Rapid Prototyping of an AmI-Augmented Office Environment Demonstrator

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Abstract. This paper presents the process and tangible outcomes of a rapid prototyping activity towards the creation of a demonstrator, showcasing the potential use and effect of Ambient Intelligence technologies in a typical office environment. In this context, the hardware and software components used are described, as well as the interactive behavior of the demonstrator. Additionally, some conclusions stemming from the experience gained are presented, along with pointers for future research and development work.

1 Introduction

The field of Ambient Intelligence envisages a future where our surrounding environment is populated by several interoperating computing-embedded devices of different size and capabilities, which are interweaved into “the fabric of everyday life” and are indistinguishable from it [1]. In such “intelligent” environments, the way that people perform everyday tasks is expected to radically change. Multimodal, direct, “natural” interaction methods such as speech, touch, and gestures, are expected to be widely used, in combination with knowledge about contextual factors such as the user’s profile, preferences and location.

Recently, the Institute of Computer Science of the Foundation for Research and Technology – Hellas (ICS-FORTH) has been running a horizontal interdisciplinary Research and Development Programme in the field of Ambient Intelligence (AmI) that serves as a connecting thread for the activities of the Institute’s individual laboratories. In this context, a small-scale prototype has been set up exhibiting the concept of Ambient Intelligence in a typical office environment, showcasing, on the one hand, the potential impact of related technologies in everyday activities, and, on the other hand, the expected paradigm shift in the way that people will perceive and interact with information and communication technologies (ICT) in the future. This paper provides an overview of the demonstrator prototyping (design and development) process and its outcomes, elaborating on the constituent hardware and software components and interactive behavior.

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2 Related Work

During the design phase of the demonstrator, related published work was taken into consideration. For example, in 1999, Stanford University started the interactive workspaces project [2]. A prototype workspace, the *iRoom*, was created that contained several types of large displays including a conference-room table. The room was equipped with cameras, microphones, wireless LAN support, and several interaction devices. A dedicated *meta-operating system* (iROS) was developed to tie together the individual devices, and three subsystems addressing the tasks of moving data, moving control, and dynamic application coordination. A couple of years later, IBM, in the context of its BlueSpace project [3] constructed a prototype future office and implemented some related applications. The workspace incorporated several types of sensors and environmental effectors, and alternative displays including a steerable projection system. The applications developed were related to workspace and technology personalization and configurability for either collaborative or individual work. The Fraunhofer IPSI Institute in Darmstadt, based on the idea of *cooperative buildings*, introduced the notion of *roomware components* [4] as room elements (e.g., furniture, wall) integrating information and communication technologies. In this context, some related inter-operating components were developed, including a large touch-sensitive wall, a touch-table, and a chair with an integrated pen-based computer. Finally, Pingali et al. [5] have investigated the concept of *augmented collaborative spaces* and presented some of the technology and architectural challenges that need to be addressed to realize such spaces. Furthermore, they introduced the concept of *steerable interfaces* that can be moved around to appear on ordinary objects and surfaces anywhere in a space.

3 Development of the Smart Office Demonstrator

3.1 Physical Space, Requirements and Constraints

The physical space available for creating the demonstrator was part of an existing office at the premises of ICS-FORTH. Two sides were blocked by brick walls and one by a glass window, while the facet was not separated from the rest of the office by any physical barrier. The space was furnished with a meeting table, seven chairs and a 60 inches LCD TV. The key requirements given to the demonstrator development team were the following:

1. ***Technological "transparency"*:** Ideally, the space should remain "as is". In other words, no noticeable alterations should be made to the pre-existing office environment. The technological components used should be hidden within the surrounding environment (e.g., walls, ceiling, and furniture).
2. ***Seamless experience*:** The demonstrator should provide the feeling of a versatile, multi-faceted tool, rather than a loose collection of various applications.
3. ***Robustness*:** The entire system should work consistently and without failures even in less favorable or controlled conditions (e.g., light changes, large number of visitors, and accidental use of equipment).

4. ***Budget*:** Only low-cost, everyday technological components should be used with the total cost kept below 10.000 Euros.
5. ***Time limit*:** The demonstrator should be up and running in about one month.

3.2 Design and Development Process

Due to the extremely tight time schedule, a fast-paced iterative design and development process was followed. A development team was set-up comprising a dozen people with complementary roles and skills, ranging from interaction design and software development to electronic engineering and carpentry.

