Object Augmentation through Ecological Human - Wearable Computer Interactions

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***Abstract*—One of the recurring limitations of wearable computers relates to their user interface. In order to attain transparent and natural interactions, a new interaction paradigm must be introduced. Following a short introduction on wearable computers, this paper makes the case for an ecological approach for the engineering of human-wearable computer interactions. These new interaction mechanisms, expressly based on the use of environmental objects strongly associated with the task that needs to be accomplished, ultimately lead to the augmentation of these entities. We present the current state of our research on this new interaction paradigm, from the layers of the general application architecture we devised to an example of a simple real-world application we implemented.**

***Index Terms*— Human-computer interaction, Wearable computer, Ecological design, Object augmentation.**

I. Introduction

MARK Weiser imagined omnipresent but invisible computers in his seminal vision of ubiquitous computing [12]. Such a vision laid the foundations of *pervasive computing* (disseminating computing capabilities in the environment) and *wearable computing* (integrating computing capabilities to the mobile user). This paper tries to bridge the gap between these two branches of ubiquitous computing by advocating a new interaction paradigm for wearable computers.

A. Characteristics of a wearable computer

Compared to conventional computers, a wearable computer is *useful and completely functional while worn by the user*. Such a machine is synergistically working with its user to help him/her accomplish real-world tasks. Four fundamental characteristics [8] define a wearable computer:

- it is *worn* by the user, directly on the body or integrated to clothes or accessories;
- it is *constant*, as in always available (physical constancy), always on (operational constancy) and always ready to interact with the user (interactional constancy);
- it is *(pro)active* because it is context sensitive (attentive to the user and the environment in which the human-computer interactions occur);
- it enables, or seeks to attain, a degree of *transparency* in human-computer interactions.

B. Role of a wearable computer

Due to its proximity with the user, a wearable computer is incontestably personal. Simply put, a wearable computer's role is to support real-world tasks that need to be accomplished, either directly, by providing a task-integrated computing assistance, or indirectly, by managing numerous minor or secondary activities in background. Ideally, a wearable computer would be able to assist a user in every facet of everyday life. The context of use of such a machine is highly contingent upon user mobility in an environment where human-computer interactions are NOT the primary task. Because of these differences in both context and role, a wearable computer should not be limited to traditional functions or even be forced to use current computing paradigms.

C. Challenges

Since wearable computers are technologically different and since they redefine the relationships between the computer, the user and its environment, engineering such devices offers many challenges [9] (size, weight, energy consumption, body placement of all the components, social acceptance, etc.). These challenges need to be addressed to reach a hardware/software platform consistent with mobile users needs. However, the main challenge remains the user interface. Therefore, a new interaction paradigm, with all the underlying interaction mechanisms, has to be introduced to bridge the gap between the real and the virtual, to facilitate a transition towards transparent and intuitive interactions. In order to lessen the user's perceptual and cognitive loads, it seems appropriate to try to minimize the quantity of information presented to the user (for example using just-in-time information presentation [2]) and to "integrate" as much as possible this information in the environment (for example using augmented reality techniques [4]). So as to guide the development process of this new interaction paradigm, we

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turn to naturally occurring human behaviors and habits and try to take advantage of them.

II. Designing An Appropriate Paradigm for Human-Wearable Computer Interactions

In trying to devise a new paradigm for human-wearable computer interactions, our goal is to enhance a user's performance with respect to the real-world task that needs to be accomplished. This has to be done while minimizing the required amount of attention and avoiding splitting the user's attention between the real world and the interactions with the wearable computer [10], as it is impractical for a user to shift back and forth from the focus of his/her task to the computer support. Ideally, we strive for a seamless integration of human-wearable computer interactions into the flow of user activities.

A. Distributed cognition as a foundation

In order to obtain a better understanding of the interactions occurring in a complex world where dialoguing with a computer is not the primary task and where activities are not confined to a desk anymore, we turn to the distributed cognition theory proposed by Hutchins [5]. In contrast to the vast majority of cognition theories that assume that cognition completely resides within an individual's head, distributed cognition theory argues that cognitive work is often distributed throughout individuals and artifacts, while also trying to take into account the context (physical, social, etc.) in which the cognitive processes occur. An analysis framework larger than the individual is required to explain human behavior and, as a result, to design new human-computer interaction mechanisms.

