

Towards a Context Aware Multimodal Hand-Held Device

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Abstract. We present the design of a prototype for a context aware multimodal hand-held device, envisioning several improvements on the interaction with such devices. The design of this prototype is strongly based on an extensive requirements and feasibility analysis. Different context awareness and multimodal interaction issues are depicted, based on previous and actual user centered experiments. We concluded that the sets of sensing mechanisms available on commercialized devices are not enough for our aspirations and that the augmentation of such devices through the utilization of sensor platforms is not applicable on real life scenarios, leading us to design a capable device for such purposes.

Keywords: Requirement and Feasibility Analysis, Hand-held Devices, Context Awareness, Multimodal Interaction.

1 Introduction

Researchers have been focused on context since the 90's. Many definitions emerged for this concept [1]. However, one is abstract enough to include all the others and to keep a spectrum wide enough to cope with technology's evolution: "Context is any information that can be used to characterize the situation of an entity" [2]. An entity may be a person, an object, or anything that is characterizable. Context awareness defines the capability of applications to access information regarding their utilization context and react accordingly. Underneath it, locally or remotely, context sensing defines the capability of a device or infrastructure to sense context through the utilization of sensing mechanisms (e.g. sensors, cameras, microphones, etc.). Once available, context information can be exploited for different purposes [2].

Besides enabling context awareness, sensing mechanisms may also be employed in order to support input modalities (e.g. voice recognition, acceleration-based gestures, computer vision-based gestures, etc.), augmenting multimodal interaction. Multimodal interaction is a characteristic of everyday human activities and communications, in which we speak, listen, look, make gestures, write, draw, touch and point, alternatively or at the same time in order to achieve an objective. Achieving a more natural human-computer interaction, by considering the human channels of perception and communication through the inclusion of elements of natural human behavior on human-computer interfaces, is the main goal of multimodal interaction [3].

Context awareness and multimodal interaction are two concepts that are strongly related. The ubiquitous nature of mobile and hand-held applications increases the number and complexity of the contexts in which they are used. This complexity may limit or even inhibit interaction [4, 5]. However, multimodal interfaces can improve interaction for different users and usage contexts, increasing performance, stability, robustness, expressive power, and efficiency of mobile activities [6, 7]. Therefore, the interaction limitations introduced by context may be overcome by multimodality. The individual or assembled utilization of different interaction modalities, which may be automatically or semi-automatically enabled, disabled, configured, and optimized according to the different variables that define a usage context, may introduce significant improvements on human interaction with hand-held devices.

To achieve the constant and reliable context awareness desirable for this purpose, the use of remote context sensing must be minimized. The principle itself seems inadequate, and therefore very hard to conceive, in macro scale solutions, such as context-aware cities, countries or continents. Moreover, the macro scale implementation of such concept would almost certainly raise a social dilemma regarding the users' privacy. One plausible solution is the inclusion of sensing mechanisms on hand-held devices. On one hand, this would allow the majority of the context sensing and interpretation routines to be performed by the device and, on the other, it would enable richer interaction experiences for their users. Nevertheless, the integration of these devices with context-sensing infrastructures and the internet should also be considered, broadening the employments of both context information and interaction modalities.

This paper focuses on the relations between sensing mechanisms, context-awareness, and multimodality aiming several improvements on human interaction with hand-held devices. The next section introduces the background and motivation for the work presented. Following, we describe the requirements and feasibility analysis of our context-aware multimodal hand-held prototype. Some of the improvements suggested are validated referencing several experiments and others through our own experiments, which are further described. A sketch of the prototype is presented and, finally, conclusions and future work directions are articulated for this on-going research.

