INVITED PAPER Special Section on Human Communication I

Bottles: A Transparent Interface as a Tribute to Mark Weiser

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SUMMARY This paper first discusses the misinterpretation of the concept of "ubiquitous computing" that Mark Weiser originally proposed in 1991. Weiser's main message was not the ubiquity of computers, but the *transparency* of interface that determines users' perception of digital technologies embedded in our physical environment seamlessly. To explore Weiser's philosophy of transparency in interfaces, this paper presents the design of an interface that uses glass bottles as "containers" and "controls" for digital information. The metaphor is a perfume bottle: Instead of scent, the *bottles* have been filled with music — classical, jazz, and techno music. Opening each bottle releases the sound of a specific instrument accompanied by dynamic colored light. Physical manipulation of the bottles — opening and closing — is the primary mode of interaction for controlling their musical contents. The *bottles* illustrates Mark Weiser's vision of the *transparent* (or *invisible*) interface that weaves itself into the fabric of everyday life. The *bottles* also exploits the emotional aspects of glass bottles that are tangible and visual, and evoke the smell of perfume and the taste of exotic beverages. This paper describes the design goals of the bottle interface, the arrangement of musical content, the implementation of the wireless electromagnetic tag technology, and the feedback from users who have played with the system.

key words: *Mark Weiser, ubiquitous computing, pervasive computing, invisible computing, transparent interface, tangible interface, tangible bits, bottles, musicBottles, weather bottle*

1. Introduction

"Ubiquitous" has become a popular buzzword used by virtually every media in Japan today. Unfortunately, however, Mark Weiser's original concept of "ubiquitous computing" [19] was not well understood, and was often misused as a label for the old idea such as "anytime & anyplace computing" or as an acronym of "mobile/wireless broadband services."

This paper first discusses the core message of Weiser's "ubiquitous computing" vision based on my personal communication with him, and then presents "bottles" as a tribute to him. The *bottles* illustrates Weiser's vision of *profound technologies* that disappear by weaving themselves into the fabric of everyday life.

2. Ubiquitous

2.1 Anytime & Anyplace?

The word *ubiquitous*, meaning "omnipresent," is often interpreted as "anytime & anyplace." However, the concept of "anytime & anyplace" is nothing especially new. This term has been used since the 80's in a variety of contexts such as "groupware," "multimedia," "wireless," and "advanced information network society" long before the term *ubiquitous* was coined by Weiser. It is ironic that *ubiquitous* is used as a new label for the old idea. In the current context of IT (Information Technology) industry in Japan, *ubiquitous* implies the wireless/mobile broadband computing/communication systems and services that enable online information access and interpersonal communication without the constraints of time and place. Cell phones with internet capability is one example often cited. RF (Radio Frequency) ID tags are also often discussed as the technology that enable ubiquitous computing. However, they are not the core theme of Weiser's original vision.

2.2 Multiple Devices per User?

The term *ubiquitous* suggests that each individual user will have a large number of networked computing devices. Weiser used this as the first definition of his ubiquitous computing vision. When this word *ubiquitous* became popular, most of the computers manufacturers and communication companies jumped on this bandwagon of *ubiquitous*. They started using *ubiquitous* as a banner for the sales promotion of their gadgets suggesting that each user has to have (buy) many devices. However, the increase of the number of gadgets did not necessarily translate into the seamlessly integrated services and systems. It often results in serious issues of incompatibilities (or *seams*) among the devices and services. However, as you will see in Weiser's note in Appendix, the number of computers per person turned out not to be the essential notion of his vision.

2.3 Transparency

Mark Weiser presented his vision of ubiquitous computing in his landmark paper entitled "*The Computer for the 21st Century*" in Scientific American 1991 [19]. This paper started with the following paragraph:

> "The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it."

The above two sentences capture the most important philosophy of ubiquitous computing in the context of interface design. It is concerned with the ultimate form of the

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user interface that disappears, rather than the number and distribution of embedded computers. Unfortunately the various scale of gadgets with small, medium, and large GUI (Graphical User Interface) screens presented in his paper have not reached the level to illustrate his vision of the "disappearing computer" in a compelling manner. His prototypes inherited all the problems that current GUI devices (PCs, PDAs, cell phones) have, and could not convey his interface design vision well.

However, the biggest issue was not his prototypes, but the inadequacy of the term "ubiquitous" for his vision. He later represented his vision using the new term "calm technology" since he realized that the *ubiquity* of computers was not the most important issue (see Appendix).

The keyword: "invisible" or "transparent" should have been used instead of "ubiquitous" to illustrate his core idea. "Invisible" or "transparent" describes the ultimate state of human perception of advanced technology (ideal user interface). He himself admitted this problem of naming, and tried to use "calm technology" instead of "ubiquitous computing" to stress the ambient interface aspect [7]. However, the term *ubiquitous* had already become popular in the computer science field. It was too late for Weiser to change the name although he was deeply concerned about the gap between his vision and the connotation of the name *ubiquitous*. Mark Weiser expressed his concern to me in the following personal communication sent on January 26, 1997, after he reviewed my paper "Tangible Bits" submitted to CHI 97 conference [7]. (See Appendix for full text.)

> "I recently had a chance to read your CHI 97 paper "Tangible Bits"! Great work! In my opinion this is the kind of work that will characterize the technological landscape in the twenty-first century.
>
> I do have a request. — [snip] — My request is that you help me stop the spread of misunderstanding of ubiquitous computing based simply on its name. Ubicomp was never just about making "computers" ubiquitous. It was always, like your work, about awakening computation mediation into the environment."

When I received this message from him, I was excited about the resonance between Tangible Bits and his ubiquitous computing visions. At the same time, I agreed with him that the label of *ubiquitous* was misleading, and not the best one to capture his philosophy of transparent interface.

