Interactive Textbook and Interactive Venn Diagram: Natural and Intuitive Interfaces on Augmented Desk System

Hideki Koike† **Yoichi Sato‡** **Yoshinori Kobayashi†**
Hiroaki Tobita† **Motoki Kobayashi†**

†Graduate School of Information Systems
University of Electro-Communications
1-5-1, Chofugaoka, Chofu
Tokyo 182-8585, Japan
+81-424-43-5651
koike@acm.org

‡Institute of Industrial Engineering
University of Tokyo
7-22-1, Roppongi, Minato-ku
Tokyo 106-0032, Japan
+81-3-3401-1433
ysato@cvl.iis.u-tokyo.ac.jp

ABSTRACT
This paper describes two interface prototypes which we have developed on our augmented desk interface system, EnhancedDesk. The first application is Interactive Textbook, which is aimed at providing an effective learning environment. When a student opens a page which describes experiments or simulations, Interactive Textbook automatically retrieves digital contents from its database and projects them onto the desk. Interactive Textbook also allows the student hands-on ability to interact with the digital contents. The second application is the Interactive Venn Diagram, which is aimed at supporting effective information retrieval. Instead of keywords, the system uses real objects such as books or CDs as keys for retrieval. The system projects a circle around each book; data corresponding the book are then retrieved and projected inside the circle. By moving two or more circles so that the circles intersect each other, the user can compose a Venn diagram interactively on the desk. We also describe the new technologies introduced in EnhancedDesk which enable us to implement these applications.

KEYWORDS: augmented reality, computer vision, finger/hand recognition, information retrieval, Venn diagram, education, computer supported learning,

INTRODUCTION
One of the important goals in Computer Human Interactions is to develop more natural and more intuitive interfaces. Graphical user interface (GUI), which is a current standard interface on personal computers (PCs), is well-matured and provides an efficient interaction for users who have already had experience with PCs. However, it is not true that GUI always provides natural and intuitive interfaces. Consider, for example, a mouse, which is a standard pointing device in GUI. Even though the mouse enables rapid and exact pointing, moving the mouse on a desk in order to move a cursor on computer screen does not come naturally to humans. Very often, users experience confusion when they attempt to use a mouse for the first time. To select an item from an item list on display or to point rough position on display, it is more natural and more intuitive for them to use their index finger. This statement is supported by the fact that there are many touch panel interfaces (e.g., ATMs) which are used by ordinary people.

There are many information systems which can provide more natural and more intuitive interface when we remove the restrictions imposed by the GUI. For example, Bolt demonstrated effectiveness of a multi modal interaction with gesture and speech in SDMS [3]. It is mainly the high cost of hardware along with immature sensing technology that have prevented us from developing such systems. Now the cost of hardware has been reduced and many sensing technologies have been developed. It is time to discuss and develop alternative interfaces. Some researchers have proposed new interface frameworks. For example, Turk [18] proposed the Perceptual User Interface (PUI) which uses several sensing technologies to interact with computers. Fitzmaurice et al. [4] and Ishii et al. [6, 7, 19, 20] proposed the Graspable/Tangible Interface which uses real world objects to manipulate digital information; that group developed many prototype systems.

We have developed an augmented desk interface by using computer vision as a key technology. EnhancedDesk [9] is an infrastructure to develop applications supporting work in the office. EnhancedDesk is influenced by Wellner's DigitalDesk [21]. The basic hardware configuration such as the use of a desk, a CCD camera, and a video projector is similar to that of DigitalDesk. However, some novel technologies are introduced in EnhancedDesk to enable more advanced interaction.

This paper describes two interface prototypes developed on EnhancedDesk. One is the Interactive Textbook, which is intended to provide and effective learning support environment. The other is the Interactive Venn Diagram which is aimed at supporting effective information retrieval. The next section describes the Interactive Textbook. Section 3 describes the Interactive Venn Diagram. The implementation of EnhancedDesk is discussed in detail in Section 4. In Section 5, we discuss advantages and limitations of our systems. Section 6 concludes the paper.

COMPUTER SUPPORTED LEARNING ENVIRONMENT

Issues in Computer Supported Learning Environment

In any course of study, textbooks are generally the tools that are used. It is, however, difficult to learn correct pronunciation by relying only on a textbook. It is also difficult to understand dynamic behavior in scientific experiments merely by reading text and by looking at static figures in the textbook.