2 Background and Motivation

The first contribution for the mobile context awareness domain was the Active Badge system, which integrated a positioning technique with a distributed computing infrastructure [8, 9]. Following, the Ubiquitous Computing vision pointed out the importance of location and context for the next era of computing [10]. These contributions underlie the ParcTab experiment, where hand-held devices were augmented with locality in order to access location-based services [11, 12]. Nonetheless, these pioneer projects all employed indirect awareness, with sensors located on an infrastructure responsible for the context sensing. These infrastructures have proven to be very useful in controlled environments such as museums, art galleries and tour guides [13, 14], presenting an enormous potential for many others

such as hospitals, enterprises and offices [15]. However, the fully infrastructure-based context awareness paradigm does not seem to scale in order to achieve macro scale solutions (e.g. context aware city).

Due to the recent boost in sensing technologies, researchers increased their interest in embedding direct awareness into hand-held devices [16]. The trend is leading to sensors in small packages that enable powerful sensing at very low cost. The amount of context information that can be sensed locally on these devices is considerably larger than before and in constant growth. Actual hand-held devices are significantly more powerful and integrate more sensing mechanisms. Experiments conducted show that context information can be gathered locally and constantly by hand-held devices. Location [8, 9], orientation [17], lighting, temperature [18], noise [19], posture [20], movement [21], activity [22], and grasp [23] have been accurately identified and explored for different purposes. Nevertheless, these were mostly laboratory experiments conducted in order to prove concepts. Regardless of the growing availability of sensing mechanisms on commercialized hand-held devices (e.g. cameras, accelerometers, g-sensors), the available sets have proven to be insufficient for the goals here proposed. Some researchers augmented existing devices employing sensor platforms that enable the exploitation of different sets of sensing mechanisms [24, 25, 26]. Despite the good results achieved, the approach does not seem adequate for real life scenarios. Users do not want a sensor platform attached to their devices on their day-to-day lives. Moreover, the simple fact that these platforms are attached to the devices may introduce interaction difficulties.

Available studies [5, 27] show the impact of context in mobile and hand-held interaction, suggesting the creation of intelligent applications that react to context, adapting the modalities provided for interaction, accordingly. Other studies employ these suggestions in order to improve HCI on different aspects (e.g. automatic noise-based volume adjustments) [19, 21]. Even some commercialized devices start to employ these concepts (e.g. adjusting graphical user interfaces according to screen orientation, adjusting brightness and contrast according to the environmental light).

Facing the amount of context information that is technologically possible to acquire on hand-held devices nowadays, the actual employments of the concept seem rather simple. Due to the lack of devices integrating a reliable and robust set of sensing mechanisms, most experiments conducted consider and employ different context variables separately. The potential inherent in the merging of such contextual aspects broadens the spectrum of human interaction with hand-held devices. This motivated the design of the prototype further presented in this paper. This prototype envisions a reliable, robust and technologically feasible solution for local context awareness. It aims at several improvements on human interaction with hand-held devices, through the utilization of different sensing mechanisms, and focuses 3 main topics: 1) acquisition and interpretation of context; 2) creation and utilization of sensing based input modalities; 3) contextual adaptation of interaction modes and modalities.

3 Prototype Design

This section starts with a description of the requirement and feasibility analysis conducted in order to enable the design of a context-aware multimodal hand-held device. Afterwards, the envisioned device is presented and described.

3.1 Requirement and Feasibility Analysis

In order to design the prototype proposed on this paper, requirements and feasibility proofs were gathered from the data assembled on ours' and others' experiments. The experiments available on the bibliography are just referred, while new experiments conducted are presented and discussed. The process focused essentially the relations between:

Sensing mechanisms and context variables. Sensing mechanisms enable the interpretation of context variables (e.g. a microphone enables noise-awareness). In some cases, the values of specific context variables may be employed in order to infer additional context information, especially if the temporal dimension is also considered (e.g. inferring velocity from a location historic). The accuracy of the contextual information gathered is defined by the accuracy of the sensing mechanisms used, the length of their inactivity periods, and the accuracy of the inference methods used.

