Ubiquitous Memories:
Wearable Interface for Computational Augmentation of Human Memory based on Real World Objects

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Abstract

This paper presents a novel computational human memory augmentation concept, Ubiquitous Memories, used to support everyday information related activities. Memory aid architecture has been used to annotate augmented video data as wearable information. We have developed a prototype system, Ubiquitous Memories, composed of a head-mounted display, a wearable camera and a Radio Frequency Identification (RFID) device, which attaches to an individual user, as well as a set of RFID tags and web servers. These RFID tags are set on their corresponding real world objects. A user might link a desired video data with a certain real world object by means of a RFID tag on the object. We have adopted touching as the natural operation of the system. Two experiments have been conducted to evaluate the effectiveness of the system and the results have shown that this system effectively supports memory recollection of past events.

1 Introduction

We propose a real-world oriented augmented memory concept, Ubiquitous Memories. Augmentation of human memory using computational technologies has been studied extensively in recent years. Rhodes (1997) termed the augmentation of human memory "augmented memory." A computational memory aid system such as Ubiquitous Memories is crucial for the augmentation of daily life because psychological results show that the human brain causes mistakes in the encoding process, the storing process or the retrieval process. Nickerson et al. (1979), for example, showed that most American test subjects could not draw even 50% of the design of a 1-cent coin when asked to remember the coin visually. Wrewer et al. (1981) investigated what strategy people can use to memorize environmental contexts in a room.

In the field of memory aids, two representative works on ubiquitous computing and wearable computing exist. Lamming et al. (1994) developed Forget-me-not, a prototype system for a portable episodic memory aid. Their system recorded a user's action history using sensors that were implanted in a laboratory and Active Badges worn by users. The user can refer to their history and easily recall past events to a PDA. The study is based on the concept of "ubiquitous computing" proposed by Weiser (1991). Mann (1998) described a user who wears a CCD camera and sensors to record the user's daily life. The system allows the user to get information anytime and anywhere the user wants. The human-centered computer technology is called "wearable computing." The wearable computing technology should be made aware of the wearer's internal (desire, emotion, health, action, etc.) and external (goings-on, temperature, other people, etc.) state at any time.

In the field of supporting human memory on wearable computers in daily life, Jebara et al. (1998) proposed the video replay system, DyPERS, which stores a user's visual and auditory scenes. The system can retrieve a video clip using a signal that was explicitly registered by the user by pushing a button while the user looked at an interesting scene. Jennifer et al. (1998) developed the StartleCam, which records a video data triggered by skin conductivity from a startled response from a user. Aizawa et al. (2001) proposed a system that summarizes a video from a wearable camera using brain waves. The above two systems automatically start recording when the user shows a noticeable interest. The VAM system by Farrigdon et al. (2000) detects a human face, which was recorded at previously, and displays information of the retrieved person. These researchers have developed human-centered computing systems that focuced on recognizing the user's interests by representing augmented memory. Remembrance strategies, however, are not only operated with interests or information in the human brain, but these strategies are also involved with the relationship between events and real world objects.

The concept of Ubiquitous Memories has the strong ability to reduce a user's memory overload, because the user is able to recall experience by simply touching the object linked with the experience. Realizing Ubiquitous Memories, physical objects are implanted or attached micro-miniature type tags. We use a Radio Frequency Identification (RFID) device and RFID tags because the tag does not need battery. The tag is some studies to utilize real world objects in human support by computers. Rekimoto et al. (1998) proposed a system for browsing information that included the physical context of a user's current situation. Their aim is to develop interactive technologies in physical environments. However, neither a computational augmentation of human memory nor a development for operating a memory aid system was considered. Michael et al. (1997) proposed artefact-centerd computing, called MediaCups. This system needs electric power to use digital artefacts.

In this paper, we define augmented memory as video data recorded by a camera worn by a user. Our concept provides the user wearing the Ubiquitous Memories system two abilities: i.e., the ability to link augmented memories to real world objects, and the ability to recollect augmented memories by simply touching the objects. The overall aim of our concept is the realization of a digital nostalgia based on real world objects as an augmentation of human memory in daily life. Digital nostalgia creates an autobiographic history by linking a human experience with a real world object contained in the experience. The user wearing the Ubiquitous Memories system can be easily reminded of a certain past event linked to the object as if the user were virtually there.