When he passed away in April 1999, I have decided to make my interpretation of Weiser's vision tangible through the design of "transparent interface." I co-invented the concept of *bottles* with my colleague Dr. Rich Flether, and implemented it in collaboration with many colleagues including Ali Mazalek, Jay Lee, Joanna Berzowska, Seungho Choo, Craig Wisneski, Charlie Cano, Colin Bulthaup, and Prof. Joe Paradiso at the MIT Media Lab. The *bottles* system was first presented at SIGGRAPH 99 [8], and then at ICC 2000 exhibition in Tokyo [9] followed by Ars Electronica exhibition 2001–2003 in Linz Austria [1].

3. Transparent Interface

Glass bottles have been a part of human culture for thousands of years, serving both practical and aesthetic functions. We present an interface that utilizes these glass bottles as "containers" and "controls" for digital information. This interface was designed to provide easy and aesthetically pleasing access to digital information for users who are unfamiliar or uncomfortable with current personal computers. By integrating glass bottles, a custom designed table, music, and colorful lighting, we hoped to create an engaging and aesthetic interface that could provide a rich emotional experience to users (Fig. 5).

The *bottles* project illustrates our attempt to explore the "transparency" of an interface. By "transparent" we do not mean that the user interface is something that people cannot see with their eyes. It is more a matter of the user's focus of attention and consciousness. A transparent interface (or tool) is one that does not get in the way, allowing users to concentrate on the task at hand [19].

3.1 Origin — A Weather Forecast Bottle

The idea of a bottle interface originated from the concept of a "weather forecast bottle," which I envisioned as a present for my mother. Upon opening the weather bottle, she would be greeted by the sound of singing birds if the next day's weather was forecasted to be clear. On the other hand, hearing the sound of rainfall from the bottle would indicate impending rain (Fig. 6). Such an interface would be consistent with the everyday interaction with her familiar physical environment - opening a bottle of soy sauce in the kitchen, for example. She never clicked a mouse, typed a URL, nor booted a computer in her life. But she opened and smelled bottles of soy sauce thousands of times. She knew what was contained in a bottle and how to access it.

Although we can access a variety of information sources today through the web (internet), we have to go through the process of booting a PC, starting a web browser, typing URL (or clicking a bookmark), and reading small text on a screen to choose a menu. Some people do not want to be bothered by such a process because it is irrelevant to their interests. My mother simply wanted to know the following day's weather forecast. Why should this be so complicated? That is why we started our design around ubiquitous glass bottles.

3.2 Bottles Scenario

Although the original concept of a bottle interface used a single bottle to give users access to weather forecast information, we decided to use multiple bottles in order to explore more artistic contents such as music. Given its cultural significance and wide range of emotional expressions, we felt that music would appeal to a greater number of people.

We eventually converged on the design of multiple sets of bottles that could be manipulated over specially designed table in order to activate music and lighting. Figure 5 shows snapshots of *bottles* playing different types of musical compositions with accompanying lights. We envisioned the following scenario:

We enter the Symphony Hall and take our seats. It is two minutes to curtain time. The whispers become quieter, and there is a feeling of anticipation in the air. Through the parted curtain, we can see glimpses of the violinist, as she looks through the music one last time and checks her bow. She starts tuning her instrument...

The user approaches the triangular bottles table. Three bottles sit upon the corners of the table. She picks up a bottle and places it into the circular "stage" area. A soft blue light illuminates the bottle from below. She picks up another bottle, and places it on the stage. A soft red light now shines on the stage, mixing with the blue. In placing the third bottle upon the stage, three lights representing violin, cello and piano illuminate the table.

She removes the corks from the bottles. The musical piece begins to play. The lighting changes with the movement of the music, abstractly reflecting the frequency and the volume of each instrument. Curious, she replaces the cork on the third bottle. Suddenly, the piano becomes muted and its accompanying light dims. The user continues to control the musical piece and lighting patterns by opening and closing bottles.

In the following sections, we describe the conceptual model of interaction based on physical bottles, followed by a description of our implementation of wireless magnetic tag technology to detect the presence and opening/closing of bottles. We also report the initial user feedback from SIGGRAPH 99 exhibition of our system in August 1999 [8], and discuss future directions of the bottle interface.

4. Related Work

The vision of "Ubiquitous Computing" [19] and the emerging new field of "Augmented Reality" [2], [4], [20] inspired and set a context for our work. In addition, the research on "graspable user interfaces" [5] and "tangible user interfaces" [7]–[11], [14], [15], [17], [18] directly stimulated our work on a physical interface for digital information.

4.1 Ubiquitous Computing

Our work was stimulated by Mark Weiser's vision of Ubiquitous Computing [19]. Weiser proposed that computational services could be delivered through a number of different devices, the design and location of which would be tailored to support various tasks. He stressed that the delivery of computation should be "invisible." This concept of "invisible computing" is particularly relevant to our work, although marked by important differences. The Tab/Pad/Board examples are largely characterized by exporting a GUI-style interaction metaphor to a variety of computer terminals situated in the physical environment. Our interest lies in looking towards the bounty of richly-afforded physical devices of the last few millennia (such as glass bottles) and inventing ways to re-apply these objects by augmenting them with digital technology.

4.2 Augmented Reality

Augmented Reality (AR) (or Computer-Augmented Environments) is a new research stream which tries to integrate the "real world" and computational media [2]–[4], [20]. The most common AR approach is the visual overlay of digital information onto real-world imagery with see-through head-mounted (or hand-held) display devices or direct video projections. Our approach is differentiated by a strong focus on the utilization of graspable physical objects as representation (output) and control (input) of digital information.

4.3 Graspable User Interfaces

The graspable user interface [5] proposed by Fitzmaurice, et al. allows direct control of virtual objects through physical handles called "bricks" that can be "attached" to virtual objects, making them physically graspable. Bricks encourage two-handed direct manipulation and allow parallel input specification, thereby improving the communication bandwidth with the computer. This work led us to a strong focus on graspable physical objects as a means to access and manipulate digital information.

4.4 Tangible User Interfaces

Tangible user interfaces [7] employ physical objects, surfaces, and spaces as tangible embodiments of digital information, exploiting the human senses of touch and kinesthesia. Their goal is to take advantage of the richness of multimodal human senses and skills developed through a lifetime of interaction with the physical world. Recent examples include Illuminating Clay [15], Senseboard [10], Sensetable [14], mediaBlocks [17] and Luminous Room [18].