In short, distributed cognition theory views a system as a set of representations, and tries to model the interchange (the propagation and the transformation) of information between them. These representations can either be in the mental space of the individuals or be external representations available in the environment. Any given activity can thus be described in terms of interactions between individuals and artifacts (objects, computing devices, etc.) taking part in the system in which cognition is viewed as a dynamic and emerging property instead of a static and purely mental structural manifestation.

This theory can be applied to various systems in which individuals are interacting with each other and/or their environment. For example, different studies have been performed ranging from shared memories to distributed problem resolution and decision making in various settings (ship navigation, airplane cockpit, aerial control room, etc.). More interestingly, distributed cognition can effectively be applied to conventional human-computer interactions to describe the relationships (the interactions) between the individuals (the users of a computer system) and the artifacts (widgets, peripherals and the various hardware and software components of a computer system) [3].

The key lesson that needs to be derived from distributed cognition theory is that a good portion of human cognition can naturally reside around the individuals. Since the environment plays a prominent role as a resource supporting human cognition and thus human task performance, we believe that it should also play a significant part in human-wearable computer interactions. From our point of view, distributed cognition theory tends to suggest a decentralized model for human-wearable computer interactions.

B. An ecological approach to interactions

Rationally, the more the real-world task involves physical objects, the more the interface of the computer support should be shifted into the physical world. Instead of forcing the user to interact with this support through intermediaries (conventional computer peripherals for example) or artificial spaces (graphical user interfaces for example), we believe that wearable computer functionalities should be accessible through the real world. If at all possible, a user should perceive the wearable computer interface as emanating from his/her immediate surroundings. This "ecological" approach, i.e. the use of environmental artifacts to guide human-wearable computer interactions, means that, instead of trying to adapt the real-world task to fit the traditional and widely accepted interaction capabilities of conventional computers, interactions should be designed to take advantage of natural human abilities and of the environmental characteristics and capabilities made available through the task. For example, individuals often capitalize on their immediate perception of the environment: by manipulating and exploring the surrounding artifacts they intentionally, but often spontaneously, engage in activities that will expose the information they need. Trying to exploit this naturally occurring phenomenon that draws upon the affordance of real artifacts to design human-wearable computer interaction mechanisms can be beneficial. If the affordance is strong, the individual will intuitively know how to interact with the artifact (because of acquired automatisms, of its culture, etc.) and the appropriate artifact manipulation will emerge from the interaction between the user and the environment.

We thus strongly believe that human-wearable computer interactions should be initiated and driven using environmental artifacts: *the real-world IS the interface to the wearable computer*. All the artifacts in the environment can be seen as potential entry points, anchors if you wish, of the interface and interactions with those artifacts can be seen as requests to access wearable computer functionalities. As a result, the wearable computer interface is actually diffused throughout the environment, and manifests itself through a multitude of local entities (objects, devices, persons, etc.). In this completely transformed direct manipulation paradigm, the environmental artifacts can be used to interact with the wearable computer either implicitly (through a manipulation occurring naturally during the task) or explicitly (through a dedicated manipulation artificially designed to be recognized by the computer).

To some extent, a *diffuse interface* seeks to give a physical signification to the functionalities provided by the wearable computer. It contributes to bridging the gap existing between the real and the virtual by trying to make these two spaces coincide, erasing the discontinuities between them for both perception and action.

III. Augmenting Real-World Objects : Towards A New Breed Of Tangible Interfaces

The new interaction paradigm we put forth, which pushes in the same direction as the current research on natural interfaces [1] and situated computing [7], can be seen as a form of Ishii's and Ullmer's tangible user interfaces (*TUI*) [6, 11]. Tangible interfaces try to eliminate the traditional distinction between the representations of the information to be manipulated and the controls that act as portals to facilitate this manipulation. These interfaces embody virtual information and give it a real-world presence to enable the user to explore it, process it or combine it by actually physically manipulating the information. However, as opposed to such "pure" tangible interfaces, we do no seek to actually embody virtual data but rather to embody in the environment virtual software processes that can be triggered by natural user actions.