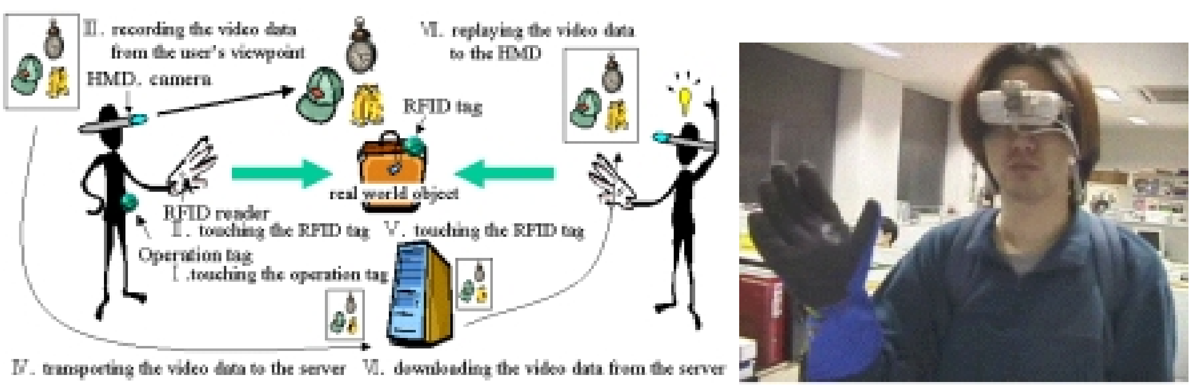
In the research field of memory aids, a proposal for the concept and the development of a system are not only important points, but an investigation into the effectiveness of the system must also be evaluated. We therefore did two experiments for a single user. Our experimental results show that the system effectively performs in retaining the user's past events. First, we investigated the influences when a particular context in a video can give the user. Second, we examined how many events the user can retain with our system.

In the next section, we briefly discuss an overview of the Ubiquitous Memories system. In section 3, we present the experiments and results to show how the Ubiquitous Memories system can support a user. The discussion section in section 4 evaluates the availability of Ubiquitous Memories. The final section, section 5, concludes this paper.

2 Overview of the Ubiquitous Memories system

We have developed a prototype system of Ubiquitous Memories to realize a real-world oriented augmented memory concept. Figure 1 illustrates an overview of the Ubiquitous Memories system.

It is crucial for such a system to provide "natural" operations. In everyday life, a user picks up a real world object when the user is interested in that object or needs that object. "Touching" is a natural operation used to establish a link between the user's external activities and an operational object. So, we decided that the operational object is selected by the 'touching" operation in the Ubiquitous Memories system.



(a) An operation procedure of the system (b) An appearance of the user

Figure 1: Overview of the Ubiquitous Memories system

The current system hardware consists of a Head-mounted Display (HMD), a wearable camera, which is attached at the center of the HMD, and a Radio Frequency Identification (RFID) device for a wearable system, RFID tags for objects, and web servers. The RFID device is incorporated into a gloved hand. The RFID device can immediately read the RFID tag data when the device approaches the tag within 3cm distance. The entire system connects to the World Wide Web via a wireless LAN.

We show a basic procedure of the system's operation in Figure 1. The system state has a base state i.e., MEMORIZE and REMEMBER. The state of the system is normally at REMEMBER. The user can select and execute one of the defined operations of the system by touching a RFID operation tag with a special ID associated with the operation, called an "operation tag." Operation tags are worn on the opposite wrist of the user's gloved hand. The Ubiquitous Memories system allows the user to use the following the two operations:

MEMORIZE The state of the system is changed from REMEMBER to MEMORIZE when the user touches the operation tag MEMORIZE (I). The user then approaches the gloved hand near a physical object (II). The system then records a video from the head-mounted camera (III). The system connects with the web server to store the video linked with the RFID tag ID that is attached to the object (IV).

REMEMBER The user just touches a RFID tag attached to an object the user chooses to remember (shown in Figure 2 (a)) (V). The system retrieves the video data from the web server (VI). The retrieved video data is then replayed in the top-left area in the screen of the HMD (shown in Figure 2 (b)) (VII).

(a) Selecting the object (b) Replaying the video

Figure 2: An example of operation (REMEMBER)

3 Experiments and Results

3.1 Influence of a Context in a Video to Human Memory

In the experiment, we investigated how a context in a video can give influence to a user of the Ubiquitous Memories system. It is important to find effective operation rules about memorization, as well as what kind of context should be recorded in a video and how such memories should be linked with a physical object for memory aid and identification.

