THE PENDLE: A WEARABLE MEDIATOR FOR MIXED INITIATIVE ENVIRONMENTS

N.Villar, G. Kortuem, K. Van Laerhoven and A. Schmidt[±]

Lancaster University, UK.
[±] Ludwig-Maximilians-Universität, Munich.

ABSTRACT

In this paper we propose a novel interaction model for augmented environments based on the concept of mixed initiative interaction, and describe the design of the Pendle, a gesture-based wearable device. By splitting control between user and environment, the interaction model combines the advantages of explicit, direct manipulation with the power of sensor-based proactive environments while avoiding the lack of user control and personalization usually associated with the later. The Pendle is a personalizable wearable device with the capability to recognize hand gestures. It acts as mediator between user and environment, and provides a simple, natural interface that lends itself to casual interaction. Experiences with two concrete examples, the MusicPendle and NewsPendle, demonstrate the advantages of the personalized user experience and the flexibility of the device architecture.

1. INTRODUCTION

The emergence of wearable computing devices that can be used continuously, and of augmented environments that provide rich interfaces to multimedia information, holds a potential for interesting synergies. Wearable devices have the advantage that they are personal, trusted, and instantly accessible under the exclusive control of their user, while augmented environments may offer complementary resources for interaction and localized information. It has been argued before that the integration of both facilities can give rise too many useful services that exploit the combination of personalized information with localized resources (22). A prototypical scenario is the use of environment-based screens to display personal and privacy-sensitive information held and controlled on a wearable computer or personal information server (22, 26). In this example, the initiative for interaction is allocated in the wearable, i.e. with the user. In other systems combining wearable and local resources the initiative is allocated in the environment. For example, systems that use small wearable devices such as active Pendles to identify users have been used to proactively provide personalized information in the environment (12).

In this paper we investigate wearable technology to enable mixed initiative environments. We take as point of departure proactive environments that adapt their behaviour to whoever is present at any given time (to focus our discussion, we assume a single-user perspective for most of the paper). Proactive environments currently receive considerable interest, as the research field moves forward from early demonstrations of smart rooms (20) to large initiatives investigating ambient intelligence (13). Proactive environments are fundamentally based on machine inference of user activity and context, employing sensor infrastructures and perceptual computing components. We are concerned that this focus is problematic for two reasons. First, environment-based perception of user context is inherently limited and not likely to facilitate any significant personalization unless observations can be combined with personal profiles. Such profiles though are privacy sensitive which suggests users may want to maintain them on personally controlled devices. Secondly, many scenarios of ambient intelligence appear to be unrealistic and even undesirable from a user experience perspective. They tend to assume users will want their environments to act on their behalf and that users will agree with the proactive behaviours they exhibit. However, HCI studies of adaptive interactive systems have consistently emphasized controllability as fundamental usability issue (17).

What we propose in this paper is a wearable device that serves as mediator between user and proactive environment. This device is designed to provide the user with control and influence over their environment's proactive behaviour on the basis of a simple user interface that lends itself to casual interaction. We call our device the Pendle, alluring to its realization in the form-factor of a pendant, as well as to its design as dependable in the sense that proactive environments depend on interactions with this device for provision of suitably adapted services. A Pendle may be specialised for interactions over particular types of content, e.g. music or news. Our main concern in the design of the Pendle is the interactive experience of a user in an augmented environment. We seek to provide a smooth integration of environment-controlled interaction (experienced by the user as implicit interaction, triggered by their presence) and user-controlled interaction (i.e. explicit interaction to directly manipulate the behaviour of the environment). In Section 2 we will discuss implicit vs. explicit interaction between user and environment further to motivate mixed initiative environments. The concepts on which we base our approach to mixed-initiative interaction are maintenance of user interests within the wearable, proactive behaviour implicitly triggered by these interests, and explicit interaction to modify or override the proactive behaviour (cf. Section 3). These concepts are implemented in the Pendle device which integrates wireless radio for interaction with the environment, and sensors and perception techniques for provision of an easy-to-use gesture-based user interface (cf. section 4).