By striving to eliminate the need for a conventional and explicit dialogue between the user and his/her wearable computer, this interaction paradigm introduces a new kind of real world objects as byproducts of the interface diffusion. Conventional objects, while retaining their usual properties and attributes, also gain new properties and attributes as they become portals to data and functionalities for users equipped with a wearable computer. Ideally, the real part of an object (its multi-sensorial and tangible aspects) and the virtual part (its dynamic and artificial aspects) should complement each other in order to emphasize ease of learning and ease of use so that the wearable computer fades away in front of the augmented object. When it happens, the wearable computer becomes only a tool enabling a user to access a new dimension of reality. By managing every aspect of the augmented objects of the environment, a wearable computer becomes a truly personal agent representing the user in the ubiquitous computing world.

IV. Sample Application

A. General architecture

In this section, we present the general software architecture we devised to support human-wearable computer interactions. This architecture is built around the fact that the user should not directly interact with his/her wearable computer but should instead focus on his/her real world tasks. To do so, the wearable computer needs to be context sensitive and must rely on real world objects closely associated with the current task to interact with the user, as explained before. Thus, it makes sense for our human-wearable computer applications to rely on two distinct classes of services: one that searches and interprets the user's environment (context sensitivity) and another that presents information to the user (object augmentation). Figure 1 illustrates the information flow during human-wearable computer interactions. On the wearable computer side, we find four major layers: 1) a sensor layer, 2) an interpretation layer, 3) an investigation layer and 4) a presentation layer. The sensor and interpretation layers, along with the presentation layer, are considered low-level services that are accessible by all the client applications running within the investigation layer.

The sensor layer, which can be composed of cameras, GPS devices, accelerometers, microphones, etc. to replace conventional input devices monopolizing the user's attention, is used as a direct, transparent input. This layer presents raw data to the interpretation layer which can be divided in two sublayers. The first one is in charge of raw data transformation. It is for example in this sublayer that speed is computed according to the accelerometer data, that a GPS position is transformed into a map location, that traditional image or sound processing occur so as to track the user's hands or to isolate objects and events. The interpreted data is then sent to the second sublayer which is in charge of identifying the user's environment and analyzing the user's task context. The second sublayer is responsible for the interpreted raw data fusion needed to generate a high-level understanding of the user's environment. Once the context has been acknowledged and tangible information isolated, clients registered within the investigation layer can search for any information they are interested in, be it a debit card with a given serial number for a banking client, a clock displaying time between 11 o'clock and noon for a meeting reminder client, etc. Depending on the information found by a client or multiple clients, the presentation layer can be invoked to relay specific data to the user. The presentation layer takes into account the relevance of the information to relay compared to the importance of the one currently presented and decides which information should be passed on to the user depending on each client's priority and on the mean used to convey it so as to prevent any overload.

In short, the architecture we devised 1) acquires sensor data, 2) interprets it to obtain a task specific context, 3) exchanges context information with registered clients, 4) lets clients react according to a high-level logic. As Figure 1 illustrates, no direct interaction takes place between the user and his/her computer: the interface is diffused in the user's environment.

B. Augmenting a debit banking card

We present here an application we developed to illustrate diffused human-wearable computer interactions and objects augmentation. The development of this application exemplifies the general architecture we proposed to implement diffuse human-wearable computer interfaces. Our application is focused toward personal banking operations and enhances conventional debit cards. Using augmented debit cards a user can access his/her current balance and could manage fund transactions between two accounts. Though this application is simple, it properly illustrates context sensitivity, objects manipulation and recognition along with information presentation relayed through the user's environment in an everyday task. It also illustrates both implicit and explicit manipulations of real-world objects.