3.1.1 Experimental Methods

This experiment was conducted at the Nara Institute of Science and Technology (NAIST) in Nara, Japan, among graduate students of the Information Science Department. 17 Japanese test subjects were participated in the experiment.

The experiment used pairs of an object image and a video in a trial (Figure 3). We set a notebook PC under laboratory conditions. A pair of an object image and a video was displayed on a PC monitor. The linked video is replayed automatically when the subject clicks the displayed image. The experiment contains 20 trials. In the 10 trials,

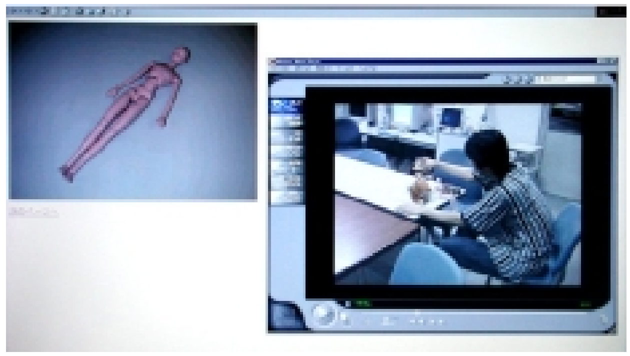


Figure 3: Reference display for experiement 1

each object in the displayed image is contained in the linked video. In the other 10 trials, each object and the video have no semantic relationship. In the experiment, each trial was alternately performed. Test subjects could watch a video 2 times in a trial, and then, the subject could proceed the next trial immediately.

After the subject finished all trials, there was a 3-minute delay period. In the period, the Japanese test subject had to read an scientific international journal paper and translate outloud each and every sentence from English into Japanese. The subject then answered a questionnaire. In addition, after a 1-week delay period, the test subjects had to answer the same questionnaire again. 11 questionnaires were returned.

The questionnaire contained 20 recall questions in Japanese. Each question showed an object image used in the experiment. The subjects filled in as many answers as they could in less than 10 minutes. It should be noted that the sequence of questions was different from the sequence of trials. The test subjects could answer these questionnaires in a random order.

3.1.2 Results

This section analyzes the results of the 17 (3-minute delay) and 11 (1-week delay) questionnaires that we collected from the Japanese graduate students of the Information Science Department at the NAIST in Nara, Japan.

Figure 4 shows the average number of correct answers. The left side of the figure shows the average number of the correct answers in the 3-minute delay questionnaires. The right side illustrates the average number of correct answers in the 1-week delay questionnaires. Black dots result of the questions for images with videos containing images themselves. White dots illustrate for images, which were not contained in the video.

In the 3-minute delay questionnaires, the average number of black dots is approximately 1.4 times greater than the average number of white dots. This result shows a significant difference ($p<0.0005$). In the 1-week delay questionnaires, a difference between the average number of black dots and the average number of white dots widens to approximately 2.3 times. This result shows a significant difference ($p<0.0005$).

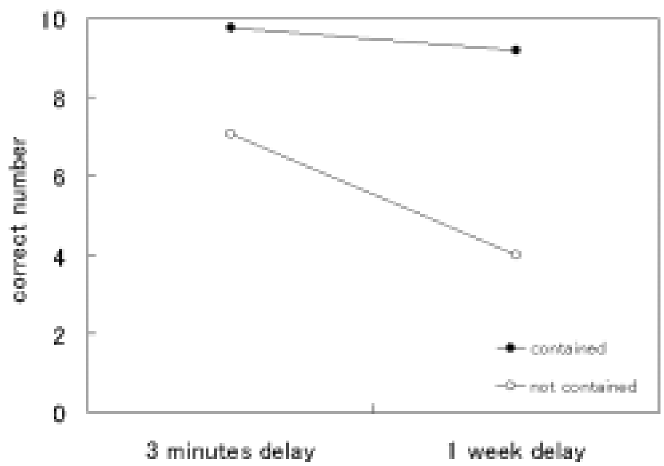


Figure 4: Context effect

3.2 Recollection Efficiency of a Memorization Strategy

The purpose of the experiment was to examine how many events a user can retain using a quantitative analysis. We adopted a comparative experiment with 4 memorization strategies.

3.2.1 Experimental Methods

This experiment was conducted at the NAIST in Nara, Japan, among graduate students of the Information Science Department. 20 test subjects were included in the experiment.