Our work on the Pendle device was to a large extent motivated by the aim to facilitate new services in an augmented common room within our research lab. This environment has served as test-bed for exploring a number of usage scenarios, and we will use two of these in Section 5 to illustrate our system's interactive behaviour in the context of particular applications.

2. BACKGROUND: INTERACTION MODELS FOR AUGMENTED ENVIRONMENTS

As environments become richer in resources and services the question arises of how users can best make use of services that are available in their surroundings without being overwhelmed by the number of possible interactions. This section examines two largely opposite approaches to enabling interaction with augmented environments: environment-controlled implicit interaction and user-controlled explicit interaction. In Section 3, we propose a mixed initiative model in which a wearable device is used to mediate the interaction between the user and their environment.

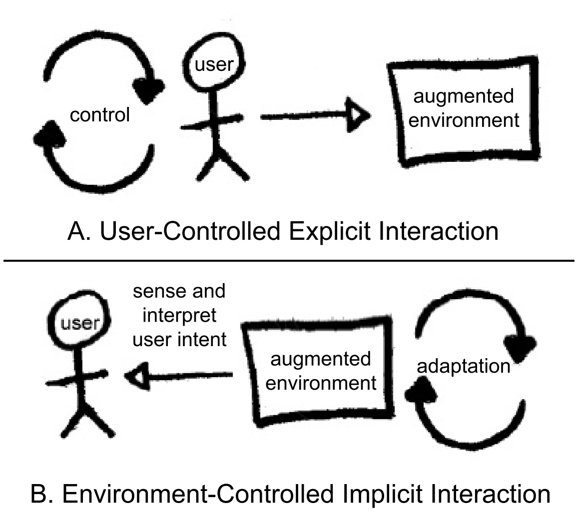

Figure 1: Interaction models for augmented environments.

2. 1 User-controlled Explicit Interaction

The most common interaction model for today's home and office environments is explicit interaction. Explicit interaction refers to a form of interaction between a user and an environment that gives direct control to the user (Figure 1a). With explicit interaction the environment is merely a passive entity waiting to execute specific, highly detailed instructions issued by the user. Explicit interaction can be realized with a variety of technologies: graphical user interfaces, command-driven speech interfaces, tangible interfaces, gesture interfaces and augmented-reality interfaces are all examples of explicit interaction. Explicit interaction is most closely related to direct manipulation (16, 23), a term coined to describe interfaces that support a sense of engagement – the feeling of direct involvement with the task at hand, rather than of communicating through an intermediary computer system. While direct manipulation is often understood to apply to visual interfaces only, we use explicit interaction to refer to an interaction model without implying a specific manifestation.

In today's environments, explicit interaction is the most common model. Interaction is usually performed by manipulation of physical control elements: lights and heating systems are operated by wall-mounted switches; sound and video systems are operated by embedded control elements or by remote control. As environments become richer in resources and services, explicit interaction leads to increasingly complex interfaces. For every new device or service introduced into an environment it is also necessary to introduce a new way to interact with it. For example, many home entertainments systems are composed of several devices (Television, digital decoder, video, stereo…) that all need direct manipulation by the user to operate. This illustrates the main problem with explicit interaction – while it performs well when interacting with a single or few devices or services it does not scale well, quickly leading to an overload in the number of direct interactions. A common approach to address this is to factor out control into a separate device, such as a universal remote control, or, as in our approach, a personal wearable device.

2.2 Environment-controlled Implicit Interaction

Explicit interaction inherently restricts users to discover information and functionality they actively look for. Augmented environments can offer added value by proactively pushing information and by offering resources of potential interest and use that otherwise might not be obtained.

The principle that underlies augmented environments is the attempt to determine the user's intentions and preferences and to adjust the environment's behaviour accordingly. As result, interaction is controlled not by the user but by the environment (Figure 1b). From a user's point of view, proactive adaptation can be seen as a form of implicit interaction: a user's mere presence in an environment or seemingly innocent actions like walking or sitting down might cause the environment's behaviour to change; the user can observe these changes but he is not necessarily aware of what triggered them and how to control them.