Video or multimedia teaching materials make up for these textbook shortcomings. For example, foreign language teaching materials provide aids to correct pronunciation, and those for science demonstrate experiments by the use of video clips and/or computer graphics.

The problem with such materials is that they require students to perform additional tasks which are not directly related to the learning tasks. For example, students might be required to execute an application program in a CD-ROM whenever they read certain pages. To accomplish the execution, they have to insert the CD-ROM into the CD-ROM drive, search the application program, and then execute the program. The students' main purpose is to understand the experiment rather than understand how to use a computer. Such additional tasks might well cause them to lose their concentration.

On another perspective, unnatural interaction might disturb effective learning. Consider, for example, an interactive application which enables users to see a weight-spring experiment in Physics. Even though the students can manipulate a weight by using a mouse, it is unnatural for them to manipulate the weight on the screen indirectly.

Design Approach

As one solution to the issues described in the previous section, we propose a computer vision supported learning environment.

- Automatic retrieval and execution
  In the study of Physics, the main task of students is to understand the experiments described in the textbook, not to demonstrate their ability to use a computer. Therefore, it is more convenient for the students if the system recognizes what the student is currently studying and then shows corresponding digital contents automatically.
- Dynamic manipulation
  Whether or not the student understands a particular subject and remembers it longer depends on how real their experience is. As we described previously, direct manipulation by hand or finger will give more real experience than indirect manipulation by mouse. Although mouse is useful in practical office work, hand/finger manipulation is much more effective in educational environment. We developed novel techniques to recognize two-dimensional matrix code and users' hand/finger as is described in later section. These techniques were introduced in EnhancedDesk.

Interactive Textbook

In Interactive Textbook, a matrix code [12] is attached to the page which has digital contents as shown in Figure 1. Each matrix code corresponds to each application program. When a student opens a page containing a matrix code, the system recognizes the matrix code and projects the digital content onto the desk. The system not only identifies the unique ID of the matrix code but also recognizes its size and orientation. By using such size and orientation information, the system decides where to project the digital contents. For example, if the book is inclined on the desk, the digital contents are projected to the right position, i.e., the correct slant.

Figure 1 shows a student reading a textbook of Physics. When the student reaches the page describing the spring-weight experiment, computer graphics simulation of the spring-weight experiment is automatically projected onto the right side of the textbook. The student can manipulate the weight by his or her hand and observe the dynamic behavior of the spring and the weight. By exchanging the weight, the student can compare the different dynamics of the spring. When the student opens a page describing the pendulum experiment, CG simulation is projected onto the desk and the student can drag the pendulum to see its dynamic behavior.

INFORMATION RETRIEVAL

The most popular technique in current information retrieval is keyword searching. In keyword searching, people use one or more keywords and formulate queries by combining the keywords with Boolean operators such as AND/OR/NOT. Historically, such keyword searching has been used by a small number of people such as database operators who are trained to use database systems, computer-related people who are knowledgeable about database systems, or people who use online retrieval systems at libraries. However, the widespread World Wide Web (WWW) has enabled the general public, who not necessarily familiar with database systems, to become adept at using keyword searching via WWW search engines.

Issues in Keyword Searching

- Selection of appropriate keywords
  The lone trigger in keyword searching is the keyword; therefore, inappropriate keywords make it impossible to retrieve relevant information. Also, because they produce a huge number of hits, keywords that are too generic make it difficult to retrieve relevant information. The key to effective retrieval is how to select