Our *bottles* project is strongly influenced by the tangible user interface vision of exploring the interactive techniques to go beyond the currently dominant GUI (Graphical User Interface) paradigm. The uniqueness of this work in comparison with most other tangible interface work is our pursuit of a *minimal* interface for non-computer-experts based on well-understood generic physical objects — glass bottles.

5. Design Goals

One of the design challenges of transparent interfaces is to develop a clean and simple underlying conceptual model. In the *bottles* project, we looked for a conceptual model that is grounded in the physical world and can be seamlessly extended to the digital domain. Our design of the interactive technique has the following three goals.

5.1 Coherency of Interactions

When we add new digital meanings and functionality to inert physical objects, we need to maintain coherency of the conceptual model in both the physical and digital domains. To achieve coherency, we have to seamlessly extend the metaphor and built-in physical affordances of objects to the digital domain.

The underlying metaphor of bottles is the perfume bottle (or soy sauce bottle). Upon opening the bottle, one can smell the scent (or the soy sauce). Alternatively, one can say that opening the bottle causes the scent information to be "displayed." Likewise, by opening the bottles, their digital contents are released into the air in the form of sound. We hear the music by uncorking the bottles.

Mismatches of metaphor occur when digital functionality is extended beyond the real world analog. Although it is tempting to provide a variety of functionality, by choosing to implement the minimal interaction of opening and closing the bottle (to represent playing and muting audio tracks), it was possible to achieve consistency and clarity.

We also need to maintain consistency with the "physical affordances" [12] of the objects. We need to provide consistent "perceived affordances" in both physical and digital interactions. We have extended the basic affordance of bottles — to store content inside the bottles and access it through removing the cork or stopper — to the digital domain.

5.2 Direct Manipulation

The second goal is to provide a strong sense of "direct manipulation" [16] through the manipulation of real and persistent objects coupled with digital information.

GUI designers use visual representations of familiar real world objects, such as document icons. However, since those representations are purely graphical (and sometimes auditory) imitations of real things, there still exists a gap between manipulating an object on a screen and manipulating a physical object in one's hands.

By using a real bottle to access digital contents, users get a familiar tactile feedback in addition to the visual feedback. Although the bottles are used as a metaphor, they also serve as the actual mechanism that allows interaction with digital contents. Tactile feedback from grasped objects and the consistency of physical operation and digital consequence strengthen the perceived control of action.

5.3 Aesthetics

The third goal is to create emotionally engaging (or seductive) interfaces. We feel aesthetic pleasure when we touch and manipulate beautifully crafted artifacts (such as a perfume bottle). However this kind of pleasure or comfort is missing when we use a computer mouse and plastic keyboard.

The *bottles* exploits the emotional aspects of glass bottles. The interaction engages all of our senses. The bottles are *tangible* and *visual*, and also evoke the *smell* of perfume and the *taste* of exotic beverages. And they are filled with music.

6. System Design

The general bottle interfaces have three basic layers: digital contents, tangible interface using bottles, and sensing technologies, as shown graphically in Fig. 1. It was necessary to decide on the choice of digital contents that would be controlled by the interface, to converge on a proper design for the bottles and table, and to devise the appropriate sensing technology for the task. Each of these is described briefly below.

The *bottles* is an example of a bottle interface designed to play musical contents using sets of bottles. We will later discuss different types of bottle contents and different applications such as the tracking of medicine consumption with tagged bottles.

The *bottles* system consists of several sets of tagged bottles and a triangular table with a distinct circular central area. The table houses three Color Kinetics™ lights, a speaker system, a tag-reader board and an electromagnetic sensing coil embedded in the surface that detects the presence and state of bottles on the tabletop. A laptop computer controls the hardware components. Figure 2 illustrates the computational architecture of the system. Figure 7 illus-

digital contents	**music**	news	weather			
tangible interface	**bottles / table**					
technologies	**wireless tag technologies** to identify the presence and sense the states of bottles					

Fig. 1 Three layers of bottle interfaces.

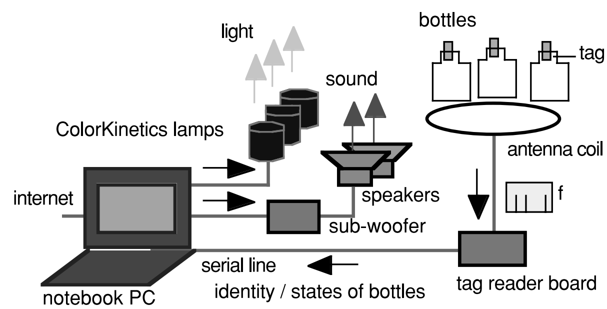


Fig. 2 System configuration of the *bottles*.

trates the hardware (table) configurations of two iterations of the system. In the following sections, we will describe the design of user interaction, digital contents (music), bottles, table, and lighting.

6.1 Basic Interaction

Unlike a graphical user interface, which is well-constrained by a program, the manipulation of objects in the physical world is much less constrained. As a result, it was necessary to identify a fundamental set of interactions that were both appropriate to the task and also compatible with the available sensor technology. With this set of interactions in mind, we set out to explore the design possibilities.

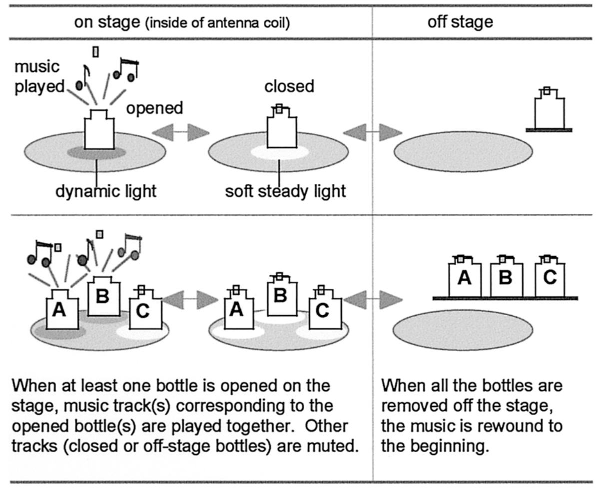
The first implementation of the *bottles* interface employed a rather literal representation, where each bottle functioned as a separate instrument in a musical trio.