Environment-controlled implicit interaction is realized on the basis of sensor observation of the user's activity and context. Perceptual computing components are employed to interpret observations and to relate them to models of the user's situation. Machine inference techniques are used to link perceived user context to actual adaptation of services in the environment. It is important to understand that this process inherently involves ambiguity and uncertainty (11), while also raising significant challenges to address user concerns (10):

Uncertainty: sensor observations provide partial and limited descriptions of the world and inherently involve imprecision and inaccuracy. As a result, machine perception inevitably involves a degree of uncertainty which may become a source of erroneous inferences.

Modelling user activity: perception process match observations against higher-level models of phenomena in the real world. Unlike phenomena observed in traditional sensor applications, human activity is highly unstructured, unpredictable and impossible to fully capture in any model. As a result, inferred descriptions of user context may misrepresent the actual situation even if we were able to eliminate sensor uncertainty.

Limited personalization: unlike personal and wearable technologies, shared environments are highly problematic with respect to personalization. Environment-based observations of the user are a very limited as a source for personalization, unless they can be combined with personal profiles. The sensitive nature of person-related information dictates that environments should have no or only limited access, in agreement with the user or under their explicit control.

User acceptance: scenarios of proactive environments often appear to be unrealistic and even undesirable. That your favourite tune is played out as welcome when you enter the office may be useful to demonstrate technological opportunity yet users are unlikely to accept futures in which mundane aspects of their lives become automated. For any proactive or adaptive system it is therefore important to address issues of predictability and controllability.

In sum, proactive environments offer new services beyond those that are explicitly controlled but both technological limitations and usability concerns need to be considered carefully. One way of addressing these issues is to foresee a more active role for the user, based on the integration of implicit interaction with explicit intervention.

3. MIXED INITIATIVE INTERACTION

We propose a *mixed initiative interaction* model for augmented environments. The goal of the model is to provide a smooth integration of environment-controlled and user-controlled interaction and to combine implicit and explicit interaction. Previous work has demonstrated how this can be employed to allow users to 'have the final say' in an augmented environment (8), however our concern is to also support a stronger sense of personalization, for which we regard wearable technology as key.

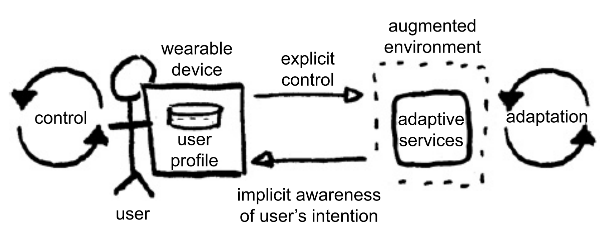

Figure 2: Our architecture for Mixed Initiative Interaction between user and augmented environment is based on smooth integration of implicit adaptation with explicit control, with a wearable device acting as mediator.

To illustrate mixed initiative interaction, we present a usage scenario for a personalized music service (we assume a Pendle wearable as shown in Figure 4 that is able to recognize hand gestures. The design of such a device is described in Section 4; a system implementing this scenario is described in Section 5.):

Nicolas walks into a departmental communal area to have his lunch. Finding the area empty, he thinks he would like to listen to some music while eating his lunch. He activates his MusicPendle wearable device by placing it around his neck. As result, the environment becomes aware of the musical preferences that he has *specified beforehand in his user profile, and a music service running in the environment selects a track which it infers Nicolas might like. As the first bars of the song play over speakers dispersed throughout the room, Nicolas recognizes it as a number currently in the charts which he hears almost daily. Thinking to himself how tired he is of hearing this particular song, he performs a particular gesture with the Dependable to signify that he does not want to listen to this track. The song fades away, replaced by another one much more to Nicolas' liking. It is unlikely that the music service ever plays that song to Nicolas again, as it remembers his displeasure with it. Having finished his lunch, Nicolas prepares to go back to work as a relatively obscure track by one of his favourite artists starts to play. "It has been ages since I last heard that. I really like it, I wish I heard it more often" he thinks to himself. As he is leaving the room, he performs a different gesture to signify that he approves of the music service's excellent choice, so that next time he is back and listens to some music this song is more likely to be played again*.