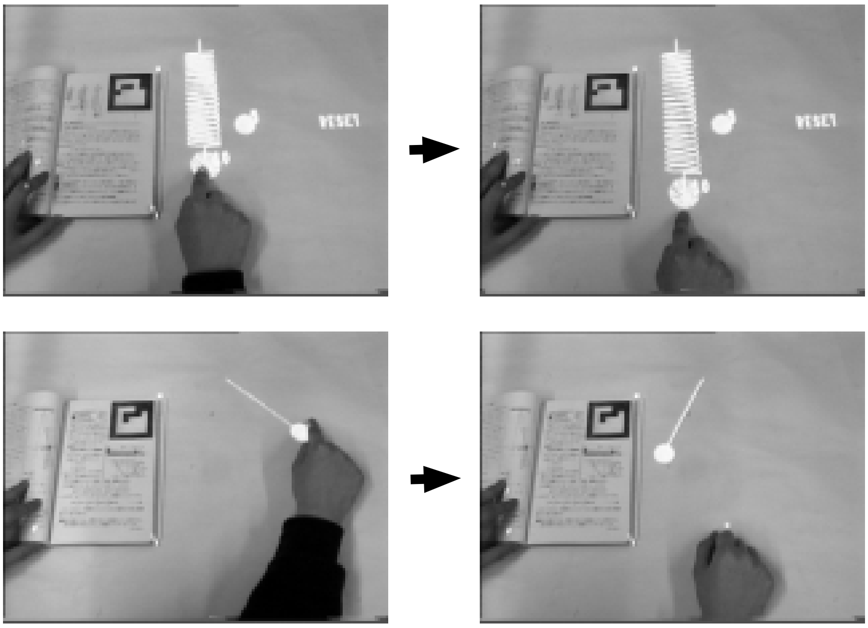


Figure 1: Interactive Textbook. When a student reads a page in a physics textbook that describes a spring-weight experiment, computer graphics simulation is automatically projected onto the desk. The student can drag the weight by using his or her finger. Then, the student opens another page describing a pendulum experiment. The system projected another CG simulation.

appropriate keywords.
Such keyword selection requires skill and knowledge for target domain. For example, when we use a keyword *information retrieval* to find this paper in a database, a huge number of papers corresponding to information retrieval would be retrieved. People who know that the phrase *information retrieval* is too generic would avoid using it. If, however, they use the keywords *augmented reality*, they could find this paper more efficiently. Such keyword selection is, however, a little difficult for novice users.

- Formulating complex queries
When too much information is retrieved, we could refine the query retrieval by combining two or more keywords with Boolean operators such as AND/OR/NOT. However, such query formulation is a little difficult for the general public. For example, when we retrieve papers which have keywords *information retrieval* and *augmented reality* and papers which have keywords *information retrieval* and *visualization*, we would form the query such as:

  (*information retrieval* AND (*augmented reality* OR *visualization*)). —(A)

  The difficulty of formulating such a query increases as the number of keywords increases.

- Observing different conditions
In most information retrieval systems, each query produces one result. When we refine the query, the previous result is cleared and a new result is displayed on the screen. If the refinement is so strict that the result does not contain relevant information, the user has to search again to return to the previous result. To see a result with a slightly different condition, the user has to formulate a new query and search again. Moreover, it is difficult to compare both results.
For example, when the user who performed the previous query (A) would perform another query with slightly different condition such as:

  (*information retrieval* AND *augmented reality* AND *visualization*). —(B)

  Although people might notice that (B) is a subset of (A), it is relatively difficult to recognize data which are not in (B) but do appear in (A).

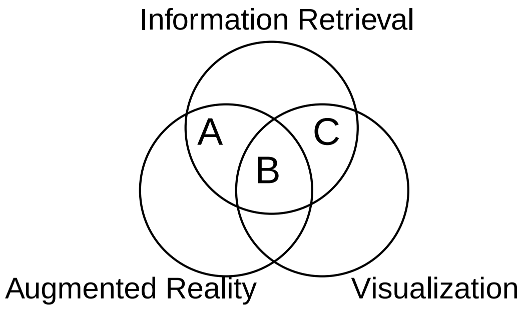


Figure 2: Venn diagram.

Design Approach

As one solution to this issue, we propose a visual interface for an information retrieval system.

- Visualization

Figure 3: A book with two-dimensional matrix code. When a user put the book on the desk, a circle is projected around the book.

Figure 4: Interactive Venn Diagram in use. When a user selects one of the regions in the Venn diagram, the images of the books in that region are displayed on from screen of EnhancedDesk.

To represent a concept of mathematical set intuitively, the Venn diagram such as shown is Figure 2 is very popular. A set represented by the query (A) is shown as region A and B and C, and a set represented by the query (B) is shown as region B.
In the Venn diagram, each set is visualized intuitively. Moreover, even people who are not familiar with database query can understand each subset visually.