For the first couple of days an initial concept formation and brainstorming session was held, where alternative scenario ideas and candidate technologies were discussed. After that, a one-day feasibility analysis (*reality-check*) followed, combined with an informal qualitative evaluation of each suggestion, using five selection criteria: (a) relevance to the demonstrator's goals; (b) feasibility in the available time-frame; (c) immediate availability of required technological components; (d) pre-existing know-how; and (e) robustness and fail-safety. As an outcome of this phase, some of the suggested ideas were eliminated, some were combined and a few new ones came up. The "surviving" ideas were prioritized using an ad hoc weighted algorithm calculating their conformance to the aforementioned criteria and were then assembled in the form of a narrative walkthrough scenario. Additionally, several sketches were created illustrating: (a) the envisioned layout of the required technological components in the available space, and (b) the indicative interaction behavior and correspondent user interfaces. This material (*scenario plus sketches*) was used as a shared roadmap for the team,

Subsequent steps in development process entailed interleaved activities for hardware installation, software programming and space construction, with daily partial integration and testing phases. In parallel to these activities, a monitoring and design / re-design process was running that (taking into account interim progress, problems, and new ideas, as well as the initial set of requirements) continuously updated the design documents and goals.

The last few days of the available time were dedicated to exhaustively testing and "debugging" the demonstrator as a whole.

3.3 Technological Infrastructure

The technological infrastructure integrated in the office space is illustrated in the diagram provided in Fig. 1. The top part of the diagram provides a side view of the entire space, while the bottom part is a top-down view of the meeting table. More specifically, the following components were employed:

1. *Deskpad*: An ordinary leather deskpad that can double its size when opened. Inside the top part of the deskpad an RFID tag has been concealed.
2. *Projector*: A small projector (1024x768), hidden inside the room's ceiling. It is used to project information on the deskpad's surface.
3. *Color camera*: Used to track: (i) the position of objects placed on the deskpad; and (ii) whether an arm has been extended to the left or right of the deskpad.

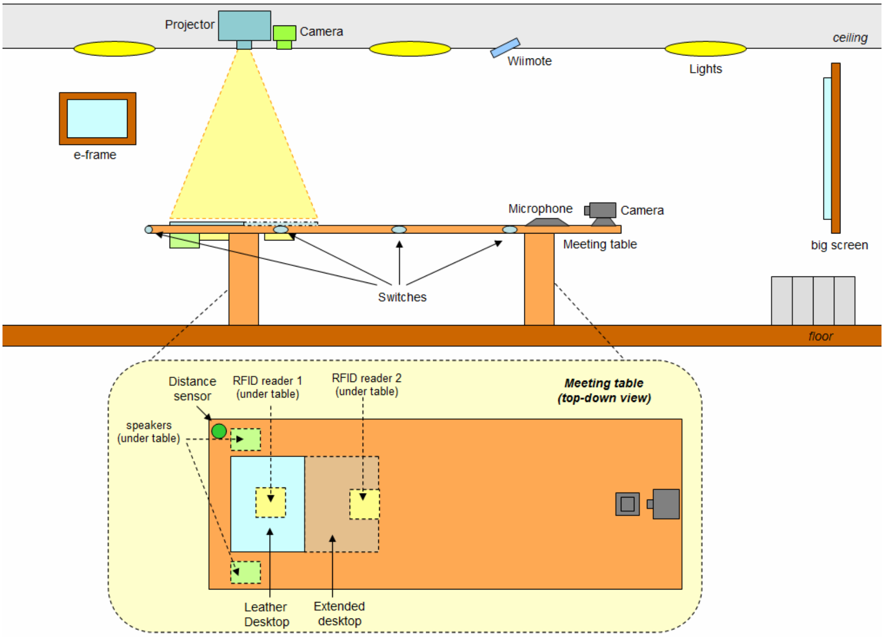


Fig. 1. Overview diagram of the installed technological infrastructure (*top part*: side view of the entire space; *bottom part*: top-down view of the meeting table)

