The Smart Home Controller on Your Wrist

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Abstract
This paper addresses human-home interaction mediated by everyday objects, with a particular focus on wrist watches. Everyday wrist-worn devices are turned into flexible home access points by exploiting a modular architecture independent from the underlying home automation system, and from the specific watch device, provided that the necessary capabilities are available. A first working prototype based on a cost-effective consumer watch is presented, and experimental results confirm the viability of the approach.

Author Keywords
Home Automation, Smart Environment, Human-Home Interaction, Wearable Computing

ACM Classification Keywords
H.1.2 [Models and principles]: User/Machine systems; H.5.2 [Information interfaces and presentation (e.g., HCI)]: User Interfaces.

Introduction
Ambient Intelligence (AmI) environments, or Smart Homes, are defined as "*digital environments that proactively, but sensibly, support people in their daily lives*" [4]. Such "sensible and proactive" support is achieved by continuously and unobtrusively

complementing human activities. While research-level solutions already support this kind of interaction, although on specific, customized settings, only, few residential homes employ AmI on an everyday basis. Several factors can be identified, which can cause this lack of adoption: (a) the highly-customized nature of research-level solutions, (b) the high installation costs, (c) the inability of existing solutions to actually blend with the inhabitants life background. Human-home interfaces are still under investigation and a suitable tradeoff between traditional (e.g., switches, etc.) and PC/mobile-based interfaces, has not yet been found. Traditional interfaces are well understood, easy to use and not intrusive at all, as they are already part of householder's daily activities. PC/mobile-based interfaces, instead, are typically intrusive and impose additional cognitive load (explicit mediators) on the home inhabitants [10]. Moreover, computers and mobile devices have some known limitations: they are multi-purpose devices, and they could be controlled by other home inhabitants (e.g., for gaming, etc.); they are not always carried around in the home [12]; they need to be picked up, opened or turned on before they can be used; and, finally, there are situations where is not possible, secure or suitable to use them (e.g., with wet hands or under the shower). As a consequence, their adoption is often confined to small niches, whereas more effective interaction would unveil the full AmI potential.

Wearable computing aims at overcoming part of these user-home interaction issues [6, 11] by enhancing the invisibility of AmI systems (e.g., interfaces) and by improving the level of acceptance of proposed solutions in accomplishing home tasks. Wrist watches, or bracelets [13], are among the most attractive solutions for AmI wearable interfaces as they offer a suitable form factor, they have the advantage of always being with users and can be instantly viewed/operated by flicking the wrist. User studies [12] confirm their viability since: (a) a large fraction of population is already accustomed to wearing watches and/or bracelets; (b) watches are less likely to be misplaced with respect to phones, tablets or other mobile devices; (c) watches are more accessible than other devices one may carry; (d) the wrist is ideally located for body sensors [9] and wearable displays [5]. Unfortunately, also in this domain, actual exploitation is still confined to niches: on one hand research-level solutions are not mature enough to support everyday use, lacking optimization, packaging and wide diffusion, as in [9]; on the other hand commercial solutions are more focused on technologically advanced gadgets, or mobile phone extensions, rather than on fully integrated solutions. This paper addresses the problem of unobtrusive user-home interaction with a strong application-oriented approach. Basing upon the proven viability of wrist-watches as interaction means, requirements for transforming them into flexible home access points are discussed and formalized. These requirements drive the design and development of an end-to-end system based on off-the-shelf and open source components.

Requirements

The use of wrist-worn interfaces, such as a watch or bracelet, enables many user-required features for smart homes [3], but poses additional requirements on both hardware and software functionalities. By analyzing the current literature on wearable and pervasive computing, a base set of requirements can be identified (see Table 1 for the full list). Watch/bracelet used in smart homes must carry standard sensors on-board, in particular temperature sensors and accelerometers, to exploit user movements [7] and environment conditions (context) in interaction design [8].

