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ORIGINAL ARTICLE

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Ubiquitous Memories: a memory externalization system using physical objects

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Abstract In this paper we propose an object-triggered human memory augmentation system named "Ubiquitous Memories" that enables a user to directly associate his/her experience data with physical objects by using a "touching" operation. A user conceptually encloses his/her experiences gathered through sense organs into physical objects by simply touching an object. The user can also disclose and re-experience for himself/herself the experiences accumulated in an object by the same operation. We implemented a prototype system composed basically of a radio frequency identification (RFID) device. Physical objects are also attached to RFID tags. We conducted two experiments. The first experiment confirms a succession of the "encoding specificity principle," which is well known in the research field of psychology, to the Ubiquitous Memories system. The second experiment aims at a clarification of the system's characteristics by comparing the system with other memory externalization strategies. The results show the Ubiquitous Memories system is effective for supporting memorization and recollection of contextual events.

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1 Introduction

The ultimate goal of this study is to realize a real-world-oriented memory encoding support system to augment human memory in everyday life. Technologies for supporting human memory activity have been studied because of the increasing interest in wearable and ubiquitous computing [1–5]. In recent years, "augmented memory" [6, 7] technology has been investigated extensively [8–13]. These technologies will help us to perform various daily tasks such as reducing wastes of time, facilitating human–human communication, and recycling our experiences [14].

We propose a novel concept of an augmented memory system named *Ubiquitous Memories*. The concept design employs a touching operation to enclose a user's experiences gathered through his/her sense organs into a physical object, and to disclose the experiences accumulated in the object using the touching operation. We term this operation a "memory externalization," which is a cognitive behavior enabling a user to index his/her experience through a physical object. For example, suppose that a person won first prize in the 100-m dash at an athletic event and then got a trophy. That person can easily recall the event abstractly by simply looking at the trophy because he/she has associated the event with the trophy in his/her mind. Furthermore, the person can recollect the actual scene of the event by using the *Ubiquitous Memories* system. This operation using the touching has the following two advantages:

1. *Cognitive design (vs. subliminal vs. rehearsal)*: Memory externalization is a memory-encoding operation for augmented memory [14]. In the encoding operation, DeVaul et al. [15], for example, have investigated the subliminal effect of memory glasses. This study has focused not only on improving a problem of misdirection but also reducing a problem of divided

attention. The aim of this study is to suggest that a wearable subliminal cuing system including nonconscious attention/awareness of a user. Therefore, they have investigated a performance of subliminal cues in output images. Also, Ikei et al. [16] have employed a rehearsal approach on the iFlashBack system. The iFlashBack system gives a user a rehearsal video again and again to make him/her memorize an event which is recorded on the video from a wearable camera. This system automatically records the video by using an RFID device when the user uses an object that is attached to an RFID tag. This study has investigated an effective presentation method of the video. Both the subliminal and rehearsal operations, however, are problematic. When a user is over-supported by these operations, memory augmentation will be hard to obtain. In contrast, our proposed operation, which does not require any computational techniques, provides a memory externalization strategy that uses the human's cognitive traits. Therefore, a user can control a cognitive load by him/her self to arrange his/her memories in the real world. The simultaneous use of both controllable conscious and unconscious cognitive traits is an important operation necessary for realizing the augmented memory system.

2. *Touching operation (vs. gazing operation)*: A ‘‘touching'' operation compared to a ‘‘gazing'' operation is more appropriate for enclosing/disclosing a user's experiences into/from a physical object. Gazing-based operations have been proposed using various types of methods in recent years; for example, a pattern-recognition method [17] and a two-dimensional (2D) barcode method [18]. We assume a method in which a radio frequency identification (RFID) tag is attached to an object to detect the touching operation. The 2D barcode is also assumed for the gazing operation. Figure 1 shows an example of a typical environment in the real world. In order to select an object, the system must detect the object under the following two conditions:

Fig. 1 A typical environment in the real world

- *Dense/dust-covered objects*: A user cannot enclose/disclose his/her experiences into/from an object without picking out (touching) a target object. A ‘‘dense'' object is an object that is one of thickly gathered objects or one of piled objects such as a paper in a heap. A ‘‘dust-covered'' object represents an object that is not used often. The object may be put away somewhere, such as in a bookcase, a cupboard, or a closet, for example. But the object might be important to remember his/her experiences. In order to select one of such kind of objects from its surroundings, the user must physically pick up the object, rather than simply gaze at it.
- *Position of an object*: The position of an object can be easily changed, and therefore, a tag on the object can sometimes be difficult to see, especially if the tag is placed in the opposite direction to the user's view, and the object is not close enough to the user for him/her to see the tag. The user must then get close to the object. Under this condition (i.e. of closeness), the significant difference between a touching operation and a gazing operation does not exist.