In the experiment, we used 10 physical objects, 10 portraits of unfamiliar people, and two sets of 10 playing cards composed of number 1 through 10. We conducted the experiment under laboratory conditions. One experiment was composed of a memory test and a recall test. The memory test asked the subject to memorize 10 trials. The recall test meant that the subject answered a questionnaire.

In a trial of the memory test, the subject was shown a pair consisting of an object and a portrait. The subject then selected one of the four corners of the portrait. Finally, the subject was shown the predetermined pair of cards. The subject looked at these numbers within 30 seconds. The subject had to memorize the object and portrait pair, the corner of the portrait and two card numbers. The subject continuously tried to memorize all trials. All subjects had to do two experiments within the following 4 conditions.

C1: use human memory

C2: use only facial characteristics (record with a paper and a pen)

C3: refer to portraits that were used in a memory trial

C4: use the Ubiquitous Memories system

Test subjects were divided into four groups. Group 1 did two experiments using conditions C1 through C3. Group 2 experimented using in conditions C3 through C1. Group 3 experimented two times using conditions C2 through C4. Group 4 did two experiments using in conditions C4 through C2.

In the recall test, a questionnaire contained 10 recall questions. The subject was given one object image in each question. There were three empty boxes (portrait, corner and card numbers) in a question. Next, the subject selected a portrait id from a list of 40 portraits, marked a corner (Left-Top, Left-Bottom, Right-Top, Right-Bottom), and wrote down two card numbers. The subject was given a list of 10 portraits used in the memory test only in condition C3. All subjects filled in some or all answers within 10 minutes. The sequence of questions was changed from the sequence of trials in the memory test. All subjects could answer the questions in a random order.

3.2.2 Results

This section describes the result of the 20 questionnaires collected from the graduate students of the Information Science Department in NAIST.

Table 1[1] illustrates recall rates from 20 questionnaires. In this paper, we defined N,

Table 1: Recall rate

	C 1	C 2	C 3	C 4
N**	24.0%	31.0%	10.0%	2.0%
PB'F'	11.0%	8.0%	19.0%	19.0%
P'BF'	12.0%	9.0%	5.0%	3.0%
PBF'	23.0%	20.0%	32.0%	31.0%
P'B'F	8.0%	4.0%	3.0%	1.0%
PB'F	4.0%	9.0%	11.0%	19.0%
P'BF	5.0%	1.0%	3.0%	0.0%
PBF	13.0%	18.0%	17.0%	25.0%
P**	51.0%	55.0%	79.0%	94.0%
B	53.0%	48.0%	57.0%	59.0%
F	30.0%	32.0%	34.0%	45.0%

P, B, F and '. N, which is a percentage of errors, is represented as follows: no answers of a portrait, a card and card numbers were correct answers on several questions. P shows that the answer of a portrait was correct. B and F have the same relation as that between P and the answer of a portrait. B shows that the answer of a corner was correct. F represent that the answer of card numbers was correct. X' (X is either P, B or F) represents the answer of a question related to X that was not correct.

In Table 1, N and P show a significant difference among the 4 test conditions ($p<0.001$). P by C4 is, however, not 100%. Ideally, C4 must be 100% because our system gives a directly related portrait. In the sum of P'BF', P'B'F and P'BF, we can see the influence on the difference among the test conditions (C1: 25.0%, C2: 14.0%, C3: 11.0%, C4: 4.0%, $p<0.001$). A sum of PBF' and PBF shows the transparency on the difference of test conditions (C1: 36.0%, C2: 38.0%, C3: 49.0%, C4: 56.0%, $p>0.1$).

Figure 5 shows an F-flow model to explain dependency among P, B, and F in Table 1. We can investigate the test subject's remembrance strategies for the experiment. We introduce O that represents an object as a question in the questionnaire. We envisioned a flow rate of a flow path for the model. A flow pattern in the model corresponds with

