible interfaces applied to smart spaces and assistive technologies are presented. Each of these examples outlines some of the AmI challenges, such as, in particular, space awareness, smart space flexibility to include new smart entities and natural interfaces.**

Keywords: ambient intelligence; wireless sensor networks; smart objects; wearable devices, tangible interface, assistive technologies

I. Introduction

The quality of everybody's life depends largely on the interactions with other human beings, the environments and the objects we come in contact with. This is particularly true for not fully self-sufficient persons (because of age, illnesses, impairments), for which the need of safe and helpful interactions can be of vital importance.

For such interactions to be really satisfactory, both environments and objects should also be intelligent, so as to become active partners of the humans, capable to understand the situations and react in the fastest and more appropriate way. Furthermore, all interactions should possibly avoid the need of specific, and sometimes cumbersome, commands, but be based on the "natural" expressions of inter-human communication [1][2].

Up to a few decades ago, the idea of people interacting with a smart space and with objects was only a dream. Today, however, the progress of modern Information and Communication Technologies (ICT) has made such a dream come true. In particular, with Ambient Intelligence (AmI) the space can be made able to understand what is going on in its interior by means of suitable sensors, communicating wirelessly with each other for more flexibility and smaller installation cost to form Wireless Sensors Networks (WSN).

At the same time, objects can be made "to think" by means of microcontrollers' (embedded) systems, while all the communications between humans, space and objects can take place via "natural interfaces", exploiting voice, gestures and expressions as the humans normally do when interacting with each other.

In fact, today's fields of AmI, Natural Interfaces and smart objects' inclusion in intelligent environments represent a challenging area of research, attracting a large effort worldwide, with the University of Bologna taking active part in the process.

In this work, I would like to illustrate some of the most interesting research projects that I am involved in. For this purpose, I have chosen three different examples, each emphasizing a different aspect of the problems mentioned above, namely: aware and intelligent environments (Ami); inclusion of intelligent objects; Natural Interfaces.

The first point is at the forefront of the "Casattenta" Project, of T3Lab [3], a Lab dedicated to Technology Transfer and created by the University of Bologna together with the Bologna Association of Industries. Casattenta is a practical example of smart house, that is a space aware of its inhabitants and that assists them to increase their sense of safety. The choices done to enable the user to access the digital environment go towards empowering elderly that usually lacks of expertise in use of ICT products. In this case, the access to AmI services is performed (i) transparently from the user by use of worn and environmental sensors empowered with intelligence to capture important events; (ii) by means of a familiar device, i.e. the remote control and the TV set [7].

The second example is taken from the research on going in SOFIA project [4], where we consider the challenge of how to provide the user with a means of connecting new physical spaces and new objects to the existing smart environment, means that must be user-friendly and natural.

Here and in other two research projects, TANGerINE and IT4CAD, we explore the use of gestures and smart objects as a key to reach a seamless way to interact with the space. Smart spaces, similarly to virtual reality environments [5], require 3D interaction paradigms to deal with the intrinsic immersive nature of AmI. Services are in fact not constrained in a single appliance, such as a personal computer but distributed in the physical space surrounding the user. The effectiveness of 3D interaction based on body movements and gestures has been recently proven even in gaming by the introduction of new input devices [6].

In TANGerINE and IT4CAD, in particular, the focus is on the potential of tangible interface and gestures in two scenarios with different requirements regarding accuracy. In TANGerINE the smart object is a control device and therefore the focus is more on augmenting the expressivity of the interaction than on accurate tracking. In IT4CAD,

978-0-7695-4322-2/10 $26.00 © 2010 IEEE
DOI 10.1109/EUC.2010.69

instead, the application domain is Computer Assisted Design (CAD), where the need for natural interaction must be conciliated with the need of drawing surfaces and lines with accuracy in the range of millimeters.

The reminder of the paper is therefore as follow: first, the introduction of Casattenta and its main functionalities is proposed; afterwards the concepts explored in SOFIA project are presented. Finally, natural interface such as use of gestures and smart objects are described as they are implemented in IT4CAD and TANGerINE projects.

II. CASATTENTA: TECHNOLOGY INTEGRATION IN ASSISTIVE ENVIRONMENTS

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.

A list of other significant projects in the field can be found in [23]. Many of them dedicate considerable deployment work to create living labs or smart houses from scratch. However, Casattenta targets elderly persons living alone and therefore the buildings in which they live that, typically in Europe, 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.