This scenario illustrates how we envision users to be engaged with proactive environments: users have control to initiate a proactive service; they can influence or override the proactive behaviour; and they can finish a session at any time. To facilitate this, our approach is based on the following key elements:

- An augmented environment that provides a set of adaptive services.
- A personalized wearable device that serves as mediator between user and proactive environment.
- A user profile maintained by the wearable device under the user's control.
- A mechanism for implicit awareness that gives the environment access to a user's profile for adaptation of its services.
- A set of explicit controls with which the user can modify or override the behaviour of the adaptive services.

Figure 2 illustrates how these components play together in an architecture that supports mixed initiative interaction. Note that in this architecture we abandon the notion of an environment derived user model and instead introduce a user profile to be stored under the control of the user on their own personal device. The structure and content of this user profile can vary from application to application. Typically it will contain a description of the user's interests and preferences with respect to a particular application domain, for instance in the form of keywords or attribute-value pairs. The services in the environment interpret the user profile as clue as to how the service they provide can be modified to best suit individual user's preferences. This has several benefits over using a user model derived from sensor data: the complexity of the entire system is drastically reduced; the imprecision introduced by deriving a user model from sensor data is removed; and personalization is achieved for free. Placing the user firmly in control of what the environment can 'sense' about them helps to allay fears about disclosure of personal information. As user profiles do not need contain information that lets the environment identify individual users (user id, names etc.) our model supports anonymity as a central principle – addressing a major concern for users who would be reluctant to reveal preferences if these could be traced back and associated with them. For the implementation of our concept, the wearable device constitutes the central component. Not only is it used to store and maintain the user profile, it also the hub for interaction between user and environment. It integrates both mechanisms for the environment to implicitly interact, and lightweight controls for the user to explicitly interact. In the following we will describe the device implementation in detail.

4. THE *PENDLE* WEARABLE DEVICE

The Pendle is a personalized, wireless, wearable device with the capability to recognize hand gestures. In our prototype we have realized it as a pendant on a ribbon that can be worn comfortably around the neck. Figure 4 shows the Pendle without its casing as it is worn by a user. The Pendle is a self-contained device of small size and weight that makes it a relatively unobtrusive item to wear; suspended from a ribbon around the neck it can be comfortably manipulated by their user while it is worn.

4.1 Interaction Modes

The Pendle is a device for interacting with services provided by an augmented environment. It supports three interaction modes:

- *Inactive*: If the device is not being worn it is inactive. In this mode no interaction takes place between the device and the environment.
- *Implicit*: In implicit mode the Pendle wirelessly transmits the user profile to the environment. This mode is in effect as long as the device is being worn by the user (unless the explicit mode becomes active). The environment uses the information contained in the profile to adapt its behaviour to suit the user.
- *Explicit*: The explicit mode is in effect whenever the user performs gestures with the device. Each

gesture represents a specific command. As soon as the Pendle recognized a gesture, it transmits the corresponding command to the environment.

The state transition diagram for the Pendle device is shown in Figure 3. Whenever the device is in implicit or explicit mode we say it is active. The perception algorithms for determining whether the Pendle is active or inactive are described in Section 4.5.

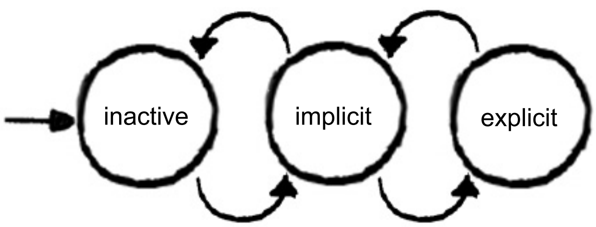

Figure 3: The Pendle device state transition diagram

4.2 Implicit Mode

The implicit mode is in effect whenever the user wears the Pendle but does not perform any gestures. It is characterized by repeated transmission of the user profile from the Pendle to the augmented environment (in our implementation every 5 seconds; obviously more efficient schemes can be foreseen but have not been the focus of our attention). As soon as the user removes the Pendle, it stops transmitting. This behaviour provides two important advantages: First, it enables users to control when the environment is able to sense their presence. Second, it ensures that power consumption is drastically reduced while the device is not being worn, thus increasing the battery lifespan. The user profile is stored as words or phrases in memory onboard the device.