- Augmented reality
  Suppose, for example, a user wants to buy unknown music CDs. It seems difficult to express his or her tastes by the use of appropriate keywords. The user's collection of CDs, however, would be a representative example of those tastes.
  Our idea is to introduce this concept to information retrieval. That is, instead of giving keywords to the information retrieval system, the user would show real objects such as CDs or books to the system.

Interactive Venn Diagram

In the Interactive Venn Diagram, a two-dimensional matrix code is attached to each book cover. Each matrix code corresponds to multiple keywords. For example, a matrix code on the book "C Programming Language" is associated with two keywords, *C Language* and *structured programming*. A matrix code on the book "OpenGL Programming Guide" is associated with two keywords *OpenGL* and *computer graphics*.

When a user puts a book on EnhancedDesk, the system recognizes the book's matrix code and projects a circle around the book as shown in Figure 3. Then the system searches the database using keywords associated with the matrix code. Finally, the retrieved data are projected onto the desk as an icon and they move inside the circle.

In the same way, when the user puts another book on the desk, another circle and retrieved results are projected onto the desk. If the user moves these books so that the two circles intersect one another, data corresponding to both books are displayed within the intersection of the two circles.

Figure 5 shows that three books have been put on the desk. Those three circles are projected onto the desk and finally the Venn diagram, as shown in the figure, is completed (Figure 5(B)).

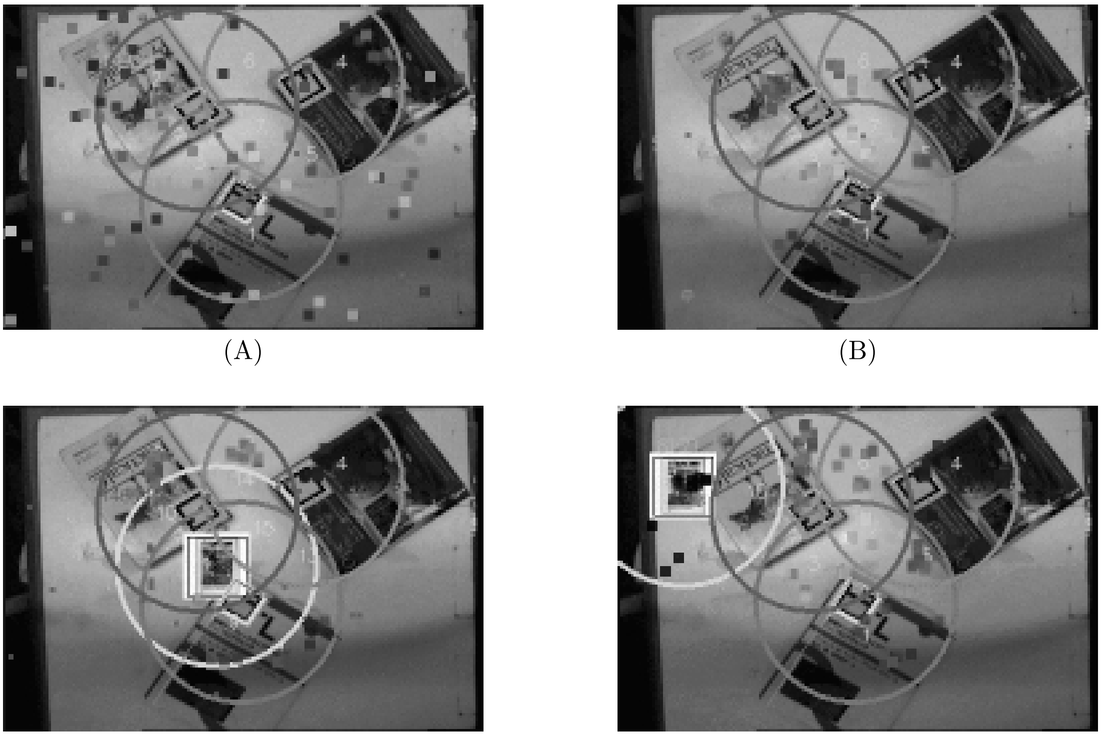
When the user points to one of the subregions, the details of the data in the region are displayed on the front screen of EnhancedDesk 4. If the user selects one of the books, a textured image of the book is projected onto the screen (Figure 5(C)). Then a circle is projected around this textured image and data associated with this book moves inside the circle. The user can perform further retrieval using three real books and one virtual book.