The Casattenta system is conceptually composed of two parts: a fixed one and a mobile one and it is thought to be highly interactive with outdoor users (caregivers, relatives) interested in tracking the indoor user state or communicate with her/him. Therefore, the system implements some typical functionalities of a smart environment such as: (i) User indoor tracking; (ii) Environmental monitoring, access control and fall detection; (iii) Social interaction support.

Compared with the previous release of Casattenta [8] and with similar projects, the present implementation considers the use of a set top box as home gateway, with the aim to exploit the TV set, a very popular terminal among elderly.

A. General Architecture

Casattenta system is composed of a ZigBee WSN that communicates with a digital TV Set Top Box through the wireless network coordinator. The user can interact with the Set Top Box by use of a standard remote control, navigating the graphical interface, displaying data from the sensors and controlling the network. Moreover, the system has a GSM/GPRS module that interacts with the Set Top Box to send and receive short text messages. Finally, the Set Top Box can access the Internet and receive video messages to be shown on the TV screen (Figure 1)

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 user-friendly terminal for the interaction with the external world.

On the Set Top Box, we installed a Java Virtual Machine Micro Edition (JavaME) with CDC Profile (Connected Device Configuration). JavaME is designed for low end devices, which do not have as much computational power and memory resources as a common PC.

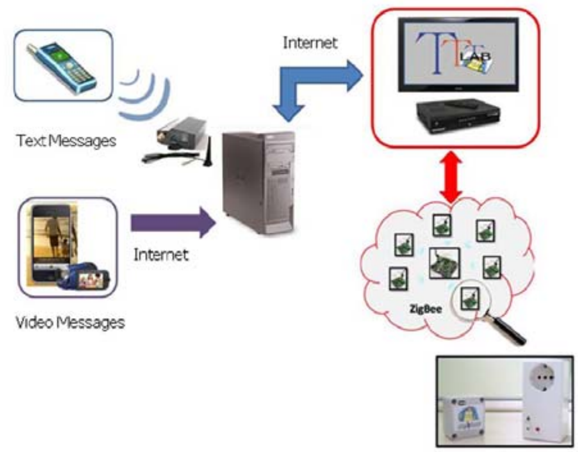

Figure 1 Casattenta general architecture

B. User indoor tracking and fall detection

As previously mentioned, Casattenta is composed of a wireless sensor network, based on the CC2430/31 development kit by Texas Instruments. The CC2431 embeds a "location engine" able to extract coordinates of a mobile node inside a grid of static nodes, therefore enabling the implementation of an indoor localization service of a user wearing a node. Therefore all Casattenta services can be location aware.

Casattenta mobile nodes include a tri-axial accelerometer to implement a wearable inertial fall detector placed at the belt. In fact, in these nodes we embedded the algorithm proposed by Kangas et al. [10], which is not excessively challenging from a computational point of view and with a high recognition rate, according to authors. This algorithm uses data sampled at 50Hz from the accelerometer. We explored this solution on a group of 11 subjects on a set of 13 different kinds of fall and 5 daily life activities, referring to the experimental protocol proposed by Noury et al. [9][11]. These experiments enabled us to identify the most suitable version of the Kangas algorithm for our specific needs and setup: we applied the one identifying 4 phases during the fall: start, free fall, impact and end. We obtained high specificity (100%) but poorer sensitivity (45%) w.r.t. what declared by Kangas et al. and therefore we applied some corrections to the original algorithm. Mainly we lowered the speed threshold (from 0,7 m/s to 0.15 m/s) related to the free fall detection obtaining less false negatives and we delayed the generation of the alarm to enable the user to de-activate it[1]. In fact, when a fall is recognized by the sensor node worn by the user, the coordinator receives first a pre-alarm. The coordinator, therefore, replies to the user node activating a vibration on it. If the subject does not deactivate the alarm in 5 seconds by pressing a button, a final alarm is generated and sent to the Set Top Box, displayed on the TV interface and sent via short text message to pre-selected relatives and caregivers.