Requirement	Description	Priority
Sensing on board	The watch must carry on-board temperature sensors, accelerometers, and, optionally, blood-pressure, and heart-beat sensors	Required
Localization	The watch should support user localization through: RFID, NFC, RF power localization, etc.	Optional
Communication	The watch must provide wireless communication to the home (standard technologies are preferred)	Required
Battery life	Battery must last at least several days	Required
Visual feedback	The watch display must successfully convey information to users	Required
	Multiline display	Required
	Matrix display	Optional
Non-visual feedback	The watch must provide non-visual feedbacks to get the user attention	Required
	Sound emitter	Required
	Haptics	Optional
Touch access	The watch must provide touch-based interaction	Required
	Buttons, touch-sensitive display or bracelet	Required (at least one)
Customization	Aspect customization (color, cover, etc.)	Optional, but typically wanted
	Function customization	Optional

Table 1: Wrist-worn User-Home Interface Requirements

Additional features might include blood pressure and heart-beat sensors, which enable home-care and assistive scenarios [9, 1]. By always being on the inhabitants' wrists, watches and bracelets are ideal means for user localization. To accomplish such a task, however, they shall integrate localization technologies such as RFID, NFC, etc. Moreover, they must provide wireless communication to the home while, at the same time, ensuring good battery life, comparable to normal watches [14]. Readability of the watch display and accessibility of the watch buttons (or touch display) is another factor to account, as typical usage scenarios require easy and quick operation [11]. Finally, packaging and software customization enhances the user-home experience, allowing inhabitants to tailor the wrist-worn interface to their specific needs.

Architecture

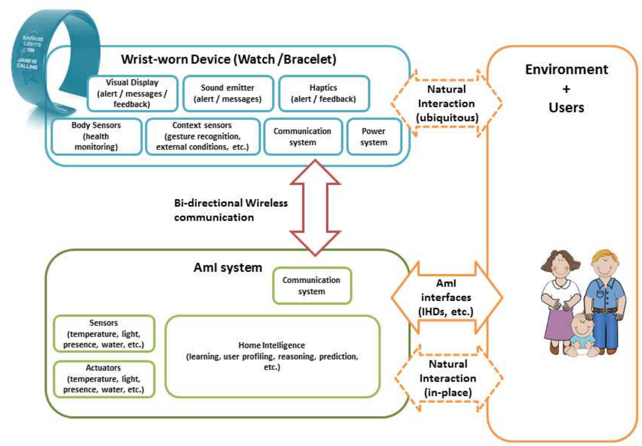

Figure 1: Logical architecture

The proposed architecture for wrist-worn interfaces (see Figure 1) involves three main tiers respectively corresponding to: the wrist-worn device, the ambient intelligence (AmI) system and the home environment, including people living in it. The AmI and wrist-worn device tiers are further organized in modules providing functionalities to support user-home interaction, according to requirements identified in the previous section.

Wrist-worn device
The wrist-worn device depicted in the architecture is a personal wearable notification, sensing and control device with a bracelet-like form factor. To fulfill the requirements reported in Table 1, it exploits a modular hardware and software structure encompassing the following functional modules.

Body sensors (optional): typically encompass blood pressure, heart-beat, and skin temperature sensors. A specific firmware takes care of sampling the corresponding measures and conveying them to the AmI system via the communication system. Some information can also be used locally.

Context sensors (required): such as accelerometers and temperature sensors. They are typically exploited for direct interaction between users and the environment. Differently from body sensors, data flows originated by these sensors are typically processed on the AmI side as the computing capabilities of wrist-worn devices are usually restricted.

Display (required): the wrist-worn device includes a display to provide feedback and information to the user. To fulfill the unobtrusiveness requirements, the display must fade in the background (e.g., shall behave as a normal watch display) and at the same time must be capable to show concise, yet useful, information about the AmI environment and the surrounding context.

Sound emitter (required): usually implemented as bi-tonal buzzer. The sound emitter supports immediate feedback and acts as trigger for user attention: whenever a user action must be timely taken to properly face a given home condition (someone at the door, a child asking for help, etc.), the sound emitter drives the user attention to the display, where further information is shown and possible actions are described.