4.3 Explicit Mode

The Pendle user interface is gesture-based (see Figure 4). It currently supports a repertoire of eight distinctive gestures:

- Holding up: lifting the Pendle up with the front side oriented upwards
- Turn Left: tilting the Pendle so that the front side is oriented to the left
- Turn Right: tilting the Pendle so that the front side is oriented to the right
- Turn Upside-Down: tilting the Pendle so that the front side is oriented downward
- Shake Left-Right: moving the Pendle to the left while holding up, then moving to the right
- Shake Right-Left: moving the Pendle to the right while holding up, then moving to the left
- Shake Up-Down: moving the Pendle upward while holding up, then moving back downward
- Shake Down-Up: moving the Pendle downward while holding up, then moving upward

Each of these gestures is translated by the Pendle into an application or service-specific command and transmitted to the environment. The algorithms for recognizing these gestures are described in Section 4.5.

4.4 Hardware Design

The hardware design of the Pendle is based on a Smart-Its context-aware embedded device (1) that provides four core functionalities: computation, storage, wireless communication and sensing. Storage is used for maintaining the user profile, sensors and computation are used for gesture and touch recognition, and an RF transceiver enables communication with the environment. These core functionalities are mapped onto two separate hardware modules, a base board and an add-on sensor board stacked onto the base board (Figure 4). The sensor board is specifically adapted for the Pendle with a QT110 proximity/touch sensor and a dual-axis accelerometer (ADXL311, Analog Devices Inc).

Figure 4: The Pendle hardware contains a processor, memory and radio in a small package to allow it to be comfortably worn around the neck. It also includes a touch and acceleration sensor used for gestures recognition.

4.5 Gestures Recognition Algorithm

The Pendle is fitted with a dual axis acceleration sensor that is able to sense the orientation relative to the earth's gravity field (also referred to as static acceleration) and dynamic acceleration (such as vibration). To recognize the proximity of the user, a binary touch sensor has been added as well. Being centred around a micro controller, the hardware provides limited resources for any algorithms abstracting the sensor signals to gesture commands. As the Pendle is designed to be able to work independently from its environment, algorithms cannot rely on off-board processing in the environment and therefore must be kept minimal.

Ideally, Hidden Markov Models (HMMs) (5) would be a straightforward choice and have been applied in similar research, for example (6). However, HMMs are particularly resource hungry and thus a simpler alternative was chosen, partly based on a peak-based feature extraction method as in (3). This complements a basic set of well-defined positions of the Pendle that are distinguished from the gestures and the special case of the Pendle not being worn.

Active/Inactive. Two assumptions are made in the design of the recognition process that constitute the Pendle as being worn: the position in which the Pendle is worn (when no interaction is in progress), and the proximity of the user whenever the Pendle is worn. If both tests fail, the Pendle will go in a standby mode to preserve its battery. The Pendle will otherwise be switched on at all times.

Position. For position, a minimum distance classifier utilizing the Euclidean measure was implemented on the device, based on training data, and hard-coded on the microcontroller. As the acceleration data are adequate for this method to be used without pre-processing, the device will go into 'position recognition' as soon as the running variance over a sliding window is low enough. This can be done very efficiently by keeping a running sum plus the running sum of squares of the sensor data, as the variance is proportional to: $\sum x^2 - \frac{(\sum x)^2}{n}$.

Gestures. The gesture recognition uses the area and sign of a peak in the accelerometer signals as features to detect atomic gestures that could constitute a part of a gesture. A similar technique was used in (3), although in our case the gestures were pre-defined on the microcontroller. Similar limitations apply (short time frame, the inability to track multi-dimensional atomic gestures, etc.)

5. SCENARIOS AND APPLICATIONS

To demonstrate our concept of a mixed initiative interaction, we now describe two example applications. The specification of each application consists of three parts:

- A description of the content and representation format of the user profile.
- A description of the user experience in implicit mode.
- A description of the user experience in explicit mode including the gesture and command repertoire supported by the Pendle device.

The first application is the personalized music service described in the usage scenario in Section 3; the second is a personalized news services that makes use of public displays. Each user has one personalized Pendle for each of the two applications. By picking up and wearing a Pendle, the user selects which service to interact with. It is possible to wear two Pendles at once and to use them concurrently.