C. Environmental monitoring and Social interaction support

In Casattenta the TV is used as interface for the user both to access data collected from the sensor networks and to interact with relatives and caregivers. Data such as temperature, humidity, light and noise for each room of the house can be displayed on the TV screen. Moreover, the TV screen can display multimedia or text messages that relatives and friends send to the elderly. In particular, we imagine the scenario where relatives, (e.g. teenaged nephews) send videos captured with modern mobile phones and make the receiver (e.g. the grand-father or the aunt) to participate in their life. This is possible having created a bridge between modern devices and communications such as the mobile phone and a traditional device such as the TV. In order to enable the mentioned service, Casattenta deployed a server that is connected to the World Wide Web and to the GSM network, through a GSM/GPRS modem. In particular, Casattenta web application is based on a LAMP server, and it is composed of a web form to upload videos, which is accessible only to registered users, together with an application that uploads the video to the Set Top Box, after converting the video format, so that the video is suitable for the box.

III. SOFIA: SMARTIFYING THE ENVIRONMENTS

The research activity at T3LAB as said aims at demonstrating the practical implementation and integration of technologies to bring ambient intelligence concept in real life. A step further towards the applicability of AmI in everyday life is the design of a framework to support upgrade, flexibility, interoperability and modularization [13] to include as far as they emerge new entities (e.g. digital objects, real objects, devices, smart rooms, sensors, etc.). This would mean having the ability to include as part of the smart environment any object and appliances of interest for the existing services and applications. To this extent, a possible approach is to represent physical entities relevant for the smart environment in the digital world, i.e. providing them a digital representation. This of course requires an adequate ontology and a middleware. The JTI SOFIA project targets these challenges.

In SOFIA the word "smartification" is referring to the process of creating a digital representation of the physical world. The creation of a digital representation can be obtained by means of an adapter, which is a software program that queries, subscribes and inserts in the middleware all information relevant to the legacy device considered. The middleware coordinates and generalizes the smart space [12]. Therefore, an adapter, which can run in a network coordinator, in a residential gateway or in a host computer, can turn sensors and smart objects information into an ontology aligned, machine interpretable representation.

The "smartification" can have many different implementations and SOFIA is addressing some of them. Our specific contribution in the project is the introduction of a tangible interface that is able to capture a number of gestures from the user, to perform some "smartification" tasks. In particular, we designed a gesture analyzer based on inertial sensing. The gesture analyzer is coupled with an RFID reader to enable objects and rooms previously tagged with RFIDs to be represented in the smart space by performing gestures. The proximity between tag and reader is used to select a certain object or a certain room; afterwards, specific gestures are used to perform a certain control request. Currently, a rotation of the device is used to select the entity (e.g. an object or room) and directional gestures are used to include it or not in the smart environment. The on-going activity is aimed at selecting further gestures as much as possible explicative of the control required by the user. The final aim is the use of interfaces to the smart environment that can be perceived natural for the user even in correspondence with complex task such as what is underneath the "smartification" process.

The gesture analyzer is implemented on a smart sensor node; therefore it is the combination of an accelerometer, an HMM based gesture recognition algorithm embedded on a microcontroller and a Bluetooth transceiver to transfer the result of the recognition to other appliances, to a gateway or as in this case to be finally used by an adapter.

The choice of using gestures captured from objects by use of sensors such as accelerometers embedded in the object itself, brings some issues, such as the need to cope with limited resources while at the same time providing an adequate set of gestures, and such as the difficulties to identify the start and stop of a gesture. The ongoing research work addresses these challenges.

In particular, we recently demonstrated the possibility to embed HMM, which are a common approach to gesture recognition, in smart objects equipped with limited computational resources. The use of fixed point data representation and the application of code optimization results in a recognition ratio comparable to the floating point case when using a 16bits microcontroller [14]. Moreover, we are looking into the issue of performing automatic segmentation in a continuous accelerometer data flow. We need in fact to isolate single gestures, which the user does intentionally to interact with the smart environment. A viable solution is to hold still the object for few instants before and after the gesture, which is a behaviour justified by the need for the user to briefly concentrate on the control command (i.e. the gesture) she/he is going to perform. This situation must be correctly distinguished from the case where the

[1] It is not intention of the present paper to go in detail of the fall detection algorithm implementation and its performance, but to provide a general overview of Casattenta functionalities.

object is still on a surface and this is obtained by observing variance of inertial data [15].

At present, in SOFIA, the start and stop of a gesture are indicated by pressing a button. In future, we will exploit the proximity between the RFID reader and the RFID tag on the object. The robustness of this solution can be increased by fusing the work of the in-built segmentation as previously mentioned and the proximity to the RFID.