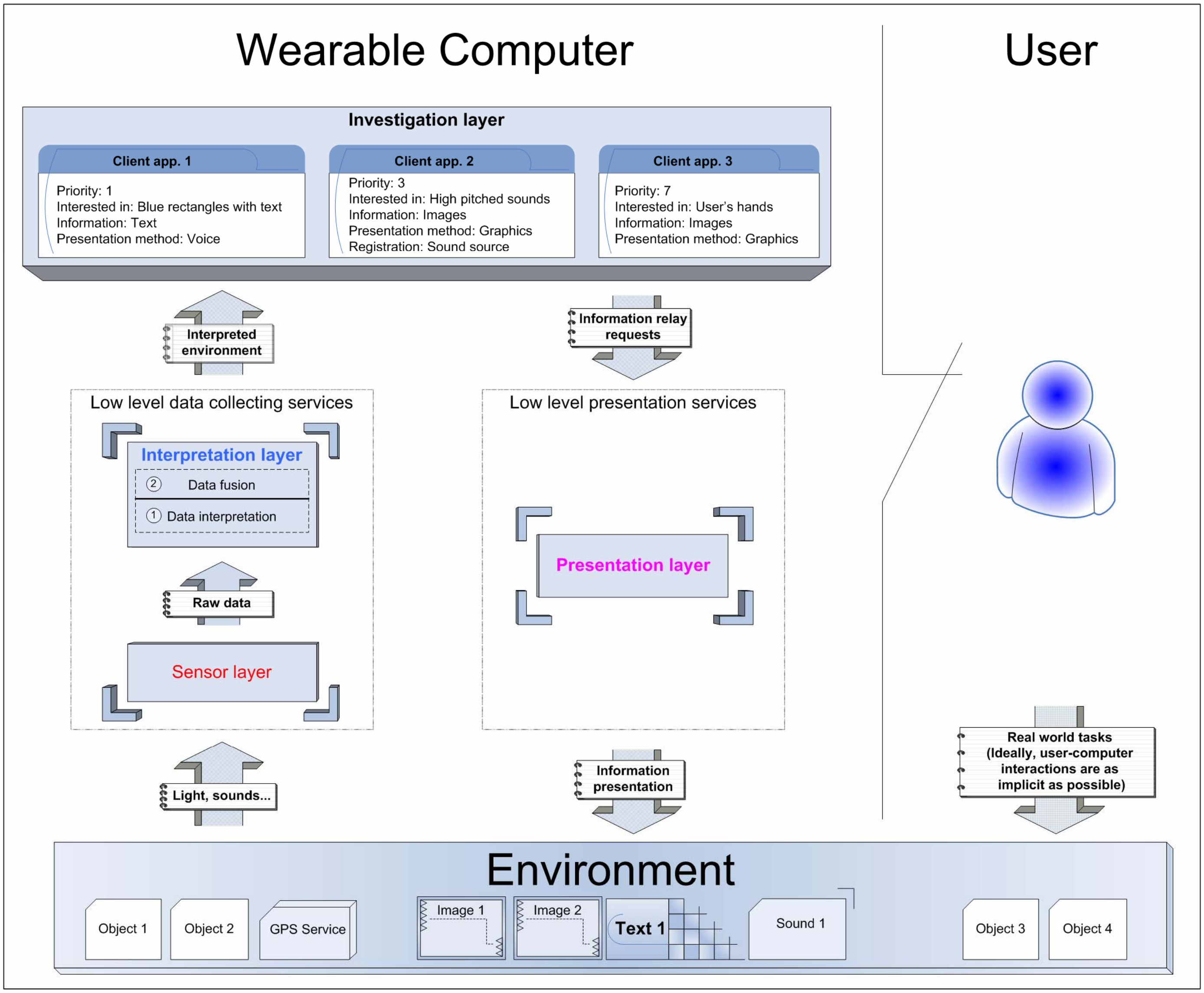

Fig. 1. General architecture for an application implementing a diffuse interface

Through this application, the user can implicitly obtain the balance of his/her account which is automatically overlaid on his/her debit card in the field when making a purchase at a local store for example. Using two debit cards, the user could also explicitly transfer funds from an account to another, not through a conventional dialogue with his/her computer but through the debit cards themselves. Compared to traditional means of accessing information and doing operations (use of an automated telling machine, explicit request to the bank server via a conventional computer, phone conversation with a banker), our application allows the user to effortlessly obtain information in the field and access his/her computer functionalities through natural interactions with his/her environment: we created a diffuse interface.

C. Implementation details

The banking application is coded in C++ and relies on Intel™ OpenCV library for image processing and computer vision. The sensor layer incorporated at first passive RFID markers to identify pre-registered objects. Though this technology is quite efficient for discerning different objects at touch distance it had two main drawbacks:

- every entity of interest needed to be altered so as to incorporate a RFID marker, which was a bit too invasive and limiting;
- a RFID reader located in the palm of a glove worn by the user was required, which hindered some of his/her movements and abilities.