- GPS is an accurate technology, which is generally used in order to enable location-awareness on outdoor scenarios. The device's location indicates its user's location; velocity may be estimated based on a location historic; and, movement can be inferred from velocity [28]. For instance, it is plausible to assume that different average velocities correspond to different movement states (e.g. stopped, walking, running, in a vehicle).
- Infrared technology has been employed successfully and accurately in order to enable location-awareness on indoor scenarios. Again, user location, velocity and movement may be inferred [15].
- Cell ID has also been employed in order to enable location-awareness. The advantage of this approach is its suitability regarding both indoor and outdoor scenarios. However, the approach is significantly less accurate than the previous two and, accordingly, the context information that may be inferred from location will also be significantly less accurate [29].
- RFID technology was successfully and accurately employed in order to enable indoor location-awareness. This technology enables entity-presence-awareness as well [18].
- Magnetic sensors (e.g. electronic compass) enable precise orientation-awareness [28].
- Microphones enable environmental sound-awareness. The sound captured may contain indicators of noise, existence of ongoing activities, and presence of other sound emitting entities (e.g. people, vehicles, machines). In this case the accuracy of the information gathered also depends on the quality and number of microphones used [19].

- Cameras enable lighting-awareness and computer vision based entity-presence-awareness [31].
- Photo sensors enable lighting-awareness [18].
- 3D accelerometers provide awareness regarding user velocity, movement [22] (e.g. stopped, walking, running), posture [20] (e.g. sitting, standing), and orientation [30]. These sensing mechanisms also supply awareness regarding the device's screen orientation [32] and position [20] (e.g. pants pocket, jacket pocket, bag).

We envisioned the possibility of using accelerometers to infer the ear in use when one is having a mobile phone conversation. In order to prove this concept, an experience involving 4 users was conducted. The experiment considered real usage scenarios defined by: 1) different movement states (sitting, standing, walking, and running); 2) distinct initial positions of the device (hand, pants' pocket, jacket pocket, bag and belt); and, 3) on-conversation ear switching. The methodology implemented presented accuracy rates of 100% on all scenarios and the possible applications of ear-awareness are presented on the description of the relations between context variables and interaction.

- Temperature and humidity sensors enable temperature and humidity-awareness [18]. Humidity sensors were left out the prototype design due to their lack of utility on most hand-held interaction scenarios.
- Matrixes of capacitive sensors wrapped around a hand-held device enable grasp-awareness. Experiments show that this approach is able to accurately distinguish 5 different classes of grasp [23]. However, these sensors were excluded from the prototype's hardware requirements. We believe that the same principle can be implemented through the utilization of matrixes of pressure sensors, with the advantage of introducing expressiveness into the grasp-awareness process.
- Wi-fi and Bluetooth technology may be used in order to enable entity-presence-awareness within the signal range (e.g. devices of other users, available services). Moreover, the technology enables the use of existing internet connections that may be used to access contextual information available on the web (e.g. weather). In this particular case the accuracy of the contextual information gathered is strongly influenced by discrepancies between the context of the sensing entity and the context of the device employing it.

We developed a simple application that enables users to create contextual reminders, a simplified infrastructure-independent version of [15]. The application enables users to associate reminders to devices that represent other users. When these other users are within the signal range, the application presents the previously defined reminders. Four users tested this application on their day-to-day lives during one week and all of them reported the immense utility of such application.

Sensing mechanisms and input modalities. Sensing mechanisms may also be used in order to support and/or augment input modalities.

- Microphones underlie the support of audio recording, voice recognition, and blow interaction.
In order to prove the concept underlying the latter, blow interaction was integrated on two well-known game applications: Pong and Space Invaders. The

first application was object of two experiments, involving 5 users each. On both experiments users had to use blow in order to move the Pong Bar on the screen. The first experiment considered the use of only one microphone. The Pong Bar position was influenced by gravity and by a force with gravity's inverse direction. Blow intensity was used in order to compute this second force. All the users involved mentioned an increased fun factor when using this modality. However, all of them emphasized the fact that the experience was exhausting and made them feel dizzy. The second experiment considered the utilization of two microphones. Again, forces were computed according to the blow intensity captured on each microphone. However, this time gravity did not influence the position of the Pong Bar. All users agreed that this type of interaction was as fun as the previous, although less exhausting.