The aforementioned sample scenario represents one possible set of interactions. Placing a bottle on the stage area produces a colored visual aura under the bottle as feedback that the bottle is "digitally active." If the bottle is opened while on the stage, the corresponding music track begins to play accompanied by dynamic colored lighting. Figure 3 (a) illustrates these basic transitions.

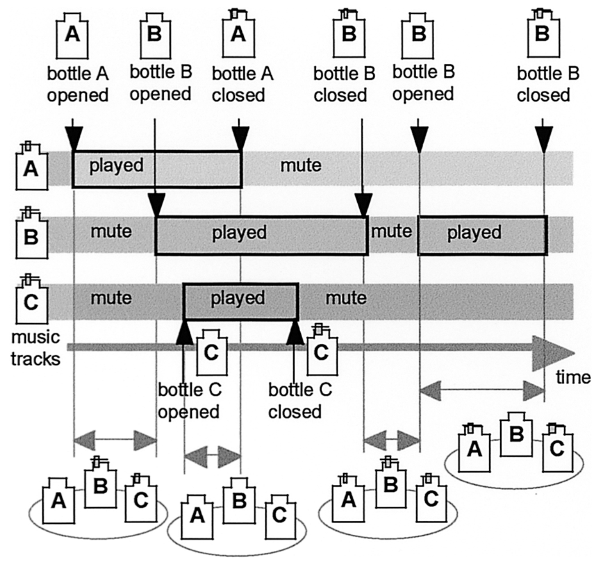
Although one might imagine numerous ways of manipulating a set of bottles, we decided to focus on two primary interactions to pursue minimal design:

1. Placing of each bottle into and out of a dedicated sensing zone ("stage") on the table.
2. Opening or closing each bottle by removing or inserting its stopper or cork.

Given this simple set of interactions, coupled with visual and audio feedback, it was possible to design a versatile interface while preserving the inherent simplicity and elegance of a glass bottle.



(a) Basic interactions.



(b) An example of interaction sequence with musical contents.

Fig. 3 Typical interaction with the *bottles*.

6.2 Musical Contents

Choosing to work with three bottles, we set out to create content where each bottle represents a singular voice in a musical piece. Unlike other types of sounds that may be asynchronous in nature — such as the sound of wind, rain, or thunder — the voices in a musical composition are usually tightly synchronized with one another. This constraint forced us to think about the structure of the musical composition itself and led us to consider a variety of ways in which the user could manipulate the information.

Our model for interaction could be represented as multiple synchronized audio streams running in parallel. The manipulation of a particular bottle would then cause a particular audio track to be played, muted, or switched to another audio track altogether. The simple case of three parallel audio tracks is shown schematically in Fig. 3 (b).

6.2.1 Classical Music

The first set of contents for *bottles* consisted of the first movement of Edouard Lalo's Piano Trio in C Minor, Op. 7. Three separate instrument tracks were captured from a live recording and later digitized. While this musical content served to demonstrate the concept of the bottle interface, it had a slight disadvantage due to the fact that the three instruments were not always playing. For example, if the user happened to open the "violin bottle" during a time when the violin was silent, the user would hear nothing upon opening the bottle. Nonetheless, through a change in the lighting pattern, it was still possible to provide the user with an immediate indication of a change of state.

6.2.2 Techno Music

In the interest of creating musical content to match our given interaction design, we commissioned a simple electronic music composition. In this case, each of the three audio streams (synthesizer, bass, and rhythm track) played contin-

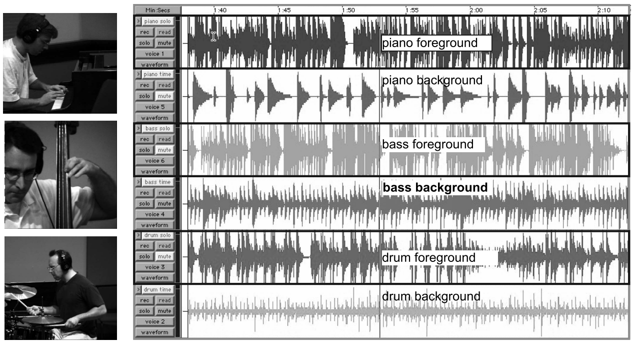


Fig. 4 Jazz music tracks. (example)

uously, and could be individually muted.

The abstract nature of the electronic music composition was quite interesting because it allowed the user to "create" a customized version of the music through the manipulation of the bottle interface. This was reminiscent of the way that a techno DJ in a dance club would use two turntables to mix audio tracks from two separate vinyl recordings playing simultaneously. Actually, we observed improvisational interaction by the visitors at the public exhibitions, which we will describe later.

6.2.3 Jazz Music

Our experience with the classical music and techno music contents led us to explore the relationship between a musical composition and the interface for playing back the composition.

Instead of using the bottles as simple switches to mute or play a particular audio track, we decided to go one step further and explore how the manipulation of bottles could be used to alter the *style* of playback. In this case, placing the "piano" bottle in the sensing zone would immediately produce the sound in the style of Count Basie, but if the bottle is then uncorked, the style would transition to the free embellished style of Art Tatum.

In order to implement this concept and stress the multifaceted nature of digital information, we commissioned an original arrangement of the jazz standard, "All the things you are" by Jerome Kern and Oscar Hammerstein. Instead of recording three live audio tracks (one for each instrument), we recorded two distinct tracks for each instrument producing a total of six synchronized audio streams. Figure 4 shows an example of jazz music tracks. From the user's perspective, a closed bottle would trigger a minimal style, whereas opening the bottle would cause a more embellished style indicative of a jazz solo.

6.3 Table Design

The pedestal for the various sets of music bottles is a custom designed table 40″ tall and 25″ across (Fig. 7). The first generation table was laser-cut from black acrylic, with a disk of lighter semi-translucent acrylic delineating the central "stage" area where the bottles were sensed electromagnetically. The stage area also acted as a rear-projection surface for the display of dynamic light compositions that accompany the music.