Environmental data is now collected through a miniature point-of-view video camera mounted on the user's glasses, a technique which also allows for more precise information registration within the user's environment compared to passive RFID markers. For each frame, a real-time color segmentation algorithm is run within the interpretation layer along with a character recognition algorithm to detect any text within the image. The extracted shapes and text are then passed to the second sublayer which is in charge of producing a high-level understanding of the environment through data fusion. For now, the second sublayer classifies the shapes (rectangles, ellipses…) using template matching, associates any present text to the correct figures and tracks the user's hands. This information is accessible to any client applications registered within the investigation layer. As of now, only two clients are registered within this layer. The first one searches for rectangles associated with a serial number (in text format). If it finds any within the information originating from the interpretation layer, the client searches for the serial number within its own database of known debit cards. If the card is known, the client makes a secure HTTP request through the wearable computer's onboard WiFi 802.11g card and a WiFi hotspot to the bank server identified in the database. After receiving and parsing the server's HTML response, the client asks the presentation layer to relay the debit card information to the user. The presentation layer uses the debit card position to register the balance in the user's environment and this balance appears to emanate from the card itself. The second client application uses the interpretation layer to access debit cards positions and hand tracking information to detect a motion from one debit card to another. If two cards are present in the user's field of view and if such a motion is found, the client starts a transfer from one account to the other if the originating debit card is known. The funds transfer is done incrementally as long as the user's hand does not exit from the receiving debit card area. The presentation layer registers the current amount being transferred between the two accounts in the environment via a text overlay on each debit card. For now, the actual funds transfers do not actually take place for security reasons.

V. Future work

A. Testing and validation

In addition to having a few bugs to iron out of our current sample application, we definitely need to evaluate it thoroughly in order to gain insights about the viability and performance of diffuse interfaces. To find out the capabilities and limits of our new human-wearable computer interaction paradigm, both the technical and human performance will be evaluated in the task domain. We will need to assess the extent to which this paradigm can be used to accomplish representative tasks efficiently and satisfactorily. These three components will be quantified through a usability study by measuring for example the percentage of the completed sample task, the execution time, the number of user errors, his/her satisfaction and required attention level during the use of our application, etc. We're planning a test phase that will comprise two stages. First, we will focus on trying to find global usability problems using short tests (85% of major usability problems can be detected by about five subjects according to Nielsen) and ethnographic observations. After refining our interaction mechanisms, we will pursue the evaluation further using enough representative users to obtain statistically significant results. It will however be hard to make direct comparisons with existing systems since we emphasize new functionalities and usability over pure performance in a very unconventional context.

B. Learning to use new objects

The implication of the diffusion in the environment of human-wearable computer interfaces could be far reaching. For example, the introduction of "augmented" objects will surely lead us to entirely rethink in some cases the way we interact with our world. User behaviors will probably be modified, new ways to accomplish tasks will emerge and it will be necessary to develop new mental models relative to the use of these augmented objects. This is interesting because even when a diffuse interface is designed to mesh itself seamlessly with the task to support, such an interface will most likely lead to a complete reengineering of the task due to new and unforeseen ways to use the new augmented objects. It could also be important to leave the door open to creativity, experimentation and imagination as users could request more control over a diffuse interface, for example to be able to make natural, ad-hoc and dynamic object – wearable computer functionalities associations. Augmented objects could as well be at the heart of the evolution of conventional objects to better support the new virtual functionalities associated with them: affordance is in fact a bidirectional link and object properties (the real ones and now the virtual ones) will therefore influence what the users request for new generations of everyday objects.

In the end, a user will be capable of interacting with a world augmented by synthetic functionalities provided either natively by his/her wearable computer or by services coming from an environment saturated with computing capabilities and accessible through the wearable computer. It would certainly be fascinating to study the sociological impacts of the massive introduction of such capabilities, starting for example with how people shopping habits are affected by constantly being reminded their account balance at checkout.

VI. Conclusion

Much more work needs to be done in order to achieve transparent and natural human-wearable computer interactions. However, we believe that the new interaction paradigm we presented is indeed a first step. The main contribution of this paper was to propose, through an ecological approach rooted in distributed cognition theory, a new way to think about human-wearable computer interactions. For us, *real-world entities ARE the wearable computer interface*. Such a diffuse interface can intrinsically support implicit and distributed interactions, but also gives birth to augmented objects. These enriched objects give us a whole new way to interact with our surroundings, as was illustrated with the simple real-world application we developed. In our opinion the new interaction paradigm we presented has the potential 1) to help support human cognition during real world tasks; 2) to encourage and augment the natural capabilities of individuals to offload their cognition using environmental objects; and, most importantly, 3) to bridge the gap between pervasive computing and wearable computing, enabling a continuous stream of interactions between an individual and future information services scattered throughout the environment.

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