5.1 MusicPendle

The MusicPendle is a wearable device for controlling the music in an augmented environment. Our current testbed environment is connected to a sound studio that controls a number of speakers that are dispersed throughout a recreation area of our department. The large number of features and components makes it difficult for ordinary people to operate it. In addition, the sound studio is physically separated from the recreation area and access is restricted to a small number of people. As consequence, non-authorized people who lounge in the recreation area are not able to operate the sound system to listen to music. To overcome this problem we explored several options that did not meet with approval: This first option was to buy a CD player for the recreation area. Although simple and cheap, this solution has the drawback that users need to bring their own (expensive) CDs to the common area where they are subject to possible abuse or theft. Furthermore, it was concluded that it would be beneficial to make use of the excellent speaker system already installed in the recreation area. The second solution we considered was to set up an endless tape in the sound studio that would continuously pipe the same music into the recreation area. This, however, did not meet with approval: it reminded potential users too much of typical airport or restaurant music. Users wanted more control over the music selection and in addition be able to adjust the volume level. Alternatively, a third option which would require users who want to listen to music to bring their own personal sound system in the form of a portable MP3 player was also rejected. Most people are not eager wearing headsets inside the recreation area because of its isolating effect. We thus set out to realize a mixed initiative interaction music system that would satisfy the following requirements:

Personalization: the system must provide listeners with a personalized music selection based on the listener's taste and preferences (as noted before, we limit our discussion to single user scenarios).

Privacy: users must not have to disclose their identity (name, user login etc.) to the system.

Control: users must be given overriding control over the system's choices.

Low distraction interface: the interaction with the service should be simple and streamlined so as to not distract from the music listening experience.

The resulting system consists of the MusicPendle wireless wearable device and service application. It facilitates the use of the existing sound equipment and enables users to listen to a wide range of music tailored to their liking with minimal (and optional) interaction on their part.

User Profile. The primary objective of the system is to play music the user wants to listen to. To achieve this goal the profile stored in the MusicPendle contains information about the user's musical taste expressed in terms of artist names, album titles and music genres. For example, the profile entry

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artist Radiohead 10;
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specifies that the band Radiohead is one of the user's favorites. The number behind the artist/band name ranges from 1 to 10 and indicates the level of like or dislike with 5 being neutral, 1 being very negative and 10 being highly positive. Table 1 shows the definition of the user profile expressed in BNF.

User Profile	<profile> ::= {<element><rating>} <element> ::= <artist>|<album>|<genre> <artist> :: = artist <string> <album> ::= album <string> <genre> ::= genre <string> <rating> ::= <integer>
Gesture and Command Repertoire	1. Shake up/down -> Volume up 2. Shake down/up -> Volume down 3. Shake left/right -> Reject track 4. Shake right/left -> Approve track

Table 1: MusicPendle Specification

Implicit Mode. To prevent the possible annoyance of having music play every time someone enters an environment, the MusicPendle is in inactive mode as long as it is not worn. The device is activated in implicit mode when as soon as the user picks it up and wears it around the neck.

In implicit mode, the service application matches a received user profile against a web based database of artists, songs and CDs that is structured hierarchically by music genre (Alternative Rock, Blues, Classical etc.). Upon receiving a user's profile, the service application identifies a suitable subtree of the genre hierarchy and selects a list of songs to play while taking into account the ratings for individual artists and songs. An alternative approach would have been to use a collaborative recommendation engine that evaluates the likes and dislikes of a community of users. However, in this experiment our focus is not on the sophistication of the recommendation algorithm but on the quality of the interaction design.

Explicit Mode. The MusicPendle supports four gestures and commands (out of a possible eight). Most importantly, the user can provide feedback about the currently playing track. A negative response, which is associated with the 'Shake left/right' gesture causes the currently playing track to stop and be replaced with a new one. At the same time, the service application sends an update message to the device indicating that the track should be marked in the profile as having a negative response, so it becomes less likely to be played again. Conversely, a positive response, associated with the 'Shake right-left' gesture will increase a tracks rating and raise its chances of getting played again.

