The Information Percolator: Ambient Information Display in a Decorative Object

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ABSTRACT

Most current interface designs require that the user focus their attention on them in order to be of value. However, as the price of computation falls, and computational capabilities make their way into many everyday objects, the demand for attention from many different directions may begin to seriously reduce the usefulness of these computational objects. Ambient information displays are intended to fit in a part of the interface design space that does not have this property. They are designed to convey background or context information that the user may or may not wish to attend to at any given time. Ambient Displays are designed to work primarily in the periphery of a user's awareness, moving to the center of attention only when appropriate and desirable. This paper describes a new ambient information display that is designed to give a rich medium of expression placed within an aesthetically pleasing decorative object. This display – the *Information Percolator* – is formed using air bubbles rising up tubes of water. By properly controlling the release of air, a set of pixels which scroll up the display is created. This allows a rendition of any (small, black and white) image to be displayed. The detailed design and construction of this display device will be considered, along with several applications.

Keywords: Ambient displays, aesthetics, ubiquitous computing, tangible interfaces, manipulating demand for attention.

INTRODUCTION AND MOTIVATION

Small single chip processors are now available in the $1 price range, and the processor speed and storage capacity of these devices can be expected to grow exponentially for some time. This explosion of inexpensive computational power should open many new opportunities for creating useful products. As a result, we should continue to see a significantly expanded use of computation in a range of consumer products and everyday objects.

While this ubiquitous use of computing can be expected to bring significant new benefits, at the same time it presents significant new user interface design challenges. For example, most current user interface and information display designs are based on the assumption that they are the central focus of the user's attention – that they are either being attended to, or are not being used at all. While this assumption makes sense for the desktop computing environment where there is one computer per person, it does not hold up well in a setting where many different computational devices serve each individual. We already see problems in this regard, where some people feel they cannot escape the ringing of cell phones, or the beeping of pagers. If in the (near) future a large number of devices each require, or even demand, a little bit of our attention, the benefits of inexpensive ubiquitous computing may be overwhelmed by its personal cost.

In order to mitigate this problem, work has recently begun on interfaces which need not always be the focus of the user's attention, but which can still be of value to the user – interfaces that may move smoothly from the focus of attention to the periphery of attention [11]. One form that such interfaces have taken is *ambient information displays*.

Our everyday existence is full of ambient information sources – small indications of the state of the world. Examples include information about: how many people are "around" (via ambient noise), what the weather is like outside (via ambient light), or even whether our computer is incurring a lot of page faults (via the soft clicking of our disk drive). We typically expend very little effort (or attention) absorbing and making use of this information. Nonetheless, the information is quite useful.

Computer-based ambient information displays are explicitly designed to have similar characteristics – they seek to convey background information that the user *may* wish to be aware of, and to attend to, but not *require* that