Haptics (optional): the haptic module (e.g., vibration) has almost the same role of the sound emitter but it enables perceivable feedback in all situations were sound is not appropriate, e.g., during meetings, when hearing impairments prevent full exploitation of sounds, etc.

Communication system (required): ensures wireless communication with the AmI environment either through standard (e.g., Bluetooth) or dedicated (e.g., SimpliciTI) protocols. It supports bi-directional communication and optional message prioritization (needed for better handling of alerts).

AmI system
From a very high-level standpoint, 4 main AmI subsystems can be identified: (a) **sensors**, with which the ambient intelligence system observes the current environment state and context; (b) **actuators**, used by the ambient intelligence system to trigger changes in the environment state, possibly involving the user, both in the decision process and for what concerns the actuation results; (c) the **Home Intelligence**, providing context-awareness, activity recognition, environment operation, proactive interaction, event generation and delivery, etc.; and (d) the **communication system**, able to handle messaging between the AmI and the wrist-worn devices used as human-home interfaces.

Implementation

The reference architecture has been implemented on a real-world watch, based on the eZ430-Chronos development platform and on Dog (Domotic OSGi Gateway [2]), the latter is used to manage the AmI environment.

eZ430 overview

The eZ430-Chronos is an affordable and complete development system, featuring a 96 segment LCD display and providing an integrated pressure sensor, a 3-axis accelerometer for motion sensitive control, a temperature and a battery voltage sensor. It comes bundled with a USB-based wireless interface which permits to support PC-to-watch communication. Available functions can be reached through 2 menus located on the top and on the bottom row of the watch display, respectively. A standard button operation paradigm is defined for the entire platform, with 3 main interactions: (a) a short pressing of the "#" button switches to the next menu entry, (b) a long (2s) pressing of the "#" button provides access to sub-menus and finally, (c) a pressure of the "▼" button activates the current menu entry. From the hardware standpoint, the platform fulfills mandatory requirements for wrist-worn interfaces, i.e., availability of sensors on board and capability to wirelessly communicate with a PC-like device (AmI system). On the other hand, the standard firmware provided with the development framework is focused on standard watch functionalities, therefore user-home interaction modules must be designed and integrated as firmware extensions.

Wrist-worn device implementation

Watch-level implementation mainly involves the design and development of a firmware extension, starting from the OpenChronos open source version[1]. Visual and sound emitter modules are implemented as new watch functionalities whereas the haptic display module is omitted since the platform does not provide such type of feedback. New functionalities, i.e., gesture recognition (currently under development), message handling, battery measurement and quick access commands, are included in the watch menu located on the bottom row of the display. Such a menu is, in the eZ430-Chronos firmware design, typically reserved to advanced (non-watch) capabilities such as heart-beat monitoring, mouse control, etc. Interaction between the watch and the AmI environment adopts a client-server paradigm and, due to battery saving concerns, takes place either on a sporadic basis (every 30, 60 or 180 seconds) or manually, when triggered by the user. User-home interaction through the watch exploits 3 types of messages:

Silent messages represent low priority messages meant to inform the user about the home state. The watch firmware handles a maximum queue of 2 messages, which are kept in memory until they are overwritten by more recent messages. Received silent messages can be displayed at any time by pressing the "▼" button in the "Message" menu.

Loud messages have the same priority of silent messages, but they solicit immediate user attention by activating the integrated alarm (Figure 2). Loud messages share the same memory queue of silent ones, and they are typically used to deliver more urgent information about the home state/context, e.g., anti-burglar detection, help requests, reminders.

[1] http://github.com/poelzi/OpenChronos, last visited on May 22, 2013

Figure 2: A loud message

Reply messages encompass all messages for which a user reply is required, typically in form of a YES/NO answer. They are the highest priority messages exchanged by the watch and the AmI system, and they always require user attention by activating the watch alarm. Possible replies are YES ("▲" button), to activate the suggested action or NO ("▼" button) to avoid it. Any other button pressure is interpreted as don't care.