The design of the second table introduced rich, luxurious materials and improved the structural robustness for public exhibition. The legs were solid aluminum with shelves cut from thick mahogany wood. The stage was composed of a layer of frosted glass over a layer of tinted Plexiglas, to produce a more cloudy, diffuse surface for the projection of colored light.

6.4 Bottle Design

We assembled several trios of bottles to represent the three instruments or tracks in each musical composition (Fig. 8). For each trio, the bottles need to represent the style of music (whether classical, jazz or techno). Each bottle needed to look unique yet similar enough to appear visually cohesive. It was quite a challenge to find such sets of bottles. In some cases, we opted to use identical looking bottles and to differentiate them using distinct ribbon colors (e.g. techno music bottles).

The classical piece demanded bottles that could elegantly represent the clearly distinct instruments. We designed three abstract shapes: the cello was short and fat, the violin thin and tall and the piano had a flask shape. The bottles were crafted by a glass blower and then sandblasted to better scatter the light coming from beneath the table.

6.5 Lighting Design

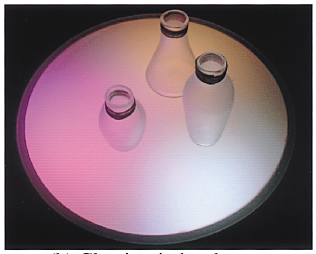
Visual feedback to the user is provided by three Color Kinetics™ digitally-controlled lamps illuminating the three corners of the stage from below. The design of the accompanying dynamic light patterns (essentially a mapping of sound to color) remains an open design question. Our first approach used digital signal processing techniques to dynamically map the light color to the pitch and volume of the musical tracks in real-time. This approach, however, did not produce a sufficiently aesthetic result for all styles of music, so it was abandoned for a manual alternative.

The most aesthetically pleasing result was achieved by treating the lighting information as a visual stream that is played in parallel with the accompanying audio stream. To create our streaming color files, we constructed a graphical interface that allows continuous color selection in real time and records a stream of HSV values to a file synchronized in time with the musical track. This more instinctive approach allows a more intuitive mapping of musical changes to dynamic color which naturally reflected the emotional changes in the music.

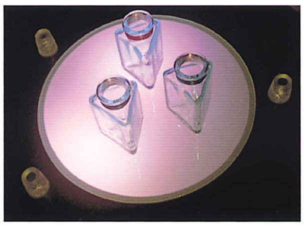
7. Sensing Technology

The *bottles* interface incorporates wireless sensing technology to allow control of digital information via the ma-

(a) Jazz trio bottles: Piano, base, and drums



(b) Classic trio bottles: cello, violin, and piano

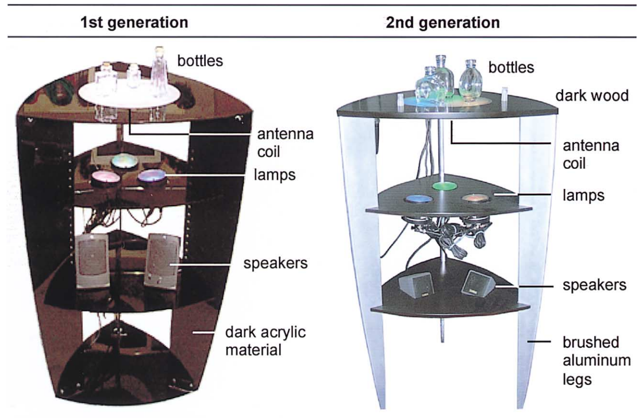


(c) Techno trio bottles

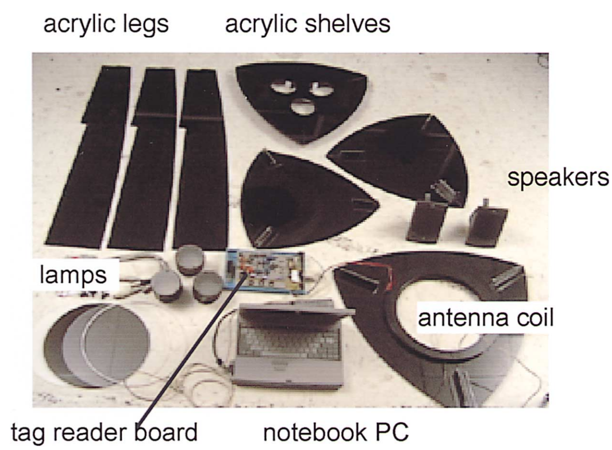
(d) Old classic trio bottles (1st generation)

Fig. 5 musicBottles sampler.

Fig. 6 A weather bottle that contains the weather forecast of Sapporo-city.



(1) Parts of 1st generation table.



(2) Parts of 2nd generation table.

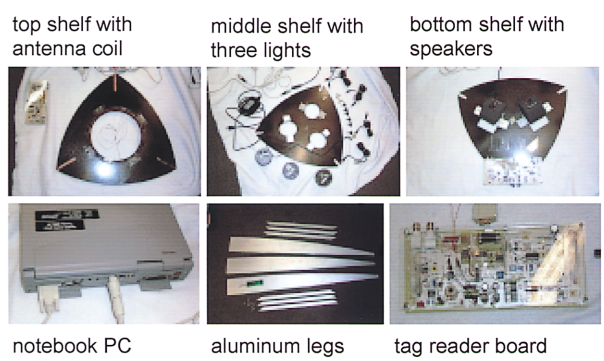


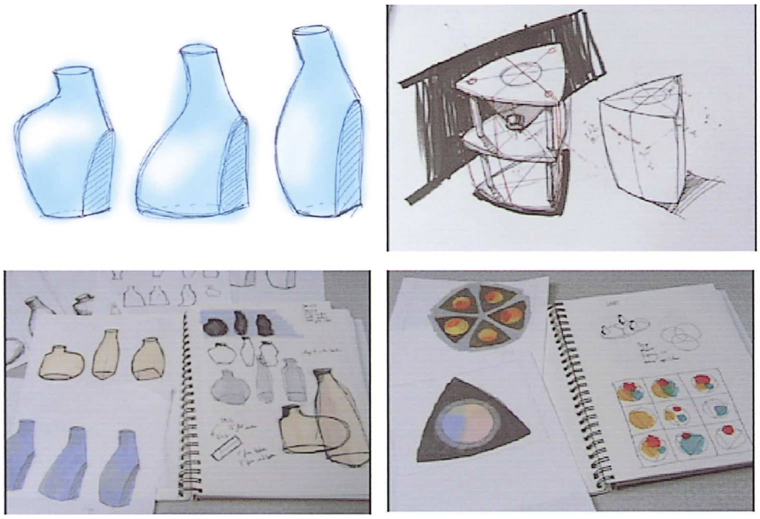
Fig. 7 Table configurations of the *bottles* system.