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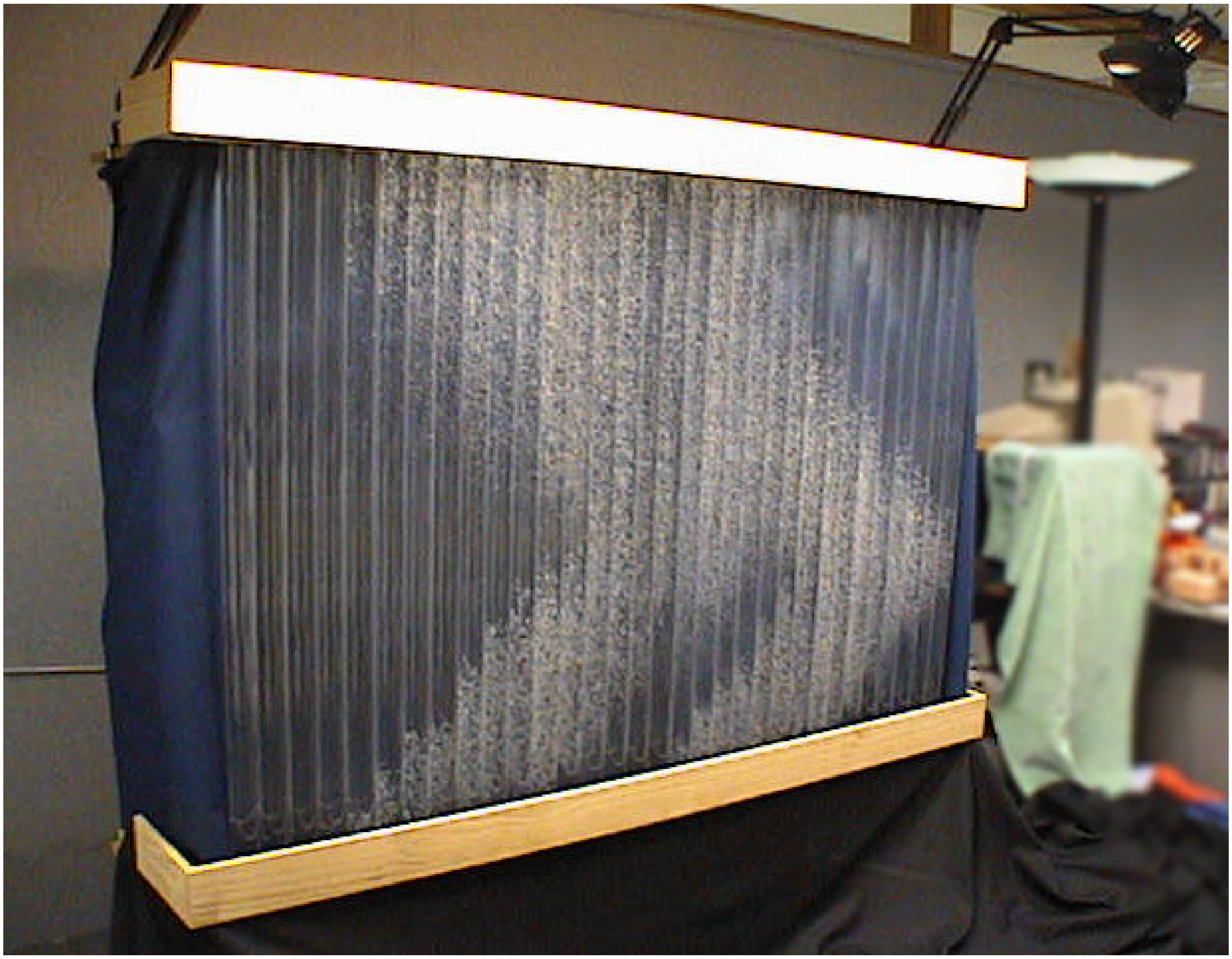

Figure 1. The Information Percolator Display (see [4] for a Video Image)

they do so. Examples of previous ambient information displays include [2,3,5,6, 12, 14].

This paper presents the *Information Percolator* – a device intended to further explore the design space of ambient information displays. Design of this device employs two important design approaches: using the vehicle of aesthetically pleasing decorative objects, and providing a rich medium of expression for the information they display.

The Information Percolator is designed both to be an ambient information display, and to be a decorative object – something that we might wish to place in a space because it is aesthetically pleasing or interesting. (To help accomplish this, the work presented here has been the result of collaboration between computer scientists – the first two authors – and an HCI researcher with a visual design background – the last author.) By starting from the point of view of creating a decorative object, it has been easier to create devices which can "fade into the background" when not being directly attended to. Further, decorative objects provide a separate intrinsic value that justifies their existence even when they convey no information at all to the user. Finally, by seeking aesthetically pleasing results from the outset, and continuously applying aesthetic criteria to design decisions, it is easier to obtain results which might gain long term user acceptance.

Of course the potential difficulty of this approach is that aesthetics includes issues of taste which are hard to evaluate, and which may vary widely from user to user. Our eventual hope is that many different kinds of decorative objects might contain ambient information displays, so that there could be something available for (nearly) any taste.

The second major design approach used in the work presented here has been to provide a rich medium of expression. Most previous ambient information displays have been designed to express a single scalar quantity, or even just a Boolean value (notable exceptions include ambient audio displays such as [6]). In contrast, the device presented here attempts to provide a form of a *pixelated* display. That is, a display that is broken into individually addressable components, which viewed together, can form an image.