Fusion of technologies is a common approach to reach better performance and therefore more natural interaction. The following examples fuse vision and inertial sensing in tangible interfaces.

IV. TANGERINE AND IT4CAD: TANGIBLE INTERFACES

Within two other projects, TANGerINE [16] and IT4CAD [19], we experienced the manipulation of objects in contexts where the fusion between vision and inertial sensing was possible.

The idea to use objects enhanced with sensing, communication and processing capabilities is common to tangible interfaces field of research. The philosophy underneath this is that tangible interfaces enable a kind of interaction more similar and close to natural language interaction. Object manipulation and gestures or movements is one of the natural ways to interact with the space around us. That is why we explored the use of a pen and a cube respectively to support fast reverse engineering in CAD software (IT4CAD project) and to interact with a tabletop in various contexts such as gaming, storytelling, musical applications, etc.

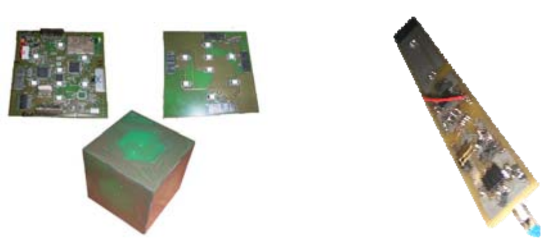

Figure 2 TANGerINE Cube and IT4CAD smart pen prototypes

As far as we know, the use of smart objects as input device in CAD is quite new. In particular, the specific approach adopted for fast reverse engineering differs from traditional methods, usually accurate but expensive and limited by the need to keep separate the two fundamental steps of measuring and reconstructing, preventing the process to be iterative and interactive.

Instead, the use of objects to enhance active surfaces (tables or walls) is experiencing a certain success in the recent years [24][25]. TANGerINE project however makes a step forward w.r.t. many similar works, since it embeds the intelligence not only in the vision system but also in the object.

Furthermore, in both projects, the advantage to combine inertial sensing, wireless communication and vision enable to overcome the limits of each specific technology (e.g. occlusion of the vision system, non-reliabilities of the communication, poor accuracy of the inertial system). Furthermore, it enables to keep handling the interaction with the user outside the limited area covered by the vision system, augmenting the potential of an application.

A. *TANGerINE*

TANGerINE project, which stands for TANGible Interactive Natural Environment, puts together previous experiences with natural vision-based gesture interaction on augmented surfaces and tabletops and with smart wireless objects and sensor fusion techniques.

Unlike passive recognized objects, common in mixed and augmented reality approaches, smart objects provide continuous data about their status through the embedded wireless sensors, while an external computer vision module tracks their position and orientation in space. Merging sensing data, the system is able to detect a richer language of gestures and manipulations both on the tabletop and in its surroundings, enabling for a more expressive interaction language across different scenarios [17].

Users are able to interact with the system and the objects in three contexts: the active presentation area (like the surface of the table), the nearby area (around the table) and the external space (a transitional space between different active areas). The TANGerINE Cube (left side of Figure 2), which is the interaction device, can act as selector, digital objects collector, tuner of a certain application parameter, manipulator, physical representative of a 3D avatar, etc.

The TANGerINE Cube has on board intelligence and components to perform sensing, actuation, storage and processing of data. Acceleration data is used to determine the active face, the one which is facing down towards the camera. On this face a basic infrared LED configuration is switched on to allow the tracking of the device by an infrared camera. Another group of LEDs is used as a binary encoding of a cube id. Computer Vision techniques are applied to detect and track LEDs in the Active Area of the tabletop to obtain cube position and orientation on its surface. Since we are working in a multi-user environment, the analysis of LEDs pattern provides also information about cube's unique visual id [18]. The cube implements also a real-time gesture recognition algorithm, which through a decision tree classifies if the object is in one of these three states: leaned down, lifted, shake. Moreover, the rotation of the cube while on the table, thanks to the fusion between inertial and vision information, can be used if needed to simulate a potentiometer, e.g. to tune the volume of music, to scroll and select items from a menu projected on the table, etc.. This gesture set can be expanded according to the application needs. In addition, 6 vibro-motors are mounted on cube faces to provide tactile stimulation to the user.