nipulation of untethered physical objects. The first generation of wireless sensing technology was developed by Dr. Rich Fletcher, and the second generation was developed by Prof. Joe Paradiso [13] at the MIT Media Lab. The electromagnetic detection does not require the use of radio transmitters or batteries in the objects. Although computer vision is a popular approach for sensing the manipulation of objects, we chose to use electromagnetic tagging since vision-based systems are still often slow and fragile, becoming confused by changes in lighting or dynamic optical clutter.

Figure 9 summarizes the two generations of sensing technologies developed and used in the *bottles* project.

7.1 Embedded Tags

Sensing the manipulation of the bottles is made possible through the use of small electromagnetic tags embedded in the bottles. Unlike Radio-Frequency Identification (RFID) tags, which employ a tiny silicon chip, these tags make use of smart material structures to produce an electromagnetic signal that changes in response to manipulation [6]. This class of electromagnetic tags, for which we have coined the



(a) Design sketches of bottles, tables, and light patterns.

(b) A variety of bottles we considered for the musicBottles project.

Fig. 8 Design of *bottles* components.

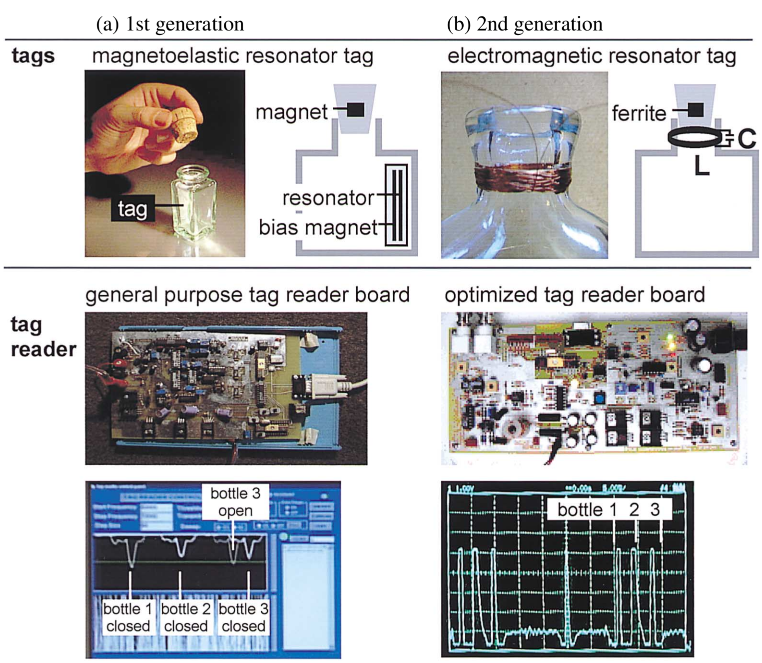


Fig. 9 Wireless sensing technologies.

term "sensing tags," can be treated as a new form of low-cost, wireless, tactile controllers. This enables new forms of interactive techniques based on the manipulation of physical objects.

The primary design goal for the tags was to achieve a detection range of at least eight inches above the surface.

In addition, since we decided that the digital identity of the object should be associated with the bottle and not with the cork, it was important that the corks be interchangeable and indistinguishable. This permits the user to manipulate the bottles freely without needing to remember which cork goes with which bottle.

7.2 Magnetoelastic Resonator Tag

Two types of electromagnetic tags were investigated for this system and are shown in Fig. 9. Early versions of the musicBottle system made use of a magnetoelastic resonator tag in the bottle and a permanent magnet embedded in the cork. The magnetoelastic resonator consisted of a 4 cm long amorphous metal ribbon with composition $Fe_{35}Ni_{33}Co_{19}B_8Si_5$ which had a resonant frequency in the range 60 KHz–70 KHz. Since the electromagnetic resonant frequency is predominantly a function of the ribbon length, the tag in each bottle could be tuned to a unique frequency simply by trimming each ribbon to a different length. In addition, the magnetostrictive properties of the metal ribbon provided a means to alter the resonant frequency of the tag simply by changing the proximity of magnet embedded in the cork.

Although the magnetoelastic resonator was an effective means of detecting the opening and closing of the bottles, the resonant frequency of the tag was susceptible to mechanical shock and vibration. As a result, the signals produced by these tags did not have sufficient long-term stability for a robust implementation of the system.

7.3 Electromagnetic Resonator Tag

The second tag technology we investigated was an electromagnetic resonator comprised of a wire inductance coil in parallel with a film capacitor. In this case, the resonant frequency of the tag is simply a function of the inductance of the coil and the value of the capacitance. By placing the electromagnetic tag near the opening of the bottle, it was possible to sense the opening and closing of the bottle by loading the cork with a ferrite material. As the cork is placed inside the mouth of the bottle, the high magnetic permeability of the ferrite increases the inductance of the coil that in turn lowers the resonant frequency of the tag.

7.4 The Tag Reader

The resonant frequencies of the various tags embedded in the bottles were detected through the use of a custom designed tag reader. In contrast to commercial tag readers that are made to detect chip-based RFID tags, the tag readers used for this project were designed to analyze the resonant frequency of objects in the vicinity of the sensing antenna. Since the identity and state of the tags is encoded in the frequency domain, the data can be collected much more quickly than commercial RFID tags which rely on time-domain modulation for data transmission. In addition, use of the frequency domain enables several dozen tags to be detected simultaneously, which is not possible with commercial RFID systems.