By providing a pixelated display, it is possible to use the same display mechanism to portray many different kinds of

Figure 2. Early Experiments Using a Single Tube

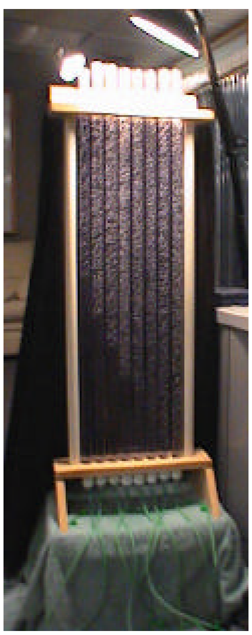

Figure 3. Initial “8-Bit” Prototype

information. In addition, it is possible to sensibly switch between information sources dynamically, and to provide more potential information from each source (for example, we can go as far as writing out actual textual messages). Finally, providing a rich and general purpose medium of expression provides more opportunity to manipulate the aesthetic aspects of the display. Overall, we believe that the much richer medium of a pixelated display offers many advantages.

In the next sections we will describe the device in more detail. Technical and aesthetic design considerations will then be considered. Finally, several applications of the device will be described.

THE INFORMATION PERCOLATOR

The Information Percolator device that is the focus of this paper is shown in Figure 1. This device consists of 32 transparent tubes filled with water, covering an area of roughly 1.4m by 1.2m (placed on a 20cm base). Inside these tubes small bursts of air bubbles are released and allowed to rise to the top of the tube. Release of air within each tube is regulated by a micro-controller as described below. By releasing air for a specific (and precise) duration, a specific size of bubble burst can be created. Each such burst can be viewed as a pixel that rises up the tube. With proper timing and coordination, a series of such air bursts across the tubes can form images which scroll from the bottom of the tubes to the top (note that the display *must* scroll and cannot be randomly accessed). Overall, the display provides 32 by approximately 25 pixels of scrolling display area.

However, the character of the display is significantly different than most pixel-based display devices. For example, the boundaries of the pixels involved tend to be fuzzy and in flux – reflecting the chaotic nature of the bubbles that create them. Further, as pixels rise through this display they disperse, spreading out along each tube, so that by the time they reach the top of the tubes they have typically “dissolved” into the pixels above and below them. This creates an aesthetically interesting effect in which the image being displayed dissolves as it rises away from its point of origin, emphasizing its ephemeral nature. Finally, a range of non-linear effects tend to make the details of the display chaotic in nature. For example, bubble speed is dependent on size – large bubbles typically rise slower than small ones (because they have more surface area). This causes smaller bubbles to catch them from below, making them larger and slower, which causes them to collect more small bubbles, etc. Overall, all these effects, while reducing the clarity of the display in the conventional sense, make it interesting to look at.

Since an important part of the aesthetics of the display is found in its dynamics, readers are encouraged to view a short video clip of the display that is available on the web at: http://www.cs.cmu.edu/~hudson/bubbles/video.html.

A conceptually related display – the Linear Rainfall fountain – is described in [8,9]. This device also uses water to create a pixelated display. However, rather than air bubbles rising in water, it employs streams of falling water. Each of many small streams of vertically dropping water can be turned on or off under computer control to form a set of falling pixels. Because of the speed of the falling water, the Linear Rainfall display tends to be faster paced making them less suitable for ambient information display.

TECHNICAL DETAILS

The Information Percolator tubes are thin (~1mm thick) polycarbonate material that was originally intended for use as a safety covers protecting fluorescent lighting tubes. Each tube is 40mm in diameter. Experimentation with an initial single tube (shown in Figure 2), then a small "8-bit" prototype (shown in Figure 3) indicated that the diameter of the tube has considerable effect on the speed of bubble rise and overall pixel characteristics. The 40mm tube size was found to work considerably better than the 25mm tubes of the "8-bit" prototype, or the 20mm tubes used in our first experiments.

As shown in Figure 4, each tube has at its base a cap with two 7mm aquarium air hoses passing through it (sealed with epoxy and attached to the tube with aquarium sealant and vinyl tape†). One hose serves as a drain and water equalization path, with all such hoses linked together along the length of the device and a drain valve at the end. The other hose in each tube is capped by an "airstone" type diffuser and provides the air supply for the tube. Previous static "bubble wall" displays sold commercially for decorative purposes (see for example [1]) do not use diffusers. However, our experimentation showed them to be clearly necessary to achieve the desired appearance of the device. (Figure 2 shows an initial experiment without a diffuser. Note the "clumping" and wide separation of bubbles in this continuous release of air.)