ENHANCEDDESK: IMPLEMENTATION DETAIL

In this work, we propose a new method for tracking a user's palm center and fingertips by using an infrared camera and template matching based on normalized correlation.

Unlike regular CCD cameras which detect lights in visible wavelength, an infrared camera can detect lights emitted from a surface with a certain range of temperature. Thus, by setting the temperature range to approximate the human body tempature, image regions corresponding to human skin appear particularly bright in input images from an infrared camera.

The use of an infrared camera is especially advantageous for our application, EnhancedDesk, in which a user can manipulate both physical objects and electrically projected objects on a desk. In this situation, the previously proposed methods would fail to find human skin regions. Because a LCD projector projects various kinds of objects such as text or figures even onto human skin, the observed color of the human skin can be altered completely, and the background of the input image changes



(A) (B)

(C) (D)

Figure 5: Information retrieval on Interactive Venn Diagram. (A) When a user puts three books onto the desk, retrieved data are first displayed randomly. (B) The data "flies" into each circle. (C) When the user selects one book from the front screen, the book is projected onto the desk with the circle. (D) The user can perform further retrieval using both real and virtual books.

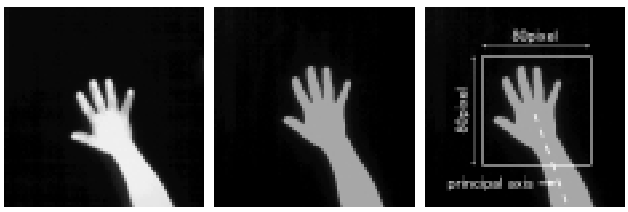
dynamically. As a result, the previously proposed methods which are typically based on color segmentation or background subtraction do not work well.

Extraction of Left and Right Arms

First an infrared camera is installed with a surface mirror so that a user's hands on a desk can be observed by the camera.

The video output from the infrared camera is digitized as a gray-scale image with 256×220 pixel resolution by a frame grabber on a PC. Because, the infrared camera is adjusted to measure a range of temperatures near human body temperature, e.g., typically between 30^o and 34^o beforehand, values of image pixels corresponding to human skin are higher than other image pixels. Therefore, image regions corresponding to human skin can be easily identified by binarizing the input image with a threshold value. In our experiments, we found that a fixed threshold value for image binarization works well for finding human skin regions regardless of room temperatures. Figure 6(a) and (b) show one example of an input image from the infrared camera, and a region of human skin extracted by binarization of the input image.

If some other objects on a desk have temperatures similar to that of human skin, e.g., a warm cup or a note PC, image regions corresponding to those objects as well as to human skin are found by image binarization. To remove those regions other than human skin, we first remove small regions, and then select the two regions with the largest size. If only one region is found, we consider that only one arm is observed on the desk.



(a) (b) (c)

Figure 6: Extraction of hand region

Finding Fingertips

Once regions of a user's arms are found in an input image, fingertips are searched for in those regions. Compared to extraction of user's arms, this search process is computationally more expensive. Therefore, a search window is defined in our method, and fingertips are searched for only within the window instead of being searched for over the entire region of a user's arm.

A search window is determined based on the orientation of each arm which is given as the principal axis of inertia of the extracted arm region. The orientation of the principal axis can be computed from the image moments up to the second order as described in [5]. Then a search window of a fixed size, i.e., 80×80 pixels in our current implementation, is set so that it includes a hand part of the arm region based on the orientation of the arm. (Figure 6(c)) We found that a fixed size for the search window works reliably because the distance from the infrared camera to a user's hand on a desk changes little.

Once a search window is determined for each hand region, fingertips are searched for within that window. The overall shape of a human finger can be approximated by a cylinder with a hemispherical cap. Thus, the projected shape of a finger in an input image appears to be a rectangle with a semi-circle at its tip.