The second application, Space Invaders, was object of one experiment involving 4 users. Blow interaction was used in order to fire against enemy spaceships. All the users involved reported that, in this case, fun factor increased significantly comparing to the traditional interaction modalities (e.g. keypad, touch) and that the experience was slightly tiring.

- Cameras may be used in order to record video, take pictures, and enable computer-vision-based interaction modalities [33] (e.g. gesture recognition, face recognition, expression recognition, object recognition).
- Photo sensors may also be used as an input mechanism. The spectrum of values between complete darkness and the average environmental light at a specific moment may be mapped into an interval of values that provide input to an interface control (e.g. button, scroll bar).

In order to prove this concept, two simple applications were implemented and experimented by 4 users. Both applications mapped lighting information to scroll input. On the first application two photo sensors were used as buttons, one for scrolling up and the other for scrolling down the document. Whenever the lighting information on one sensor was close to dark the correspondent button would be pressed. All the users involved found this approach very easy to use and applicable on real life scenarios where environmental lighting is stable.

The second application used only one photo sensor in order to compute the location of the scroll bar. Three of the users involved found the concept easy to use and applicable on situations where they just had to get a general view of the document. However, for time consuming tasks, like analyzing and commenting a document, the approach was considered difficult to use due to its lack of state memorization (e.g. the user must be constantly covering the sensor in order for the document to stay in one place).

- 3D Accelerometers enable acceleration and tilt interaction, both on 3 different axes. The variables considered were employed with success, enabling acceleration-based gesture interaction [34] and tilt interaction [17]. Actually, there are some commercialized devices that integrate such technology and exploit it for the latter mentioned purpose.
- Pressure sensors and pressure sensitive touch screens improve touch interaction, introducing pressure as a new interaction dimension. Accordingly, touch based interaction modalities (e.g. gesture recognition) may also be augmented with pressure, increasing their expressiveness.

In order to prove this concept a simple application was developed and experimented by 4 users. Interaction was supported by two pressure sensors responsible for zooming images in and out. The first experiment ignored the pressure information, using the pressure sensors as simple touch sensors. The second experiment considered pressure as an input parameter, which was mapped into zooming velocity. These experiments shown that pressure sensors may be used as simple touch sensors, and that the added pressure dimension was very intuitive and useful on the opinion of all the users involved.

- Magnetic sensors may be used to create a style of portable augmented reality interaction [17]. The concept of augmented reality relies on the handheld's display providing a moveable window into a virtual world which is somehow correlated with the real world. This metaphor tries to provide the best augmented reality possible without a special infrastructure for sensing orientation.

Context variables and interaction. Context information has a strong impact on interaction. By itself, this information already introduces interaction improvements (e.g. presenting user location and orientation on a map). However, it may also introduce interaction difficulties (e.g. environmental noise may limit or inhibit voice communication or recognition). On a device that supports several interaction modalities, context information may be employed in order to improve interaction, automatically or semi-automatically adjusting and configuring the interaction modes and modalities available. The following list presents simple examples that materialize this concept, opening doors for examples of increased complexity.

- Location-awareness is very important on the support of egocentric map applications, such as tourist guides, where the graphical representation of the user's location plays a paramount role [28]. Moreover, location information may be employed in order to discover services and automatically access information related to the user's location [35].
- Orientation-awareness is also vital for most location-aware egocentric map applications, where the user's orientation must be graphically represented [30, 28]. Moreover, it enables hand-held devices to act as virtual pointers to services and information anchored at specific entities, such as regions, buildings, and landmarks [35].
- Entity-presence-awareness enables the graphical representation of entities on egocentric map applications and access to entity related information [28].
- Screen-orientation-awareness enables the automatic adjustment of graphical user interfaces [32]. In fact, some commercial devices already implement this concept.
- Grasp-awareness may be employed in order to adjust different aspects of applications' GUIs [23] (e.g. location, size, and sensibility of the GUI controls).
- Noise-awareness enables automatic adjustments of different aspects of audio interaction. Regarding input modalities, noise can be measured in order to predict voice recognition's accuracy rates, enabling applications to suggest users the utilization of alternative input modalities in case these accuracy rates are below a certain threshold. Concerning output modalities, noise information may be employed on automatic volume adjustments directed to different aspects of audio output (e.g. ringtone volume [36], headphones and earphone volume [19]).