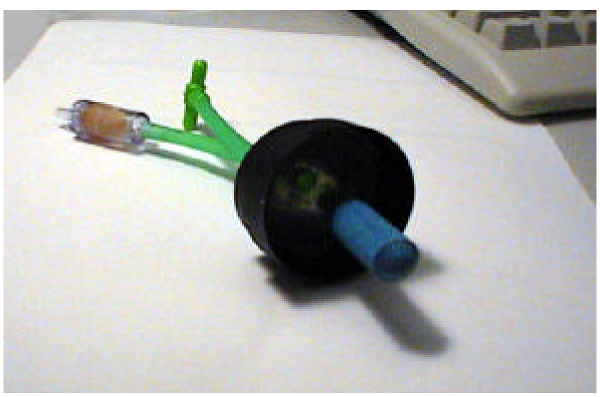

Figure 4. End Cap Assembly with Diffuser, Drain Hose, and Check Valve

In our current implementation, each air hose is connected to a separate air supply – an inexpensive aquarium air pump. A check valve and an air flow valve are placed between the air pump and the display. The check valve prevents water from flowing back into the pump when the air is off and the flow value allows us to compensate for differences in air flow between various pumps. The power for each air pump is controlled by a solid state relay, which is in turn mapped onto the bus of a small micro-controller board (each relay appears as a particular bit in the microprocessor's address space). Finally, the micro-controller is linked to a larger machine (and indirectly the network) via a serial cable. The use of individually switched air supplies in this design was primarily for expediency. In other settings it might be appropriate to provide one common air supply, with each tube's air flow being controlled by a solenoid valve. However, additional pressure regulators may be needed in such a configuration in order to maintain uniform pressure to each tube while the number of "on" tubes changes.

† Unfortunately, considerably more experimentation than expected was required to find an end-cap design that did not leak – much to the detriment of the carpeting in the authors' lab.

void open()
: Establish a connection to the bubble server and initialize the Information Percolator if necessary.

void close()
: Close a connection to the bubble server and place the Information Percolator in a reset state after pending images have been displayed.

void paint(int[] image, int millis)
: Queue an image to be displayed. The image is formed by the given array of 32 bit integers, using pixels of the given duration in milliseconds.

void reset(int state)
: Flush the pending image queue and set the display to the given continuous value (e.g., 0 for all tubes off, or 0xffffffff for all tubes on).

int remaining()
: Return the duration in milliseconds of all images currently queued for display.

void finish()
: Block until all images currently queued for display have been completed.

Figure 5. Bubble Server API

Timing of air release is accurate to a few milliseconds. However, our experiments show that timings more precise than 25-50ms are clearly not needed. In this device, a "pixel time" (*air burst duration*) of 270ms produces a roughly square (initial) pixel and has been used for most applications. Releasing air requires pushing a small quantity of water out of the diffuser and air hose, and the exact amount of that water depends on how long that tube has been "off". As a result, very short release durations (in our experience under about 50ms) do not always produce a full and consistent burst of air.

The software interface to the Information Percolator consists of a network service (the *Bubble Server*) implemented using the Java Remote Method Invocation mechanism [10]. As shown in Figure 5, the Bubble Server presents a simple API for control of the device. This API allows the device to be cleared and reset, for one or more (32 pixel) image rows of a given height/duration to be queued for display, for the requesting program to determine queue length, and for the requesting program to block until the all currently queued images have been displayed. In its simplest use, the display can be driven using simple image file. In that case the first 32 columns of any Java readable image file (e.g. GIF or JPEG files) can be displayed by applying a simple 50% threshold to obtain a pure black and white image.

AESTHETIC DETAILS

One of the critical factors in the aesthetics of the Information Percolator is the amount of visual contrast which appears between areas of clear water ("off" pixels) and areas containing a burst of bubbles ("on" pixels). As indicated above, the use of a relatively fine "airstone" type diffuser was important in creating the right look. In particular, use of a diffuser created a large number of small bubbles (see Figures 1 and 3) which shimmer and present much more contrast than the small number of large bubbles created without a diffuser (see Figure 2). Further, the larger bubbles tend to exhibit more non-linear flow effects, are slower to rise, and tend to "clump" into even larger bubbles as they move up the tube (again, see Figure 2 for an example of this visual appearance).