The first prototype of the musicBottle system used a custom multi-purpose tag reader designed to analyze the electromagnetic properties of material structures (Fig. 9 (A)). Although this tag reader collected detailed spectral information useful for investigating different tag technologies, its update rate was only a few Hz, which was insufficient for performing smooth real-time tracking of object manipulation. For this reason, an alternative tag reader design was adopted.

For the purpose of real-time tracking, a swept-frequency tag reader was designed [13] to be optimized for speed (Fig. 9 (B)) with an update rate of 30 Hz. This tag reader is based on an inductive bridge circuit, consisting of a 11.5 inch diameter sense coil balanced against a set of reference inductors. The bridge excitation is a 20-volt sinusoid, sweeping linearly from 40 to 400 kHz at a 30 Hz repetition. The bridge imbalance is synchronously demodulated and low-pass filtered to attenuate noise background. A high-pass filter then enhances abrupt changes in the bridge's null, caused by current drawn by the search coil when a tag resonance is excited. The entire frequency sweep is monitored by a PIC 16C73 microcontroller that logs the center frequency, width, and integrated height (e.g., proximity or coupling strength) of each detected peak and transmits the information to a host PC through a serial connection after each sweep.

7.5 Software Interface

Data from the tag readers is fed via the serial port to a master control program running on a 266 MHz Pentium-class laptop. This program was responsible for interpreting the tag reader data produced by the user manipulation of the bottles and generating the appropriate sound and light files.

8. Software Design

The software was divided into three main modules: the serial communications between the computer and the tag board, a state transition module, and the audio/visual controls. All software was written in Visual C++ and executed in Windows 95. At the heart of the *bottles* system is the state transition module, which responds to user interaction. Three bottle states are currently identified: 1) the bottle is present and open, 2) the bottle is present and closed, and 3) the bottle is not present. The state transition module determines what should happen in each state, and calls functions provided by the A/V and serial modules. This modularity provides a central location to easily adjust and modify the system for future installations.

The serial communication module deals with buffering and parsing the data stream from the tag board and determining the identity of any bottle present from that information. A separate software tool was written to handle calibration of bottle identities (based on the resonant frequency of their tags). The audio/visual module abstracts the hardware control of the lights and sound, and ensures synchronicity between the audio and light file information. Audio files are stored as PCM WAV files, and buffered to ensure clean playback. We found that the hard drive access time limited the number of audio tracks that could be simultaneously opened and buffered, but three-piece musical trios worked well.

9. User Feedback

The second-generation *bottles* system was demonstrated at the SIGGRAPH 1999 Emerging Technologies in August 1999 [8], and then ICC exhibition in Summer 2000 in Tokyo [9], followed by Ars Electronica exhibition since September 2001 till present in Linz, Austria [1]. At SIGGRAPH 1999, more than two thousand visitors interacted with the installation. Although we did not conduct controlled experiments, we were able to observe a variety of users and receive their feedback. This helped us understand the strengths and issues of the current system design, and observe users' responses to the bottle interface. Summarized below are our observations and findings.

9.1 Bottle Metaphor

Users quickly understood the bottle interface with little or no instruction. Although the sound was obviously generated by our speakers, many people raised the bottles to their ears to see if the sound was literally coming from the bottle. In many cases, they were disappointed to learn the audio was coming from speakers instead. Unfortunately, the exhibition space at the conference was noisy, and we had to add large professional speakers that did not fit underneath the table. As a consequence, the sound source could not be projected directly under the bottles. The use of sophisticated spatial audio technology to steer the sound in the direction of the bottles would be an interesting future direction to create the illusion that sound was coming directly from the bottles.

Most users attempted to cover the bottle with their hand rather than corking it to stop the music. This interaction is consistent with the concept of bottles and contents, and therefore caused some confusion when it didn't work. Other users wanted the music to gradually get louder as the cap was slowly removed from the bottle, rather than just quickly switching from completely off to completely on. Since proximity of each cork to a given bottle is sensed by our tag reader, this addition would be not be difficult to implement.

It was interesting to observe the various gestures people made once understanding the bottle metaphor. A number of users tried shaking the bottles to see if the sound would change. This action could potentially be an interesting interaction to gauge the amount or type of digital contents in the bottles, assuming we could develop a meaningful sound feedback. Some visitors tried pouring the contents of one bottle into another as a means of "mixing" the digital contents of one bottle with another.

9.2 User Questions and Interactions

The magical nature of the *bottles*' interface evoked users' curiosity. As a result, the most common questions concerned the underlying technologies of the system. Many users experimented with the system and tried testing its limitations. Before we explained how it worked, users went through a series of experiments trying to figure it out. Many visitors initially believed computer vision was involved. A common misconception was that the Color Kinetics™ lamps were identifying the bottles from underneath based on shape. Others looked overhead to see if a camera was present.

Although we designed the system to be used with only one set of bottles at a time (e.g. jazz), we were surprised to see that most people attempted to combine bottles from different types of music.

It was interesting to note how the different musical trios lent themselves to different kinds of user interactions. With the techno trio, many tried to play along with the music by opening and closing the bottles in time with the music to create their own musical patterns. Several people mentioned that this interaction allowed them to improvise the music as a DJ does by manipulating multiple turntables. This improvisational interaction was not observed with either the classical piece or the jazz piece, perhaps due to the more complex flow of melody within the jazz and classical compositions.

The overall reaction of visitors was enthusiastic and very emotional. Many of them pointed out the aesthetics of the design and the poetic and magical nature of the bottle interactions as contributing factors to their enjoyment. We also noticed that many people repeatedly visited the installation, and often brought friends. This positive response speaks highly of the appeal and enjoyment that the *bottles* installation provided.

10. Discussions

10.1 Accessing, Browsing, and Controlling

At the outset of this project, our intention was simply to create an intuitive means of accessing digital information. However, in exploring the relationship between the user interface and the digital contents, it was interesting to see how the nature of the information changed as the user was given more degrees of control.