[1] **: $p<0.001$, *: $p<0.05$, †: $0.05<p<0.1$

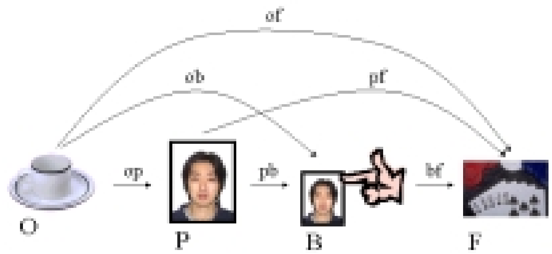


Figure 5: F-flow model

Table 2: F-flow path ratios

	C 1	C 2	C 3	C 4
of	17.9%	9.5%	7.1%	2.5%
op**	74.7%	88.9%	89.5%	97.5%
ob	7.3%	1.6%	3.4%	0.0%
pf	44.7%	50.9%	40.5%	38.5%
pb	30.0%	38.0%	49.0%	59.0%
bf	37.3%	39.6%	52.4%	59.0%

an associative pattern from O to F. The outflow of recall from O and the inflow to F are both 100% as a total. Table 2 shows the representation of the F flow in the experiment. The path of op, ob, of, pb, pf and bf show the percentages for the flow rates.

In an analysis of the variance to the result of the experiment, op shows significant differences ($p<0.0005$).

4 Discussions

We discuss how a computational augmentation of human memory based on physical objects can aid a user's recollection of past events in daily life. The goal of our investigation using the two experiments is to evaluate the effectiveness of the Ubiquitous Memories system for personal use.

First, we should examine what kind of context in a video is adequate for supporting human memory. Figure 4 illustrated how a video, which is semantically related to a physical object, had a strong and long-term effect for human memory. A person retains a relationship between physical objects and his/her memory associated with them, for a long time. Therefore, it is easy to remember a past event when just looking at a physical object.

Second, we should investigate what kind of memory aid method showed the highest performance. Table 1 showed that our proposed system had the most effective test conditions. There were 4 conditions (C1: use human memory, C2: use only facial characteristics, C3: refer to partraits that were used in a memory trial, C4: use the Ubiquitous Memories system) in the experiment. In the result of PBF (C1: 13.0%, C2: 18.0%, C3: 17.0%, C4: 25.0%) and P (C1: 51.0%, C2: 55.0%, C3: 79.0%, C4: 94.0%), C4 showed the strongest relationship of an object linked to a portrait. Each condition in the experiment supported test subjects only in the F-flow path op. The result not only showed the influence of the supporting memorization in the path op, but also showed influences in the path pb and bf. In Table 2, we observed that the C4-flow showed the most well-knit flow path in op (C1: 74.7%, C2: 88.9%, C3: 89.5%, C4: 97.5%), pb (C1: 30.0%, C2: 38.0%, C3: 49.0%, C4: 59.0%) and bf (C1: 37.3%, C2: 39.6%, C3: 52.4%, C4: 59.0%).

In the two experiments, we show that computationally augmented Ubiquitous Memories is capable of supporting human memory. Videos linked with physical objects in the real world can give a key to the user's recollection of a past event with the single user. In particular, the system shows considerable effect when a physical object related to an event was recorded in a video.

The experimental results, additionally, show that Ubiquitous Memories has the potential for sharing human memories among people. Takatori (1980) showed that cooperative recall is superior to individual recall in the memory prosess. Human memory cannot be shared explicitly in the real world. People can only trade real world experiences with external explanations. We believe that video helps facilitate memory recall in the real world. We have developed the next version of the Ubiquitous Memories system for sharing augmented memories among multi-users. This development enables us to conduct further experiments on how multi-users can operate the system to share augmented memories.

5 Concluding Remarks

This paper proposed a novel concept of Ubiquitous Memories for memory aid. A prototype system of the Ubiquitous Memories system has been developed on a wearable camera, with a RFID tag reader and a RFID tag attached to a physical object. We examined the effectiveness of Ubiquitous Memories for the augmentation of human memory. We found that the relation between a physical object and a video containing the object is capable of facilitating a memory of the object that will be retained by the user. We proved that Ubiquitous Memories gives a clear memorizing strategy to the user.

The shortcomings of this study include the necessity for developing a multi-users version of the Ubiquitous Memories for sharing augmented memories, as noted in the paper. Finally, the current system only linked one video on a physical object. We are increasing the number of videos each physical object.

In a related study, an integration problem is given for recollection strategies. Kawamura et al. (2001) proposed a memory aid system for supporting location-based memory recollection of past events. In the future, we will integrate the Ubiquitous Memories system with the location-based memory recollection support system.

We believe that the two experiments discussed in this paper provide evidence for the adoption of the Ubiquitous Memories system for memory aid using the computational augmentation of a user's memory. Ubiquitous Memories supports the effective and interactive application of wearable computing and ubiquitous computing.

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