Figure 6. Placement of Lighting for High Contrast

Other important factors in visual contrast are lighting and background. To achieve high contrast, a dark and minimally reflective background is used along with relatively bright lighting. For the background of the device we used a length of dark blue cloth placed directly behind the tubes. Lighting is provided by a pair of incandescent lamps placed above and slightly away from the tubes and background as shown in Figure 6. The light provided by these lamps is reflected by the water-air boundaries within the rising bubbles. However, in areas of clear water, the observer sees primarily the dark background. This provides the high contrast visual appearance we were seeking.

Another important, but somewhat unexpected, aspect of the aesthetics is the sound that the device makes. The aquarium pumps used are relatively quiet, but if they come in contact with a solid object (such as a power cord, the device base, or another pump) they tend to emit a slight 60 Hz buzzing sound which is not particularly pleasing. To minimize this effect, foam rubber dampening was placed around the pumps as shown in Figure 7.

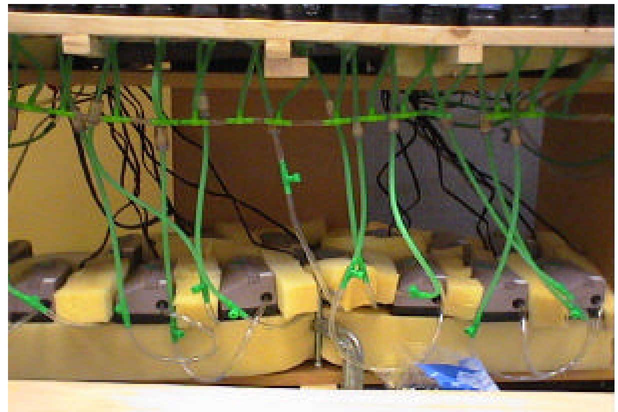

Figure 7. Sound Dampening Around Pumps

Once the noise emanating directly from the air pumps has been reduced, the remaining sound of the device comes primarily from the release of bubbles from the diffusers, and to a lesser extent from the "popping" of bubbles at the top of each tube. This sound is soft with a relatively wide distribution of frequencies, and like the sound of flowing water, tends to have a somewhat pleasing effect. (In fact, in the future we are considering placing microphones at the top of the device to capture, then amplify, the sound in order to enhance this aspect of the device's effect.)

The overall volume of sound produced by the device is roughly proportional to the number of active tubes at any given time. This means the overall activity level of the device, as well as patterns of activity over time, can be heard as well as seen. Although we did not originally consider this effect in our design, it enhances the ability of the device to operate in an ambient manner. In particular, the user does not need to look at the device to receive some forms of information. Further, explicitly manipulating the sound of the device, by for example turning all tubes on and off simultaneously in rhythmic patterns, provides a means for drawing attention to the device in a relatively subtle way when that is appropriate.

The sound of the device can, however, place additional constraints on the visual material being presented. In particular for displays that are designed to attract as little attention as possible, it is helpful to use a slowly changing total number of "on" pixels in the image over time (see for example, Figure 8 below). However, this constraint can be in conflict with the kinds of visual information that needs to be displayed. Fortunately, the overall volume, as well as the character of the sound, is such that these constraints can often be ignored.

Overall, the Information Percolator succeeds in both its goals. It is able to convey information in a very flexible (pixelated) form (although at limited resolution compared

Figure 8. An Event Signal Image and its Actual Appearance on the Display

to conventional displays), and it is aesthetically interesting – providing a pleasing object to have within a space.

APPLICATIONS

Because it is pixelated, the Information Percolator represents a new ambient display *medium*, rather than simply a single ambient display. As a result, it can support a number of different applications. We have only experimented with a few of these thus far. Because this medium is relatively rich and has some new aesthetic characteristics, we believe that considerable experimentation will be needed to tap its full potential.

To begin exploring the design space of the device, we have created four small applications: a kind of personalized clock, an activity awareness application, a poetry display, and an interactive "bubble painting" application.

The first *clock* application is designed to portray the passage of time. However, rather than being oriented towards simple continuous time, its display is structured around the events found in a particular person's electronic calendar. The application can be seen as a kind of replacement for the alarms often produced by PDAs or calendar management programs to remind people of scheduled events. However, by using the Information Percolator display, the reminders can be more subtle and less disruptive. In particular, the clock application is designed to slowly raise awareness of itself (but not disrupt the user) before the start of new scheduled events, and in some cases near the conclusions of meetings. In addition, the clock can optionally produce a display change at regular intervals (e.g., every 15 minutes) to convey the passage of time.