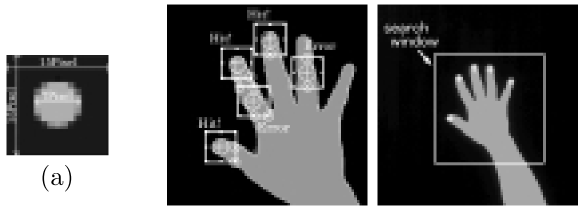
Based on this observation, fingertips are searched for by template matching with a circular template as shown in Figure 7 (a). In our proposed method, normalized correlation with a template of a fixed-size circle is used for the template matching. Ideally, the size of the template should differ for different fingers and different users. In our experiments, however, we found that the fixed size of template works reliably for various users. For instance, a square of 15×15 pixels with a circle whose radius is 7 pixels is used as a template for normalized correlation in our current implementation.

While a semi-circle is a reasonably good approximation of the projected shape of a fingertip, we have to consider false detection from the template matching. For this reason, we first find a sufficiently large number of candidates. In our current implementation of the system, 20 candidates with the highest matching scores are selected inside each search window. The number of initially selected candidates has to be sufficiently large to include all true fingertips.

After the fingertip candidates are selected, false candidates are removed by means of two types of false detection. One is multiple matching around the true location of a fingertip. This type of false detection is removed by suppressing neighbor candidates around a candidate with the highest matching score.

The other type of false detection is a matching happening in the middle of fingers as illustrated in Figure 7(b). This type of false detections is removed by examining surrounding pixels around the center of a matched template. If multiple pixels in a diagonal direction are inside the hand region, then it is considered not to exist at a fingertip, and therefore the candidate is discarded.

By removing these two types of false matchings, we can successfully find correct fingertips as shown in Figure 7(c).



(a) (b) (c)

Figure 7: Template matching for fingertips

Finding Centers of Palms

The center of a user's palm needs to be determined for recognition of various types of hand gestures. For example, the location of the center is necessary to estimate how extended each finger is, and therefore it is essential for recognizing basic gestures such as click and drag.

In the previously proposed methods, the center of a user's hand is often given as the center of mass of a hand region. However, the center of mass moves significantly when opening and closing a hand or by including a user's arm in the hand region. Therefore, we cannot estimate the center of a user's hand.

In our proposed method, the center of a user's hand is given as the point whose distance to the closest region boundary is the maximum. In this way, the center of the hand becomes insensitive to various changes such as opening and closing of the hand. Such a location for the hand's center is computed by morphological erosion operation of an extracted hand region. First, a rough shape of the user's palm is obtained by cutting out the hand region at the estimated wrist as shown in Fig.8 (a). The location of the wrist is assumed to be at the pre-determined distance, e.g., 60 pixels in our case, from the top of the search window and perpendicular to the principal direction of the hand region.

Then, a morphological erosion operator is applied to the obtained shape of the user's palm until the area of the region becomes small enough. As a result, a small region at the center of the palm is obtained. Finally, the center of the hand region is given as the center of mass of the resulting region as shown in Figure 8(c).

(a) (b) (c)

Figure 8: Center of a user's palm

EnhancedDesk System

The proposed method for tracking hands and fingertips in infrared images was successfully used for our EnhancedDesk system. The system is equipped with a LCD projector, an infrared camera, and a pan-tilt camera. The LCD projector is used for projecting various kinds of digital information such as computer graphics objects, texts, or a WWW browser on a desk.

For alignment between an image projected onto a desk by the LCD projector and an input image from the infrared camera, we determine a projective transformation between those two images through initial calibration of the system. The use of projective transformation is enough for calibration of our system since imaging/projection targets can be approximated as to be planer due to the nature of our application. In addition, a similar calibration is also carried out for the pan-tilt camera so that the camera can be controlled to look toward a desired position on the desk.

The pan-tilt camera is controlled to follow a user's fingertip whenever the user points at a particular location on the desk with one finger. This is necessary to obtain enough image resolution to recognize real objects near a user's pointing finger. Currently-available video cameras simply do not provide enough image resolution when the entire table is observed. In our current implementation of the interface system, a two-dimensional matrix code [12] is used for identifying objects on the desk. More sophisticated computer vision methods would be necessary for recognizing real objects without any markers.