Remembering an externalized memory in an object-memory-seeking behavior directly corresponds to an object-searching behavior where the object is associated with the memory in some scene. This correspondence gives a user more intuitive power to seek for the memory using the principle of human-memory encoding. The former part of the aforementioned example of the trophy for the 100-m dash shows this principle. This associative ability is called the *encoding specificity principle* [19]. Two detailed characteristic traits exist for the principle when expressed in an object-searching action. One characteristic trait is the ability to recall an event or feeling or emotion by simply looking at or thinking about an object. This associative trait allows one to decide quickly what object he/she should seek. Another trait is the remembrance of the location of the placed object. This trait allows a person to remember where he/she placed an object. These associative traits illustrate how a person can easily recall an event by seeking out an object related to that event.

In the research field of memory aids, the effectiveness of the system must be evaluated. Also, our proposed system should be conducted experiments to evaluate a performance of user interaction for a memory externalization in the real world. We therefore conducted two experiments for a single user. Note that the main issue of this study is to clarify a performance of a memory externalization and to indicate availability of touching operation for remembering object-related events. We therefore employed a stand-alone type *Ubiquitous Memories* system for the experiments although the system can perform as a multi-user system. Our experimental results show that the system effectively performs in remembering the user's past object-related events. First, we investigated the succession to the system of the *encoding specificity principle*. Second, we examined a clarification of the system's characteristics by comparing the system to other memory externalization strategies.

2 Ubiquitous Memories

2.1 Design concept

We propose a conceptual design to ideally and naturally integrate augmented memory into human memory. Conventionally, a person often perceives and understands a new event occurring in the real world by referring to his/her experiences and knowledge, and then by storing the memory of the event into his/her brain. He/she then obtains a novel and natural action for the event by analogically and metaphorically associating the event with previously occurring events. The acquisition of natural actions is important for realizing augmented memory. This acquisition positively establishes a ''conceptual design'' for seamless integration between human memory and augmented memory. In addition, the ''hand'' interface has the potential for externalizing human's experiences (augmented memory) into physical objects.

Below we introduce the conceptual design of the *Ubiquitous Memories* system. The following procedures illustrate the conceptual design:

1. A user perceives an event via his/her body.
2. The perceived event is stored into his/her brain as a memory.
3. The human body is used as media for propagating memories, i.e., memory travels all over the body like electricity, and memory runs out of the hands. (Imitating this feeling, the user can transfer memory from his/her body to a physical object by ''touching'').
4. The transferred memory remains in the object.
5. He/she transfers the memory from the object to his/her body when interested in the object and then touches the object again.
6. Finally, he/she can recall the event.

In this paper we define ''context'' as information the human can sense in the real world, e.g., the conditions of the user's surroundings (i.e. environment), the user's emotional condition, and the biometric states of the user. Note that a context is not data like an augmented memory. The ''human body'' and an ''object'' are important for our concept in realizing ubiquitous memories. Both the ''human body'' and ''object'' are essential device/media for augmenting human memory in *Ubiquitous Memories*, i.e., the human body behaves as a device/media that associates augmented memory with objects. The terms of the conceptual actions shown in Fig. 2 are defined as follows:

Enclose is shown by two steps of behavior: (1) a person implicitly/explicitly gathers current context through his/her own body and (2) he/she then arranges