Figure 8 shows one of the images used for portraying an upcoming event, along with how a part of the image appears when on the device. This display is designed to build in intensity over time, but not make any large changes at any one time.

The clock application is structured to read and display simple image files. (As previously indicated, the first 32 columns of any Java readable image can be used, and a simple 50% intensity threshold is applied in order to obtain a pure black and white image.) As a result, it is simple to customize the appearance of the clock and experiment with different looks (since a visual designer can use any convenient electronic drawing tool to provide input images).

The second example application supports an awareness display. One of the primary general application areas for an ambient display is to portray contextual, or *awareness* information [7]. This can include the awareness of one's personal electronic world, such as the state of one's email, or the arrival of certain kinds of messages, as well as information about the wider world, such as the current state of the stock market. Another important category of awareness information is awareness of one's co-workers. This can be particularly important for non co-located team members because of the absence of the normal ambient cues of presence and activity that occur naturally in a shared space [13].

To explore this later area, we have constructed an application to support awareness of people's movement in a space. In particular, it displays a representation of activities along a hallway. A video camera is placed looking down the hallway as shown at the right of Figure 9. This video image is then broken into 32 rectangular regions progressing down the hall. Each of these regions is mapped to a single tube in the Information Percolator. Frame-to-frame differencing is performed within these regions. When an above threshold change occurs within a given region, air flow to that tube is turned on. The end result of this configuration is that movements down the hall are reflected by bubble trails as illustrated in Figure 9.

Our third application explores textual display. It employs a simple "random poetry" generator to create syntactically valid but nonsensical sentences from a categorized word list. These sentences are displayed one word at a time on the Information Percolator as illustrated in Figure 10. The 32 columns of the display can hold 4-5 characters of text at a time using a typical 10 point sans serif font. This limits the base vocabulary of the application, but in this case does not represent a significant stumbling block. However, it is clear that if primarily textual information displays are desired, other display technologies might be a better choice.

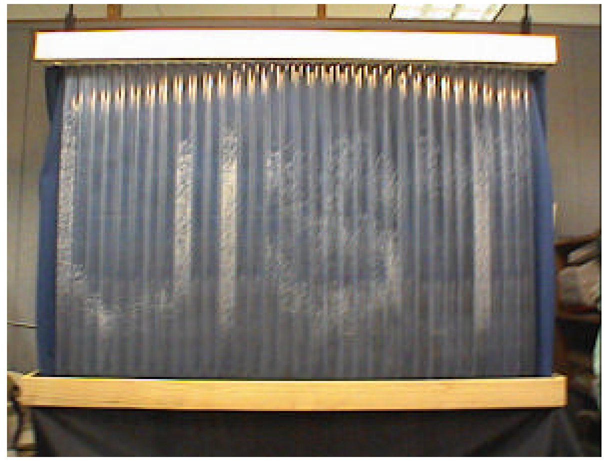

Figure 10. "UIST" Displayed by the Random Poetry Application Using a 14 Point Sans Serif Font

Our final application of the Information Percolator is not an ambient information display, but rather a participatory interactive display. This application employs the same video setup as the movement awareness application.