The activity within TANGerINE project produced several case studies such as applications to support children's face-to-face collaborative story-making, trivia quiz, musical applications or tools to collaboratively search multimedia contents. With one case study in particular, Tangerine Cities (Figure 3) showcased at the Fifth Frontiers of Interaction conference, we collected some feedback on user satisfaction obtaining good results. The idea underneath TANGerINE Cities has been developed at the MICC Lab [22] and imagines a future where technological development will have aided the reduction of metropolitan acoustic pollution, as transforming all noises into harmonic sound-scape. Some peculiar city sounds are provided to be manipulated through the TANGerINE Cube. Users can experience the application of different harmonic and sound filters as to make pleasant the resulting sound. On 20 users briefly instructed to use the application, on a scale from 1 to 5 points to be assigned, the average score was 4 both for system usability and user satisfaction related to the specific case study. Furthermore, almost all users interviewed declared that apart from the use in TANGerINE Cities, they would have liked to use the interaction paradigm proposed in other target applications. It has to be said that the audience of the conference was mainly between 20 and 40 years old and with some previous experience with computers.

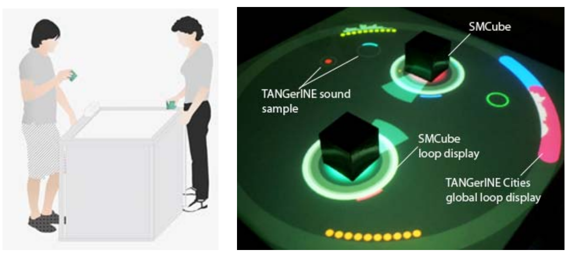

Figure 3 TANGerINE Cities setup and interface

B. *IT4CAD*

The specific field of application of Computer-Aided Design applied to industrial design or the automotive sector is challenging from the point of view of the interaction interfaces. In fact, the accuracy requirements when creating a surface or a line defining the shape of an object or a vehicle are high, since they afterwards will be transformed in physical entities. In designing the curvature of a car coffer, a difference of a few millimeters can be crucial. It is therefore difficult in this field to use natural interfaces such as gestures and objects manipulation since they are by nature more adequate to be mapped as controls for a certain application than for capturing trajectories accurately.

However, also in this field there are some phases where new interfaces can be introduced, such as the presentation to a client of the result of the design phase [21] or during the Reverse Engineering (RE) phase. The traditional RE process is performed in two sequential steps, the measurement of the physical object and its reconstruction as a 3D virtual model. We recently explored the use of a smart pen (right side of Figure 2), equipped with 4 IR LEDs and a low-cost active stereo vision system made of two infrared cameras (available in the Wii Remote controllers). Since we target the use of tangible interface in a professional domain, the physical affordance of the interaction devices must be as close as possible to the tool of the trade. The FIRES working steps flow, differently from existing RE solutions, integrates the steps of measuring and reconstruction into an iterative and incremental process that allows the user to have a real time visual feedback on the ongoing work [20]. The smart-pen 3D position is tracked by the stereo rig and the user can intuitively draw and refine the style lines of the object, i.e. the lines and curves that principally characterize the object shape (Figure 4).

Our system guarantees an accuracy in the range [−2; +2] millimetres for 75% of time/frames if the working area is not behind 1 meter from the cameras. Moreover, the proposed method for pen-tip estimation is able to estimate the pen tip 3D position with an error below 2mm for 82% of the analyzed frames. However, an interesting challenge is to improve accuracy by fusing the information of the 3-axes accelerometer placed on the pen to extract pen inclination and to fuse tracking information gained by the stereo-vision with the one obtained by inertial tracking. Furthermore, the pen can act as an interactive device by use for example of the vibrotactile actuator mounted on it, which can assist the designer e.g. to stay inside the area captured by the vision system or to know when the LEDs are hidden by the object captured or by the fingers of the user.

As it is the system is interesting also for other kind of applications, with less strict accuracy requirements such as gaming or entertainment (e.g. a game for kids enabling them to draw in air).