In opening a single bottle, such as the "weather forecast bottle," the user is simply accessing an information broadcast. But as we consider multiple streams of information and synchronized streams of information with multiple parameters, the experience of accessing information is transformed to one of browsing — or perhaps even controlling — the nature and flow of the information itself.

In the case of music, the composer and the musicians control the way the information is presented to a passive listener. In a performance, the pauses between the notes are just as important as the notes themselves, and the manner in which the various instruments in a performance go back and forth between foreground/background, melody/harmony, and tension/release provides the music with expressive richness. The simple *bottles* interface can give users a certain level of control over some of these parameters, allowing them to create their own customized information (music) through improvisation with the bottles.

10.2 Nature of the Bottle Interface and New Applications

The *bottles* are empty and unfettered by wires. The tags are well integrated into the physical form of the bottles and are masked by a ribbon around the neck. The interaction with the system is reminiscent of our everyday interactions with regular bottles. Reflecting on the feedback from a public exhibition, we believe that the juxtaposition of a well known physical interface (the bottle) and the unexpected contents (musical composition) contributes to the surprising, compelling and magical nature of this interface.

The *bottles* interface would probably be useless to a professional recording engineer, skilled in the use of an audio mixing board or modern-day computer interfaces. The bottle interface based on simple operations of opening and closing would be too restrictive to support a variety of functions for the experts. However, this constraint can be an advantage for making an interface simple and providing additional values like aesthetic pleasure and emotional richness. Perfume bottles filled with sweet melodies could be delightful for the people who seek emotional value in products. Wine bottles filled with romantic poems, and whisky bottles filled with stories of small villages where they were distilled could enrich the conversation in a social setting such as a party or a restaurant. The genieBottles project [11] demonstrates such an example application of *bottles* for story telling.

Although the *bottles* was perceived as an artistic installation, we see some practical applications that go beyond aesthetic pleasure. One application involves medicine bottles. Augmented medicine bottles in a special medicine chest could track a patient's medicine taking patterns, and remind them of prescriptions and medications they happen to forget. The record of the medications they have taken could also be sent to their medical doctors before a treatment.

11. Future Work and Conclusions

In the future, we would like to explore a variety of different physical interactions in addition to simple opening and closing of the bottles. After having observed the visitors at an exhibition, we became particularly interested in examining how the interface could be made to accommodate interactions such as shaking and pouring.

In addition to incorporating such new methods of interaction, we would also like to explore different digital contents to develop new more pragmatic applications, such as medicine bottles, for solving deep real world problem through the transparent interface.

I believe that the current "ubiquitous GUI" paradigm based on a variety of general purpose GUI devices (e.g. notebook computers, PDAs, and cell phones) is not the future that Mark Weiser envisioned. Real transparency of interface can never be achieved by the set of generic GUI devices.

The tangible interface demonstrated in *bottles* suggests an alternative path for making interface transparent by seamlessly coupling well-understood physical world with new digital world. The extension of physical affordnaces and the metaphors of objects to digital domain seems to be the key principle for designing a transparent interface. The aesthetics of physical objects can also enrich the digital experience and make it emotionally evocative. Mark Weiser wrote; *"The most profound technologies are those that disappear."* We hope this bottle interface becomes a good example of his vision of "transparent computing."

Acknowledgments

First of all, I would like to thank Dr. Mark Weiser who inspired our research on Tangible Bits and the notion of "transparent interface." Especially I appreciate his remark on my paper submitted to CHI 97 [7] (Appendix) and the discussion at Ars Electronica Festival 1997 in Linz, Austria that stimulated my thinking.

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Appendix

Date: Sun, 26 Jan 1997 23:34:10 PST
To: ishii@media.mit.edu, ullmer@media.mit.edu
From: Mark Weiser <weiser@xerox.com>
Subject: "Tangible Bits"

Dear Hiroshi and Brygg,

I recently had a chance to read your CHI 97 paper "Tangible Bits"! Great work! In my opinion this is the kind of work that will characterize the technological landscape in the twenty-first century.

I do have a request. As a former professor with tenure I well understand the need to distinguish one's work from all that comes before. And I very much appreciate your kind acknowledgement to me. Thanks!
My request is that you help me stop the spread of misunderstanding of ubiquitous computing based simply on its name. Ubicomp was never just about making "computers" ubiquitous. It was always, like your work, about awakening computation mediation into the environment. ..... [snip] .....

I tried to stop using ubiquitous computing because of its misleading implication, but it keeps cropping up again, so I keep returning to it as my umbrella name for lots of work, including Things That Think. Augmented reality was in use for awhile, but again got balkanized in meaning. I have started to talk about Calm Technology as a theme, but it better names a goal than a research project. "Tangible Bits" is very nice, and maybe could serve as an overall umbrella, but then you might lose it as the name of your research project! I think we would all benefit if we could have an allegiance to some one common thing, and define our differences within that. But we struggle with what to call that allegiance.

Anyway, great work, and I hope to visit soon and have some good chats. ..... [snip] .....

-mark
(Dr.) Mark Weiser
Chief Technologist, Xerox PARC

Hiroshi Ishii is a tenured Associate Professor of Media Arts and Sciences, at the MIT Media Lab. He co-directs Things That Think (TTT) consortium and directs Tangible Media Group. Hiroshi Ishii's research focuses upon the design of seamless interfaces between humans, digital information, and the physical environment. At the MIT Media Lab, he founded and directs the Tangible Media Group pursuing a new vision of Human Computer Interaction (HCI): "Tangible Bits." Ishii is active in the research fields of Human-Computer Interaction (ACM SIGCHI, SIGGRAPH), Media Arts (ICC, Ars Electroinca), and Design (IDSA, ICSID). Prior to MIT, from 1988–1994, he led a CSCW research group at the NTT Human Interface Laboratories, where his team invented TeamWorkStation and ClearBoard. In 1993 and 1994, he was a visiting assistant professor at the University of Toronto, Canada. He received B.E. degree in electronic engineering, M.E. and Ph.D. degrees in computer engineering from Hokkaido University, Japan, in 1978, 1980 and 1992, respectively.