4. *Wiimote*: A remote controller of Nintendo's Wii console, used to track the position of the IR pens on the table, following the approach suggested in [6].
5. *Computer-controlled lights*: Neon lights that can be turned on / off and dimmed at any intensity using the DMX communications protocol.
6. *e-Frame*: A 19 inches touch screen embedded in a custom-made wooden frame, in order to resemble a typical painting.
7. *TV*: A 60 inches flat screen TV.
8. *Tiltable camera*: A table-mounted camera that can zoom, rotate and tilt.
9. *Microphone*: A cardioid condenser table top microphone.
10. *PCs*: Four average Core Duo PCs. One is used by the computer vision software, while the rest drive the three available displays (e-frame, TV, projector).
11. *Switches:* Seven touch buttons located underneath the table. Each button corresponds to a chair position (i.e., 3 on each side and 1 at the head of the table).
12. *Distance sensor*: An ultrasonic distance sensor concealed inside a pen holder.
13. *Speakers*: Two typical USB PC speakers located underneath the table surface.
14. *RFID readers*: Two RFID readers located underneath the table surface. One at the center of the deskpad and the other near its top (when it is open).
15. *IR pens*: Two ordinary whiteboard pens (black and red) that their tip and ink have been replaced by an infra-red LED and a battery respectively. Additionally they have been equipped with a small pressure (turn-on) switch and a round RFID tag glued for identification purposes.

16. *Mobile phone*: A Bluetooth-capable mobile phone with an embedded digital camera and an RFID tag attached.
17. *RFID-augmented objects*: An identity card, a leaflet, an envelope and three rectangular paper cards.

3.4 Software Modules

The demonstrator's software modules follow a simple service-oriented architecture in order to support its infrastructure. The infrastructure's entry point is the Office manager, which communicates and interacts with a set of peripheral services and applications using a custom, simple, string-based protocol over TCP/IP connections. Arguably, the use of a more sophisticated communication platform, would allow for a more robust and flexible infrastructure. However, since the project's needs for remote communications were modest, the implemented approach was considered as the most effective solution, given the project's tight schedule. The main software modules that comprise the demonstrator will be presented in the following sections.

3.4.1 Office Manager

The Office Manager (or in short OM) is responsible for realizing the main table user interface and "orchestrating" the overall interaction process. Depending on the current context of use, as well as user actions and system events, it decides whether to run or suspend specific applications. Additionally, it keeps track of all context parameters that the various applications may need in order to adapt their content or behavior.

3.4.2 Computer Vision Subsystem

In order to be able to support natural interaction, a computer vision subsystem was integrated into the overall system. This subsystem utilizes a camera located to the office ceiling, overlooking the table surface. The main use of the vision system was to detect occurrence of the user's hand over predefined areas on the desktop, as well as, to locate objects placed on this desktop.

When the user's hand is placed above a predefined area (e.g., left-hand side of the deskpad) a software event is generated. To achieve the above functionality, a model of the background (desktop) is *a priori* constructed. The occurrence of the user's hand above this area is achieved by detection of the color change within the corresponding image region, based on a background subtraction process [7]. The method operates at a rate of approximately 20 frames per second, on a conventional PC for 480×640 images. Furthermore, to achieve robust behavior against global changes of illumination, the background model is frequently updated, based on the color values of the pixels that are unoccluded by the user's hand. In the event of a dramatic change of illumination (such as switching all the room lights on or off) the system requires approximately three seconds for retraining, during which events are suppressed, to avoid reporting spurious events. Additionally, using the above functionality, objects that are placed on the deskpad are located, by extracting the blob of active pixels that is formed in the background image. In this way, when an object (such as the mobile phone or the leaflet) is placed on the deskpad, its location is estimated through the centroid of this blob. A transfer function (*homography*) is then used to translate the location of this blob from image coordinates to deskpad coordinates.

3.4.3 Wireless Photo Manager

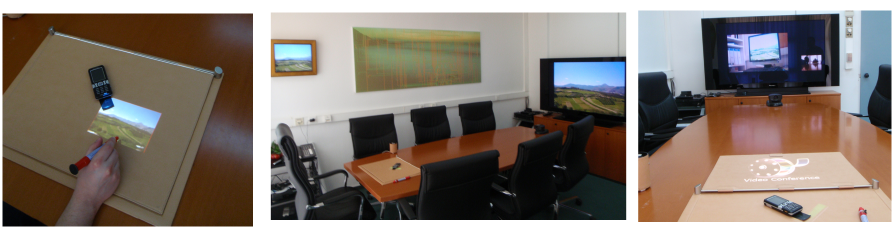
One of the concepts for experimentation was the seamless merging of the digital and the real world [5], or in other words, combining the notions of *Ambient Intelligence* and *Augmented Reality*. In this context, a small application was built for easily transferring and managing digital photos. This application works as follows:

1. The user takes a photo using a mobile phone. The choice of the mobile phone instead of a camera is motivated by two facts, (a) it is more readily available as people carry it with them all the time and (b) typically, it has built-in wireless communication capabilities.
2. When the user places the phone on the deskpad, its RFID tag is read by the RFID reader and, using Bluetooth, the photo is transferred to the PC that the OM is running. At the same time, the OM requests the computer vision subsystem to pinpoint the exact position of the phone on the deskpad. Based on this information, the OM overlays a green tick mark (✓) over the phone (using the ceiling projector) and, through speech synthesis, announces that the phone was recognized and is ready to be used.
3. The user can now use the IR pens to drag the photo out of the phone and onto the leather deskpad (see Fig. 2a). If the photo is dragged outside the top edge of the deskpad, then it appears on the TV screen (see Fig. 2b). If it is dragged outside the left side, then it appears on the e-Frame (see Fig. 2b). If the same action is performed during a video conference, then, the photo instead of appearing on the TV, it is transferred to the screen of the remote participant (see Fig. 2c).

3.4.4 Multi-display PowerPoint Presenter

A typical task performed during office meetings, is having a PowerPoint presentation. Thus, a related application was integrated to the demonstrator that works as follows:

1. The user places on the deskpad an RFID-augmented artifact, related to a specific presentation. For our demo, an ICS-FORTH leaflet was used.
2. When the RFID reader identifies the tag, the OM dims the ceiling lights over the table and starts the presentation on the TV screen (Fig. 3a). A related notification message is also spoken. If the user removes the leaflet from the deskpad, the presentation is also projected on its surface, so that the user does not need to read it from the TV screen located a few meters away (Fig. 3b).



(a) (b) (c)

Fig. 2. (a) Dragging the photo out of the mobile phone; (b) sending to it the TV and the e-Frame; (c) sending it to a colleague during video-conference

(a) (b) (c)

Fig. 3. (a) Putting the leaflet on the deskpad; (b) Taking the leaflet off; (c) Opening the deskpad

3. The user can browse the presentation slides by using bare hands. If one hand is placed to the right-hand side of the deskpad, the presentation advances to the next slide. If it is placed to the left side, the presentation moves to the previous one.
4. If one of the pens is placed on the deskpad, the user can annotate the current slide (e.g., write or draw on it) using the respective pen's color.
5. If the deskpad is opened during the presentation, then, on the top part of it, the notes associated with the slide are shown (Fig. 3c). If the deskpad is closed, then the notes are hidden again.
6. When the presentation ends, lights are restored to their previous state.

3.4.5 Video Conference

Another typical scenario of use of meeting rooms involves Internet-based video conferencing. In this context, a relevant application was developed using a third party commercial framework by LEADTOOLS multimedia[1]. A problem faced at this point was that there can be up to seven people around the table and just one camera. To overcome this problem a tiltable camera was used, along with touch switches mounted in front of each available seat. By pressing a switch the camera turns, zooms and focuses onto the specific position. Camera control was achieved through the serial port of the camera using the VISCA protocol by SONY.

3.4.6 Informative Art Display

Presenting dynamic information, in a subtle and aesthetically-pleasing way, without obstructing the users' primary task was another of the dimensions to be explorer. In this context, an *informative art display* [9] was developed for presenting "live" e-mail related information. The key idea of an informative art display is rooted in the Tangible Bits approach [8] that employed "ambient" media in order to subtly display and communicate information. This concept was later applied to the domain of dynamic paintings following several different approaches (e.g. [9, 10]). In our case, we followed the approach suggested by [10] where specific information semantics are mapped to some parts of an existing painting. The painting selected was "the Birth of Venus" by Sandro Botticelli. The Informative art display initially presents a view of the original painting from which the flowers have been removed. The display tracks

[1] http://www.leadtools.com/SDK/MULTIMEDIA/Multimedia-LE.htm

an e-mail account and, depending on the number and type of the incoming e-mails makes some painting elements appear (or disappear). For example, whenever a new message arrives a flower is added, messages from a list of colleagues appear as oranges on the tree, virus-infected messages as sharks circling Venus, etc.