Two additional gestures enable users to adjust the volume level: Shake up/down increases the volume while Shake down/up decreases it. The gesture and command repertoire of the MusicPendle is summarized in Table 1. The gesture and command repertoire is currently hard coded. A future version will allow users to define their own gesture repertoire as part of their profile.

5.2 NewsPendle

The NewsPendle is a wearable device that allows users to view personalized news on displays and TV monitors. Unlike a traditional remote control, the NewsPendle is not associated with a particular device, but with a service that is available in more than one location. The interaction with the service does not depend on the characteristics of the output device (TV, computer monitor, public display), but solely on the proactive behaviour of the service and its manifestation in the NewsPendle. Our testbed implementation uses large plasma screens that are located in our department's public recreation area. Similar to the MusicPendle, our objective was to make use of existing infrastructure while satisfying the requirements of personalization, privacy, user control and low distraction interface.

User Profile. The primary objective of the system is to display news the user is interested in. To achieve this goal the profile of the NewsPendle contains information about the user's interests and preferences. For example, the profile segment

```
topic "politics"; topic “technology”;
keyword “iraq” 1; keyword “election”
8;
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specifies that the user is generally interested in politics and technology, and that he wants to view news coverage on the election but not on Iraq. Again, the rating number behind the keywords ranges from 1 to 10 and indicates the level of like or dislike with 5 being neutral, 1 being very negative and 10 being highly positive. Table 2 shows the specification of the NewsPendle user profile expressed in BNF.

User Profile	<profile> ::= {<topic> <rating>} <topic> ::= topic <string> <keyword> :: = keyword <string> <rating> <rating> ::= <integer>
Gesture and Command Repertoire	1. Shake up/down -> Next story 2. Shake down/up -> Previous story 3. Shake left/right -> Reject story 4. Shake right/left -> Approve story 5. Holding up -> Next topic

Table 2: NewsPendle Specification

Implicit Mode. In implicit mode, the service matches user profiles against a continuously updated web-based collection of news stories. Upon receiving a user's profile, the service identifies the general topics of interest, collects relevant stories and filters them using the keywords. Each news item is displayed for two minutes, and then replaced with a new one.

Explicit Mode. The NewsPendle device supports five gestures and commands. Most importantly, the user can provide feedback about the currently displayed news story. A negative response, which is associated with the 'Shake left/right' gesture causes the currently displayed track to be replaced with a new one. At the same time, the service application sends an update message to the NewsPendle indicating that the keywords associated with the story should be marked in the profile as having a negative rating. Conversely, a positive response, associated with the 'Shake right-left' gesture will increase the keywords ratings. Three additional gestures enable users to explicitly control the display: Shake up/down jumps to the next story without providing feedback, while Shake down/up jumps back. The Holding up gestures selects the next topic from the user profile. The gesture and command repertoire of the NewsPendle is summarized in Table 2.

5.3 Service Infrastructure

The MusicPendle and NewsPendle devices wirelessly communicate with a distributed service infrastructure. Our current infrastructure testbed consists of an environment server, several wireless gateways, and several output devices (displays, speakers, etc.) as shown in Figure 5.

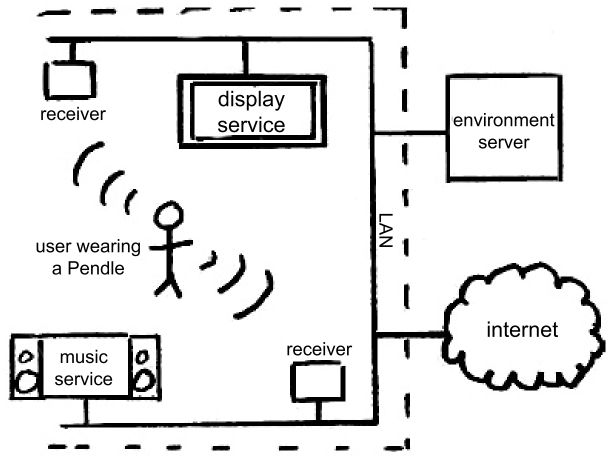

Figure 5: Testbed architecture

The wireless gateways enable communication between Pendles and services by forwarding network packages to the environment server, which hosts services. They are constructed from Smart-Its devices that are connected to a PC with LAN access. The wireless network is broadcast-based and uses a simple proprietary protocol.

6. DISCUSSION AND RELATED WORK

A core aspect of the presented research is to integrate the distinct advantages of personal wearable devices with those that augmented environments offer. The benefits of such integration have previously been discussed by Rhodes et al. who also sketched a variety of application scenarios (22). Their work highlights the distinct advantages of wearable vs. ubiquitous facilities and their combination (e.g. personalization and localization). Our work takes this forward with the focus on the interactions afforded by a combination of personal interaction devices and proactive environments. There has been further work that investigates interactions between personal devices and environment-based facilities, however generally with a focus on explicit interaction (e.g. [15] on interactive applications migrating across personal and public devices).