- Lighting-awareness enables automatic adjustments of visual-related interaction modalities. Regarding input modalities, and considering the use of a touch screen, the value of environmental light may be employed to activate voice recognition in cases where the reflection on the screen inhibits the graphical interface visualization. Regarding output modalities, screens' brightness and contrast may be automatically adjusted in order to improve graphical output quality [37]. Some commercial hand-held devices already include the latter mentioned functionality and the sensing mechanisms that support it.
- At first sight the employment of temperature-awareness might seem useless regarding interaction improvements. However, if we consider very cold scenarios where users have to interact with virtual keyboards through touch (e.g. writing a text message), the employment of such information starts to make sense. Very cold temperatures usually imply the use of thick gloves, which introduce difficulties on touch interaction.
In order to attest the validity of employing temperature information towards improving human interaction with hand-held devices, a small experiment was conducted. The experiment involved 4 users, which had to write two text messages of similar lengths while wearing snow gloves. The first task considered the use of a regular virtual keypad, while the second considered the use of a virtual keypad with larger keys (50% larger). The results present an average mistake reduction of 60% and an average time improvement of 40%, proving the feasibility and applicability of temperature-based GUI adjustments on touch-based interaction.
- Ear-awareness describes the ear through which a user is communicating during a phone call. This information may be used in order to compensate little hearing unbalances through automatic volume adjustments. However, our implementation of this concept was not evaluated from a medical point of view.
- Awareness regarding a user's velocity, movement, posture, and his/her device's position enables automatic configuration adjustments [21] (e.g. set a mobile phone to vibrate if the user is sitting with the device on his/her pocket, or set a mobile phone to ring loudly if the user is running with the device on his/her backpack). Moreover, according to these same contextual variables, certain applications may be initiated automatically (e.g. a health control application for joggers if the user is running) and provide more adequate interaction configurations according to different movement states (e.g. if a user is running and wants to write an SMS, the application may provide that user with the means to dictate that message instead).

Interaction, users' preferences and capabilities. Users' preferences and capabilities play paramount roles on the automation of interaction configurations and optimizations. The extreme importance of these two contextual dimensions on human-machine interaction suggests the utilization of user profiles. Such profiles should include information regarding users' preferences and capabilities, allowing users to define and/or configure contextual-based interaction rules. The automatic completion of this profile could also be achieved through machine learning techniques. Both these concepts were considered and employed successfully in ours' and others' previous research [19, 23]. However, further studies are necessary in order

to scale these concepts to the amount of context information and interaction modalities here proposed.

3.2 Prototype Sketch

The fusion of a set of sensing mechanisms, which, together, are capable of reliably enabling the inference of the previously exposed context information, as well as the support the above mentioned input modalities, will, presumably, improve human interaction with hand-held devices significantly. Figure 1 presents the sketch of a prototype envisioned for this purpose, enhancing the sensing mechanisms used on each side of the device. Besides these mechanisms, this prototype should incorporate a 3D accelerometer, a GPS, an electronic compass and an internal antenna for phone communication, Bluetooth and Wi-Fi connections.