3.4.7 e-mail Manager

The informative art display presented in the previous section, is responsible for presenting information regarding the number and type of incoming e-mails. In order to allow users to also read and respond to the content of these e-mails, another application was developed that also employs the alternative interaction techniques supported by the installed infrastructure. Through the e-mail manager, the user can browse incoming e-mails by using her hands, manage them (e.g., delete, organize) using the IR pens, and even write new e-mails using a Bluetooth laser keyboard. When the deskpad is closed, the e-mail manager presents just a list of the messages along with sender and reception time information. When the deskpad is open, the content of the selected e-mail is also visible. The application was implemented using KoolWired.Net[2], a publicly available open source library.

3.4.8 Game

In addition to the applications elaborated above, an entertaining activity was developed, with a two-fold purpose. In term of the process, it was an experiment on reusing the existing infrastructure for a different application, while, in the context of an office environment, it can be considered as a “tool” helping to release tension after a meeting. The theme of the game is a cowboy duel in the far west. On each side of the screen there is a cowboy that can move up and down and shoot. Players around the table control the cowboys using the switch buttons in front of their seat. Each side of the table controls the corresponding cowboy. Whenever a cowboy manages to eliminate his opponent, he gets a point. If the switch at the head of the table is pressed, a stagecoach that can shoot either way passes through the middle of the field.

3.4.9 Various Small-Scale Specialized Software Modules

In addition to the aforementioned modules, a number of smaller-scale specialized modules were developed, offering some required low-level services, such as:

1. ***User identification***: When user information is received, this service notifies the OM for the user’s access rights.
2. ***RFID reading***: When an RFID-tagged object is either placed or removed from the table’s surface, it resolves the RFID tag to a user-friendly, semantically sensible character sequence (using a text file as a database) and notifies the OM.
3. ***Video playing***: Provides the capability to play video files using Microsoft’s DirectShow framework. The OM, utilizing the functionality offered by the computer vision subsystem and the distance sensor, enables the user to pause / resume the video and change its volume by using the hand gestures.
4. ***Image presentation***: Can receive an image through a TCP/IP connection and display it in any screen.

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[2] http://koolwired.com/solutions/

5. ***Bluetooth communication***: The OM uses the Obex (http://www.irda.org) protocol through the "In the hand" (http://inthehand.com) open source library for .NET to retrieve image files from Bluetooth-enabled devices, such as the mobile phone.
6. ***IR position detector***: The functionality of the IR position detector is offered by the open source program described in [5] that translates IR position information into mouse movement events.
7. ***Speech synthesis***: Uses the Microsoft Speech API for generating synthetic speech.
8. ***Lights controller***: Uses the DMX SDK by Velleman Inc. (http://www.vellemanusa.com) to enable the OM to control the room's lights.
9. ***Distance sensor***: Calculates the distance to the nearest object through a serial connection to an ultra-sonic distance sensor and delivers it to the OM.

4 Conclusions and Future Work

The demonstrator was fully functional within the specified period of one month and, following repeated "shows" to a variety of audiences, it consistently elicited very positive responses. On a purely practical basis, the demonstrator helped us get a better understanding of the challenges that one needs to face when trying to set up an AmI-augmented environment. Furthermore, it offered us valuable, hands-on experience, and a tangible means for constructing, visualizing and evaluating concepts and envisaged scenarios towards the creation of a fully-working future "smart" office environment. In this context, some of the key findings were the following:

1. The simple, string-based protocol used, was adequate for the demonstrator purposes, but for a large-scale real-life AmI environment, the use of a sophisticated middleware communication platform is absolutely required.
2. The most common problems faced were related to hardware failures. An automated testing and failure identification mechanism would greatly improve the overall system robustness and "service" time.
3. All computers used MS Windows. A frequent problem was that messages for automated updates (and related restarts) would pop-up almost daily.
4. Bluetooth was quite cumbersome to use. A basic reason was that currently several different stacks exist that can not always "co-exist" on the same computer, but often specific devices work only with a certain stack.
5. Sun beams include infrared light that can totally mess up an IR tracking system.

Based on the outcomes of this rapid prototyping activity, we are currently in the process of developing "Smart Office 2" with many new features, including: multi-user support for collaborative tasks, integration of commercial software applications (e.g., MS Word, PowerPoint), use of biometrics for user identification, speech-based user recognition and localization, and sensor-augmented chairs.

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