A different emphasis in combination of wearable and environment-based technologies for interactive services is largely explored in many ubiquitous computing projects (e.g. [22]). Here, the focus is generally on environment-based services that integrate wearable components such as Active Badges (14) for identification and localization of users, for example to allow users to summon their remote desktops to nearby displays (4).

Key to our approach is to foresee a wearable device that provides for casual interaction on the basis of an easy-to-use repertoire of hand gestures. In related work, Starner et al have proposed a wearable gesture interface, like ours in the form-factor of a pendant (24). Their Gesture Pendant is designed for explicit environment control with user-definable gestures performed in front of the pendant. Gesture recognition is based on computer vision, requiring significantly more computational resources than provided in our compact device design. Rekimoto proposed a simple gesture input technique that is based on a wrist-mounted device with acceleration sensor and sensor electrodes (21). GestureWrist can recognize several variations of gestures. However as it is designed to be always on, i.e. not foreseeing an explicit trigger mechanism, it can yield unintended recognitions. A similar approach was presented by Tsukuda and Yasumura, using a finger mounted device for gesture control (25). Finally, Brewster et al have proposed a technique for 2D gesture recognition on a wearable pad, sonically enhanced to provide feedback for eyes-free operation (7). We believe our approach affords significantly more casual interaction ('fingering a device worn around the neck') and lower cognitive load (no hands-ear coordination).

Our focus in this paper is on the use of wearable technology to facilitate mixed initiative interaction with augmented environment. We will therefore not provide a review of the state of the art in proactive environments. Reference though needs to be made to the Reactive Room project, which took a thorough HCI perspective on augmented environment concerning itself with issues of predictability and controllability (8). We would also like to mention that many projects in this area employ computer vision infrastructure for external observation of users. This raises concerns with respect to intrusion on privacy that we believe need to be carefully weighed. Examples are the EasyLiving project visually tracking users (18) and work of Darrel et al proposing face detection in augmented environments (9).

Finally, with respect to the application scenarios we have used we should note work of McCarthy et al on proactive provision of music entertainment in public environment (19). Their focus though was on negotiation of multi-user issues which we have deliberately excluded from our discussion to focus on how implicit and explicit interactions can be integrated from a single user's perspective.

7. CONCLUSION

We have presented a new interaction model for augmented environments based on the concept of mixed initiative interaction and described a personal wearable device, called the Pendle. The model provides a smooth integration of environment-controlled implicit and user-controlled explicit interaction, and it addresses important design requirements of an augmented environment, namely personalization, privacy protection, user control and low distraction interface. The Pendle is an autonomous wearable device that combines sensing, processing, storage and wireless communication. Using personal information about the user stored in a profile, a Pendle acts as mediator between user and environment and provides for casual, personalized interaction on the basis of an easy-to-use repertoire of hand gestures. Our experiences with two concrete examples, the MusicPendle and NewsPendle, have demonstrated the advantages of the personalized user experience and the flexibility of the device architecture. The gesture and command repertoires of MusicPendle and NewsPendle are currently hard coded and cannot be changed by the user. We are currently improving the personalization feature to include the gesture and command repertoire. First, we are developing embedded learning algorithms to support long-term adaptation of the user experience; second, we are investigating the physical affordance of Pendles to identify a more natural and more extensive gesture repertoire.

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