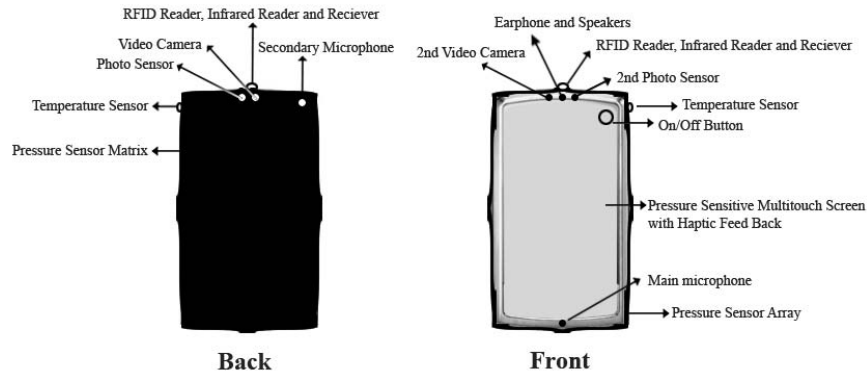


Figure 1. A context-aware multimodal hand-held device.

Most of the components available on this device were selected according to the previously presented requirement and feasibility analysis. However, some details require further justification:

Two photo sensors. The decision of including two photo sensors on our device is based on the fact that, during user interaction (e.g. answering a call) one photo sensor might be covered, presenting values that are not in accordance with the environmental light at the moment of interaction.

Two cameras. We envision the inclusion of two cameras on our device. The camera available on the front side of the device enables users to engage video conferences, while seeing the other user(s) on the screen. The camera available on the backside enables the usage of the device as a regular video/photo camera, taking advantage of the device's screen for real time previews of the videos or pictures being captured.

Two microphones. The use of more than one microphone augments the expressiveness of blow interaction. Moreover, the employment of two microphones placed in opposite directions enables the employment of noise reduction algorithms that may be very useful in order to improve audio interaction on its two dimensions: input and output.

Pressure sensitive multi-touch screen with haptic feedback. The abolishment of binary touch technology and its replacement with pressure sensitive touch technology envisions mostly an increase of interaction expressiveness. The same reason justifies the inclusion of multi-touch technology. On another strand, haptic feedback characteristics are included in order to mitigate the feedback loss, introduced by the substitution of the keypad by touch technology. Most touch screens available on commercialized hand-held devices eliminate the button feedback that users were familiar with in keypads. This introduces interaction issues, especially for visually impaired users that were suddenly inhibited of using such devices. The haptic feedback capabilities of our device's screen mitigate these issues, improving interaction for all kinds of users.

Pressure sensor array and matrix. Our device is literally wrapped in pressure sensitive technology. The pressure sensor arrays available on the device's laterals and the pressure sensor matrix available on its backside enable pressure sensitive grasp-awareness. Moreover, this technology enables the use of the sides and back of the device for pressure sensitive multi-touch input. For instance, by moving a finger on the side of the device or making gestures on its backside users may manipulate volume, scroll, zoom and other interaction parameters, without covering the screen with their hands.

Redundant context information. The prototype designed considers redundant context information. For instance, light-awareness is enabled by the available photo sensors and cameras. This redundancy may be employed in order to validate context information gathered by different sensing mechanisms that enable similar types of awareness. Moreover, it enables the use of the less energy-consuming sensing mechanisms, whenever validation is superfluous.

4 Conclusion and Future Work

In this paper we presented the initial design stages of a context aware multimodal hand-held device conceived in order to improve human-computer-interaction. The design started with an extensive requirement and feasibility analysis, which focused the contextual aspects we found necessary in order to achieve the goal proposed. This analysis included several experiments conducted in order to prove concepts that were not addressed on the literature. Afterwards, we presented the design of a prototype envisioned for this purpose and discussed the rationale of the hardware components employed.

Our future work relies on the construction of the proposed device. On the best case scenario this work will be sponsored by a well-known device manufacturer, which will be responsible for integrating the necessary hardware. On the worst case scenario, we will employ our studies and effort on the construction of a device integrating all the hardware mentioned, aiming at a proof of concept that integrates all the previously mentioned context information and interaction modalities. Some details (e.g. size, weight, battery life) were left out of this part of the research and will be focused on the continuity of the project here presented.

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