Figure 4 FIRES system at work (IT4CAD project)

V. CONCLUSION

In this paper we presented a set of research experiences held in Bologna relevant in the context of Ambient Intelligence. They outline that, besides the need for an infrastructure of sensor networks and embedded systems to augment objects and environments with processing and communication capabilities, it is important to focus on interaction. A critical issue is in fact how to create interactions with the surrounding digital intelligence that merge body, objects and space as it happens in communication between humans and with everyday life objects. Enabling objects manipulation and use of movements and gestures as interface with the digital world seems promising and it seems that the entertaining and consumer market as perfectly learned the lesson. It is sufficient to think, in fact, to the Wii controller [26], the Natal project [27] and the gesture interaction present in all touch enabled mobile phones and tablet PCs.

However, gesture interaction is not adequate for all and the paradox in some cases is that it seems better to keep supporting some non natural interaction means. This is the case of the TV remote controller for an elderly since they get accustomed to it and perceive it as a user friendly device. The challenge in this case is to potentiate the existing interaction device (the TV controller, the mobile phone, etc.) and generalize its functionalities to provide access to the surrounding intelligence and remote information. As a second example, the use of "tools of the trade" in professional activity cannot be easily replaced with natural interfaces as we considered in the IT4CAD project and therefore an effort must be done to exploit the intrinsic potential of a smart environment, i.e. the presence of many different technologies that have complementary weaknesses and strengths. The challenge is therefore to build "opportunistic" environments , aware of the different sensors and technologies available in a data moment and able to combine them dynamically to respond in a robust way to user needs. Sensor fusion technology is probably a key element in this vision.

Acknowledgment

Acknowledgments are due to the T3LAB Casattenta group and the people at MICC and at Micrel participating in the TANGerINE project. Moreover, the research described in this paper is inherent with the activities ongoing in (i) SOFIA partially funded by the European JTI ARTEMIS (sub-programme SP3 "Smart Environments and Scalable Digital Services") and in (ii) IT4CAD funded by University of Bologna as strategic project in 2007-2009 and now having a follow-up in NIIT4CAD ("New Interactive and Innovative Technologies for CAD") funded in the European program EUREKA's Eurostars (third Cut-Off 2009-2010).

References

[1] ISTAG, Scenarios for Ambient Intelligence in 2010. Final Report, Feb 2001, EC 2001. [Online]. Available at: ftp://ftp.cordis.europa.eu/pub/ist/docs/istagscenarios2010.pdf

[2] M. Weiser, "The Computer for the 21st Century," Scientific American, vol. 265, no. 3, Sept. 1991, pp. 94–104

[3] http://www.t3lab.it/

[4] http://www.sofia-project.eu/

[5] P. Hartling, C. Cruz-Neira, "Tweek: A Framework for Cross-Display Graphical User Interfaces", Computational Science and Its Applications ICCSA 2005, Springer Berlin / Heidelberg, Volume 3482/2005,, pp.1070-1079, doi: 10.1007/11424857_115

[6] J. J. LaViola Jr., "Bringing VR and Spatial 3D Interaction to the Masses through Video Games." IEEE Computer Graphics &. Applications Vol. 28, no.5 (Sep. 2008), pp. 10-15. doi= http://dx.doi.org/10.1109/MCG.2008.92

[7] T. Rodriguez, K. Fischer, J. Kingston, "Intelligent Services for the Elderly Over the TV" Journal of Intelligent Information Systems, Volume 25, Number 2, 159-180, doi: 10.1007/s10844-005-0187-x

[8] E. Farella, M. Falavigna, B. Riccò, "Aware and Smart Environments: the Casattenta project", Microelectronics Journal (2010), Elsevier, doi: 10.1016/j.mejo.2010.01.008, *in press*.

[9] N.Noury, A.Galay, J.Pasquier, M.Ballussaud, "Preliminary investigation into the use of Autonomous Fall Detectors", 30thAnnual International IEEE EMBS Conference, 2008, pp. 2828-31, doi: 10.1109/IEMBS.2008.4649791

[10] M. Kangas, I. Vikman, J. Wiklander, P. Lindgren, L. Nyberg, T.Jamsa, "Sensitivity and specificity of fall detection in people aged 40 years and over", Gait & Posture, vol. 29, Issue 4, June 2009, pp. 571-574, ISSN 0966-6362, doi: 10.1016/j.gaitpost.2008.12.008.