DISCUSSION AND FUTURE WORK

Interactive Textbook

Some people might think that everything in textbooks (e.g., texts, figures, etc.) could be included in a CD-ROM with multimedia contents so that students could learn everything just by using a computer. However, the students cannot use the computer everywhere, for example, in crowded trains. They still need textbooks. As we discussed in [9], people use paper or digital media depending on their situations. Interactive Textbook provides a way to integrate both media smoothly on the desk.

In this paper, we showed an application to physics. Interactive Textbook can be applied other subjects such as foreign languages, mathematics, geology, history, and so on. We are planning to develop more practical teaching materials. Then the system should be evaluated by students.

Interactive Venn Diagram

One of advantages of the Interactive Venn Diagram is that it can perform retrieval just by showing books even if a user cannot find appropriate keywords. However, it is inconvenient when the user knows appropriate keywords or when there are not appropriate books around the user. Therefore, keyword searching should be integrated into the system. For example, when users type in a keyword, the system would project the keyword and a circle on the desk. Then, the users could manipulate the keyword as they manipulate virtual book.

User Testing

Formal user studies have not been done yet. However, the system was demonstrated in some places and we received many useful comments. Visitors of our laboratory used Interactive Textbook and they commented that they preferred the automatic execution of applications. Most of them enjoyed interaction with CG simulation by their own hand.

Core technologies of EnhancedDesk were also applied to some media art exhibitions. At Haishi (Mirage City) exhibition at NTT Inter Communication Center on July 1997, the technologies were extended from the desktop to the floor [8]. A CCD camera and a video projector were mounted on the ceiling. The camera captured visitors of the exhibition and the projector projected a ripple around each visitor. (Although this visual effect is similar to Ishii's PingPongPlus [7], our system used only computer vision to identify visitors' position.) On February 1998, EnhancedDesk was exhibited at Bauhaus Museum in Berlin [17]. EnhancedDesk was applied to the guide/navigation system of the museum. Snapshots of exhibits were projected onto the desk. When someone touched one of snapshots, the detail of the exhibit was shown on the desk. Although no instructions for the system were given, the museum visitors soon learned how to use and enjoy the tactile system.

RELATED WORK

InfoCrystal [16] is a visual tool for information retrieval. InfoCrystal proposed to use visualization to formulate complex queries and showed its effectiveness. Instead of using the original Venn diagram, InfoCrystal used unique visualization to improve the visibility of intersections.

The two-dimensional matrix code used in our system was developed by Rekimoto [12]. It identifies 2^{16} bits of information. Also, it can be used to determine the size and orientation.

The pioneering work of an augmented desk interface was done in DigitalDesk [21]. DigitalDesk proposed a basic hardware setup which has been used in later research. DigitalDesk also experimented with basic finger recognition. Kruger [10] and MacKay [11] also experimented augmented desk systems.

InteractiveDesk [2] used a one-dimensional bar code to link from a real paper folder to email or web pages which were related to the documents in the folder. Arai also developed PaperLink [1] which links paper to electronic content. Robinson et al. also used a 1D bar-code to link from a printed web page to the original web page [15]. In these works, interaction with digital information was done by using the traditional mouse and keyboard. Although the use of bar-code is similar to ours, our two-dimensional matrix code can offer size and orientation information of the paper.

MetaDesk [6] used real objects (Phicons) to manipulate digital information such as electronic maps. Rekimoto's Augmented Surfaces [14] enable users to smoothly interchange digital information among PCs, table, wall, and so on. However, users' finger and hand recognition was not explored in both systems.

HoloWall [13] used IR lights and a video camera with IR filter. However, it detects not only human skins but also objects near the surface. On the other hand, our technologies enable to detect only human skins.

CONCLUSIONS

This paper described two interface prototypes on our augmented desk system named EnhancedDesk. Interactive Textbook automatically retrieves multi media teaching materials and projects them onto the desk surface when students open the corresponding page. The system also allows the students to interact by using their hands or fingers. It enables the students to concentrate on learning process. The Interactive Venn Diagram recognizes real books on the desk and retrieves a database without requiring users to supply any keywords. The system projects a circle around each book and the retrieved results are projected inside the circle. By manipulating two or more circles so that they intersect each other, users can perform AND-search and OR-search simultaneously without formulating complex queries. We also presented some new technologies which were introduced to EnhancedDesk. Those technologies will be useful for many researchers who are now working on the similar augmented desk interfaces.

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