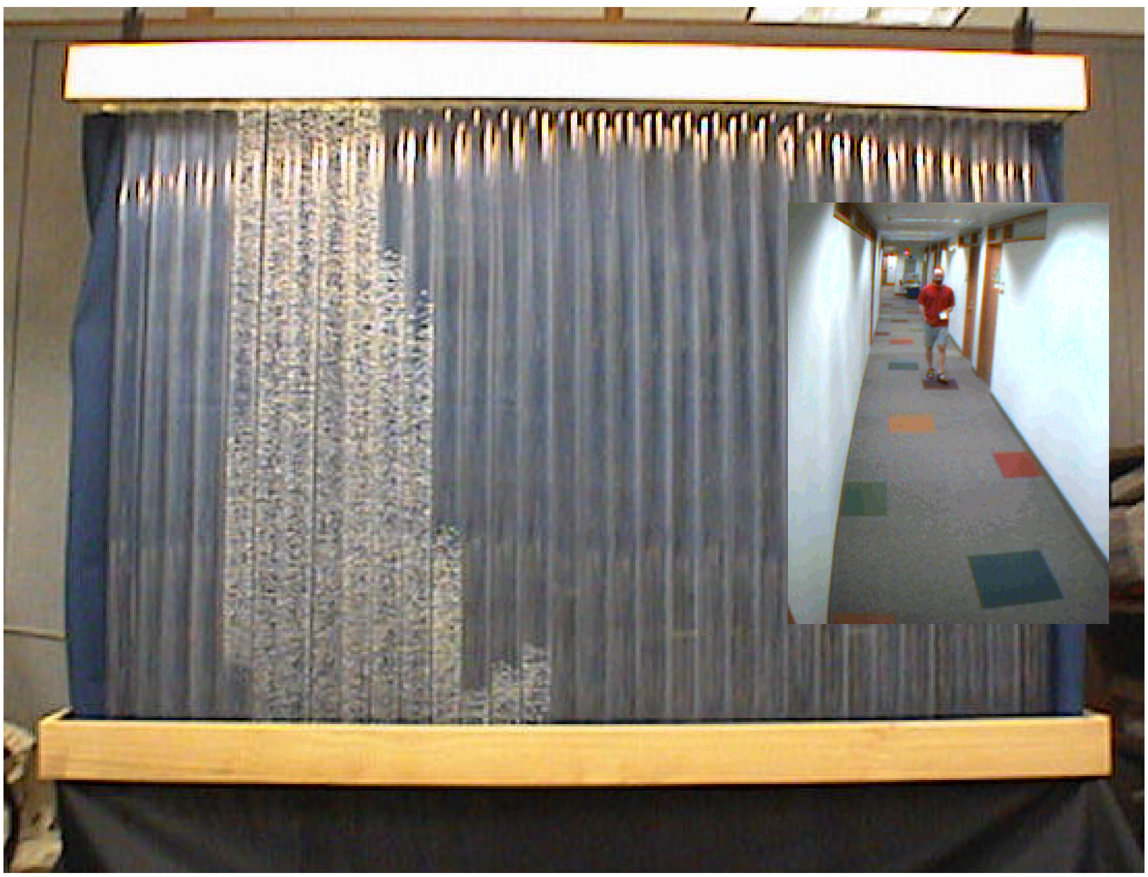

Figure 9. The Movement Awareness Application

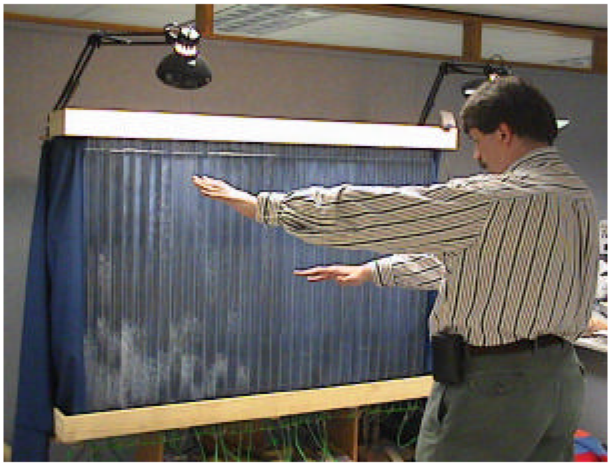

Figure 11. Interactive Display

However, it places the camera so that it focuses on the area in front of the Information Percolator itself (for example, looking down at the floor from above) with the 32 frame-to-frame difference regions aligned roughly with the corresponding display tubes along the length of the display. The result is that when people walk past the device it follows their movements with a trail of bubbles. This is intended to invite people to stop and interact with the display. When standing in front of the display the user can "paint" on the display in real time by moving back and forth in front of it, waving their arms, etc. This is illustrated by Figure 11.

Overall, these applications look at a number of different possible uses of the Information Percolator display. However, because the display is pixelated and provides a kind of blank canvas, many other applications are also possible.

CONCLUSION

In this paper, a new ambient information display device has been described along with several applications. This device makes use of the design approach of embedding an information display in an otherwise decorative object. This approach has been very helpful in improving the device's aesthetics, as well as its ability to blend into the background of one's awareness. Further, the device provides a rich medium of expression by providing a pixelated display. As a result, it is very versatile and can be used for a wide range of different applications.

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