[11] N. Noury, A. Fleury, P. Rumeau, A.K. Bourke, G.O. Laighin, V. Rialle, J.E Lundy., "Fall detection - Principles and Methods," Engineering in Medicine and Biology Society, 2007, EMBS 2007, 29th Annual International Conference of the IEEE, 22-26 Aug. 2007, pp.1663-1666, doi: 10.1109/IEMBS.2007.4352627

[12] F. Vergari, S. Bartolini, F. Spadini, A. D'Elia, G. Zamagni, L. Roffia, T.S. Cinotti "A Smart Space application to dynamically relate medical and environmental information," Design, Automation & Test in Europe Conference & Exhibition (DATE), 2010 pp.1542-1547, 8-12 March 2010

[13] A. D'Elia, L. Roffia, G. Zamagni, F. Vergari, A. Toninelli, P. Bellavista, "Smart Applications for the Maintenance of Large Buildings: How to Achieve Ontology-based Interoperability at the Information Level" Computers and Communications (ISCC), 2010 IEEE Symposium on , pp.1077-1082, 22-25 June 2010, doi: 10.1109/ISCC.2010.5546639

[14] P. Zappi, B. Milosevic, E. Farella, L. Benini, "Hidden Markov Model Based Gesture Recognition on Low-Cost, Low-Power Tangible User Interfaces", Entertainment Computing, vol. 1, no. 2, Intelligent Technologies for Interactive Entertainment, April 2009, pp. 75-84, Springer, Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering, doi: 10.1016/j.entcom.2009.09.005.

[15] Bojan Milosevic, Elisabetta Farella, Luca Benini, "Continuous Gesture Recognition for Resource Constrained Smart Objects" to be published in Proceedings of the Fourth International Conference on Mobile Ubiquitous Computing, Systems, Services and Technologies, UBICOMM 2010, October 25 - 30, 2010 - Florence, Italy

[16] http://www.tangerineproject.org/

[17] O. Cafini, P. Zappi, E.Farella, L. Benini, S. Baraldi, N. Torpei, L.Landucci, and A.Del Bimbo, "Tangerine SMCube: a smart device for human computer interaction", 3rd European Conference on Smart Sensing and Context, EuroSSC08, Adjunct Proceedings, Zurich, Switzerland, pp.23-24, Oct. 2008.

[18] Stefano Baraldi, Alberto Del Bimbo, Lea Landucci, Nicola Torpei and Omar Cafini, Elisabetta Farella, Augusto Pieracci, Luca Benini, "Introducing TANGerINE: a tangible interactive natural environment.", 15th international Conference on Multimedia, ACM MULTIMEDIA '07, pp. 831-834, Augsburg, Germany, September 25 - 29, 2007 (ISBN:978-1-59593-702-5).

[19] http://it4cad.dm.unibo.it/

[20] C. V. Beccari, E. Farella, A. Liverani, S. Morigi, M. Rucci, "A Fast Interactive Reverse Engineering System", in Computer-Aided Design Journal, Elsevier, 2010, doi:10.1016/j.cad.2010.06.001, *in press*.

[21] M. Gaiani, F. Brevi, E. Farella, A. Pignatel, L. Benini, "The use of a palm computer for design review interaction in a virtual room", 16-th International Conference in Central Europe on Computer Graphics, Visualization and Computer Vision' 2008, pp. 127-134.

[22] http://www.micc.unifi.it/

[23] V. Ricquebourg, D. Menga, D. Durand, B. Marhic, L. Delahoche, C. Loge, "The Smart Home concept: our immediate future", in: First IEEE International Conference on E-Learning in Industrial Electronics, 2006, 18–20 December 2006, pp. 23–28.

[24] Kienzl, T., Marsche, U., Kapeller, N., and Gokcezade, A. 2008. "Tangible workbench "TW": with changeable markers". In ACM SIGGRAPH 2008 New Tech Demos (Los Angeles, California, August 11 - 15, 2008). SIGGRAPH '08. ACM, New York, NY, 1-1. doi: http://doi.acm.org/10.1145/1401615.1401652

[25] Leitner, J., Haller, M., Yun, K., Woo, W., Sugimoto, M., and Inami, M. 2008. "IncreTable, a mixed reality tabletop game experience". In Proceedings of the 2008 international Conference on Advances in Computer Entertainment Technology (Yokohama, Japan, December 03 - 05, 2008). ACE '08, vol. 352. ACM, New York, NY, 9-16. doi: http://doi.acm.org/10.1145/1501750.1501753

[26] http://www.nintendo.com/wii

[27] http://www.xbox.com/en-ca/live/projectnatal/