During normal operation, the AmI system uses the communication module to monitor connections coming from watches distributed in the home environment. Whenever a watch (previously registered with the AmI service) wakes up, the AmI system inspects/updates the message queue for the watch to deliver the 2 most recent messages, giving higher priority to reply messages. It must be noticed that this sporadic operation pattern is typical in battery powered systems, where a suitable trade-off between consumption and responsiveness must be identified.

Wrist-worn user interface
The display module implemented in the wrist-watch firmware offers 3 master screens with which users interact for accomplishing all message handling tasks. They respectively involve: a main screen, a settings screen and a reply screen. The settings screen is further divided in 2 pages, needed to display all available options on the small LCD screen of the watch.

The **main screen** is the entry point for handling AmI messages. It is identified by the "MESS" string reported on the bottom display line, and can be accessed by iteratively pushing the "#" button. The "▼" button, in this menu, allows manual display of last-received messages, without triggering a watch-to-AmI communication, and thus avoiding quick battery draining due to active wireless link. On the other hand, by holding the "#" button for more than 2s, users can access the message settings pages.

The **settings screen** is organized in 2 pages. The first page is mainly focused on message handling. In particular, it supports watch users in removing the last messages from the message queue, and permits to manually check for any pending messages, without waiting the auto-synchronization trigger. Manual synchronization is the only mean to get AmI messages when the watch is in the manual synchronization mode. In such a case, in fact, no communication is carried unless triggered by the user through the "▼" button, when the watch shows the message settings page. The second page is more focused on watch configuration. On one hand, it permits to enable/disable the sound emitter module, thus avoiding obtrusiveness in all cases where a loud sound might be annoying or inappropriate. On the other hand, it allows selecting the desired auto-synchronization interval, offering three different refresh rates 30s, 60s, 180s and the manual synchronization option.

Whenever a reply message is delivered by the AmI to the watch, the **reply screen** displays the message while the watch plays a loud sound (if sound has not been disabled), blocking until the user selects one reply option. The user can either choose to ignore the message, by pressing one of the left-side watch buttons, or can explicitly answer: YES, by pressing the "▲" button, or NO, by pressing the "▼" button.

Experimental Results

A preliminary user study has been carried to evaluate the watch functions and the possible adoption scenarios. Four participants used the system, performing 3 tasks and replying to a final questionnaire. Their observations and answers were used to carry a qualitative analysis, to help identifying strengths and weaknesses of the system and to identify future directions. The four participants recruited for this preliminary study were 2 females and 2 males (aged 35-46), of which only one was working in the computer science field. All of them habitually wear a wrist watch.

Environmental setup

The user evaluation has been carried in a controlled environment where Dog acts as AmI system. In the test environment, Dog controls and receives notification from two different domotic plants, equipped with 6 lamps, 4 mains power outlets, a shutter actuator, and some switches. During the evaluation, Dog sent to the watch two different messages: a request to turn off a lamp and a warning message. Users were required to naturally react to the messages, using the think-aloud protocol for describing their decisions. The watch was able to correctly deliver the messages, forward a reply (when needed) and interacted with the AmI environment with no detectable problems.

Qualitative results

The final questionnaire asked participants to give an overall grade to the system, in a scale from 1 (the worst) up to 5 (the best). Results show that they were quite satisfied of the system behavior and functions, with a mean value of 3.5. The participants would use such a system in their homes but also in the workplace; moreover, they found the watch menus easy to navigate and to use, but only after an initial explanation. Two of them were quite interested in controlling their home appliances with the watch, whereas the other two participants were very interested in such possibility. All the participants were very interested in the possibility to control their appliances by using some gestures. When we asked for how much they would spend for a watch with such features, three participants said they want to spend 25-50$; the other participant said "less than 25$". These choices give an indication to an important "cost requirement", i.e., the watch should be a low cost device, and the adopted development kit might work as a good starting point, by only costing around 50$.

Conclusions

This paper discussed requirements for wrist-worn human-home interfaces and proposed a preliminary implementation based on a cost-effective watch. Preliminary user tests confirm the functionality of the system and the viability of the approach. Interesting aspects emerging from user testing involve both the device price, which must be in the low range (between 25 and 50$), and the willingness to adopt the watch in the home and in the workplace. This last observation supports the unobtrusiveness of the approach and fosters future investigations about the possible uses of such an interface.

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References

[1] Bestente, G., Bazzani, M., Frisiello, A., Fiume, A., Mosso, D., and Pernigotti, L. M. Dream : Emergency monitoring system for the elderly. In *6th International Conference of the International Society for Gerontechnology (ISG-08)* (Pisa, Italy, 06 2008).

[2] Bonino, D., Castellina, E., and Corno, F. The DOG gateway: enabling ontology-based intelligent domotic environments. *Consumer Electronics, IEEE Transactions on 54*, 4 (2008), 1656–1664.

[3] Bonino, D., and Corno, F. What would you ask to your home if it were intelligent? Exploring user expectations about next-generation homes. *Journal of Ambient Intelligence and Smart Environments 3*, 2 (January 2011), 111–126.

[4] Cook, D. J., Augusto, J. C., and Jakkula, V. R. Ambient intelligence: Technologies, applications, and opportunities. *Pervasive and Mobile Computing 5*, 4 (Aug. 2009), 277–298.

[5] Harrison, C., Lim, B. Y., Shick, A., and Hudson, S. E. Where to locate wearable displays?: reaction time performance of visual alerts from tip to toe. In *Proceedings of the 27th international conference on Human factors in computing systems*, CHI '09, ACM (New York, NY, USA, 2009), 941–944.

[6] Huang, P. Promoting wearable computing: A survey and future agenda. In *Proceedings of the International Conference on Information Society in the 21st Century: Emerging Technologies and New Challenges*, IS2000 (November 2000).

[7] Kim, J., He, J., Lyons, K., and Starner, T. The gesture watch: A wireless contact-free gesture based wrist interface. In *Wearable Computers, 2007 11th IEEE International Symposium on* (2007), 15–22.

[8] Lee, D.-W., Lim, J.-M., Sunwoo, J., Cho, I.-Y., and Lee, C.-H. Actual remote control: a universal remote control using hand motions on a virtual menu. *IEEE Transactions on Consumer Electronics 55*, 3 (Aug. 2009), 1439–1446.

[9] Maurer, U., Rowe, A., Smailagic, A., and Siewiorek, D. Location and Activity Recognition Using eWatch: A Wearable Sensor Platform. In *Ambient Intelligence in Everyday Life*, Y. Cai and J. Abascal, Eds., vol. 3864 of *Lecture Notes in Computer Science*. Springer Berlin / Heidelberg, 2006, 86–102.

[10] Misker, J. M. V., Lindenberg, J., and Neerincx, M. A. Users want simple control over device selection. In *Proceedings of the 2005 joint conference on Smart objects and ambient intelligence: innovative context-aware services: usages and technologies*, sOc-EUSAI '05, ACM (New York, NY, USA, 2005), 129–134.

[11] Pentland, A. Wearable intelligence. *Scientific American 9*, 4 (1998).

[12] Raghunath, M. T., and Narayanaswami, C. User interfaces for applications on a wrist watch. *Personal and Ubiquitous Computing 6*, 1 (Jan. 2002), 17–30.

[13] Smith, J. R., Fishkin, K. P., Jiang, B., Mamishev, A., Philipose, M., Rea, A. D., Roy, S., and Sundara-Rajan, K. Rfid-based techniques for human-activity detection. *Communication of the ACM 48*, 9 (Sept. 2005), 39–44.

[14] Starner, T. The challenges of wearable computing: Part 1. *Micro, IEEE 21*, 4 (2001), 44 –52.