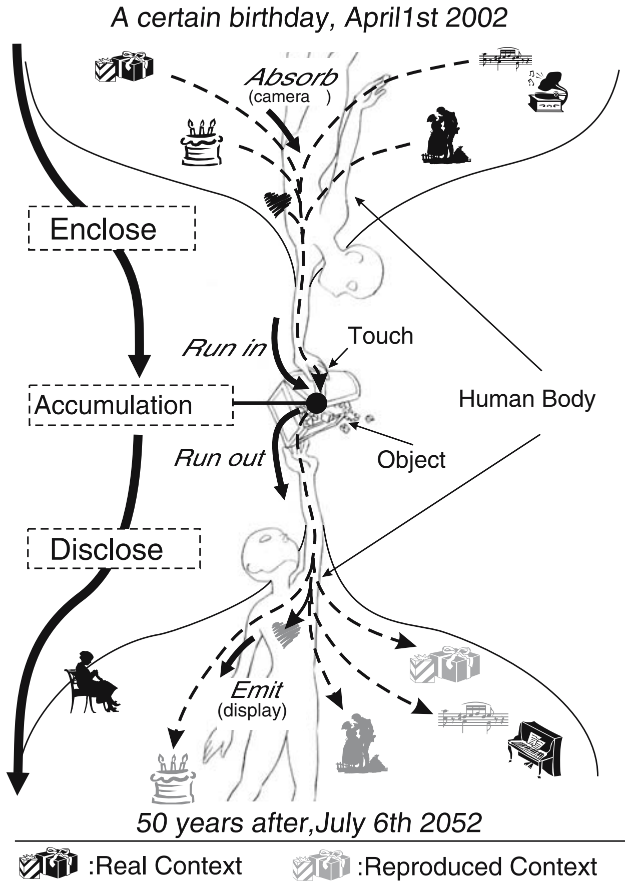


Fig. 2 Enclose and disclose for ubiquitous memories

contexts as ubiquitous augmented memory with a physical object using a touching operation. The latter step is functionally similar to an operation that records video data to a conventional storage media, e.g., a videotape, a CD-R/W, or a flash memory. The two steps mentioned above are more exactly defined as the following actions:

Absorb: A person's mind and body acquire contexts from an environment, in the same way that moisture penetrates into one's skin and is absorbed into the skin. Such an operation is called ''absorb'' and is realized by employing real-world sensing devices, e.g., a camera, a microphone, and a thermometer.
Run in: When a person touches a physical object, an augmented memory flows out from his/her hand and runs into the object. A ''run in'' functionally associates an augmented memory with an object. In order to actualize this action, the system must recognize the contact between a person's hand and the object, and must identify the object.

Accumulation denotes a situation in which augmented memories are enclosed in an object. Functionally, this situation represents how the augmented memories are stored in storages with links to the object.

Disclose represents a reproduction method whereby a person recalls the context enclosed in an object. "Disclose" has a meaning similar to that of replay (for example, the way a DVD player runs and replays a movie). This action is composed of the following actions: "Run out" and "Emit".

Run out: In contrast to "run in," Run out augmented memory runs out from an object and travels into a person's body. Computationally, the "Run out" (1) identifies the storage space where the augmented memories' linked objects are stored, and (2) these memories are retrieved from the Internet to a user's wearable PC. In order to achieve this action, the system needs contact and object identification functions such as "run in". In addition, the system must have a retrieval function to refer to augmented memories associated with an object.

Emit: A user can restore contexts in an environment to his/her mind and body. The system should employ devices, e.g., a video display and a headset that can play back an augmented memory.

3 Hardware implementation

Figure 3 shows the equipment worn with the *Ubiquitous Memories* system. The user wears a Head-Mounted Display (HMD; Shimadzu, DataGlass2) to view his/her experience data and a wearable camera (Kuroda Optronics, CCN-2712YS) to capture his/her experience as a video of his/her viewpoint. The user also wears a radio frequency identification (RFID; Omron, Type-V720) tag reader/writer on his/her wrist. Additionally, the user uses a VAIO jog remote controller (Sony, PCGA-JRH1) to control the system. The user carries a wearable computer on his/her hip. The RFID device can immediately read an RFID tag data when the device comes close to the tag. The entire system connects to the World Wide Web via a wireless LAN.

Fig. 3 Equipment of ubiquitous memories

This study assumes that each object in the real world is implanted/attached to an RFID tag. The *Ubiquitous Memories* system gets information from an object when a user touches the object by using the RFID tag reader/writer. Table 1 describes information recorded to the RFID tag. The RFID tag contains an identification number of the attached object and a control code. We have employed a serial number (SRN) of an RFID tag as a ID of the object. Also, the tag has a URL for addressing a server that has accumulated videos.

3.1 System architecture

Figure 4 illustrates the architecture of the *Ubiquitous Memories* system. This system is composed of a wearable client and ubiquitous servers. We term the server *ubiquitous memories server* (UMS). The core of this system is *UM control*. Data of the user's experience is managed by the *video buffer control*. The user can enclose his/her experience just after the experience has occurred. This system employs two types of databases. One is the *ubiquitous memories client database* (UMCDB) that only the user can use to refer to his/her own experience for private use. The other database is the *ubiquitous memories server database* (UMSDB), which is used to share users' experiences.

We have developed a transfer protocol, *ubiquitous memories transfer protocol* (UMTP) that is based on the HTTP to get/put data between the client and servers. The *Ubiquitous Memories* exchanges a message and a data by using the UMTP. Table 2 shows a type specification of transportation message and data. The transported information is composed with an identification part, a message part, and a data part. Note that parenthetic symbols mean that they are not necessarily to perform the *Ubiquitous Memories* system in the transportation. The UMSDB divides a transportation message among "only a message," "including a video data," and "including a list data" by using "message type" in the identification part. An "OID" is a ID (SRN) of a target object. A "UID" is a user's identification number. An "AT" is a permission level for

Table 1 Data construction in an RFID tag

	ID of a target object	Control code
Data	SRN	URL

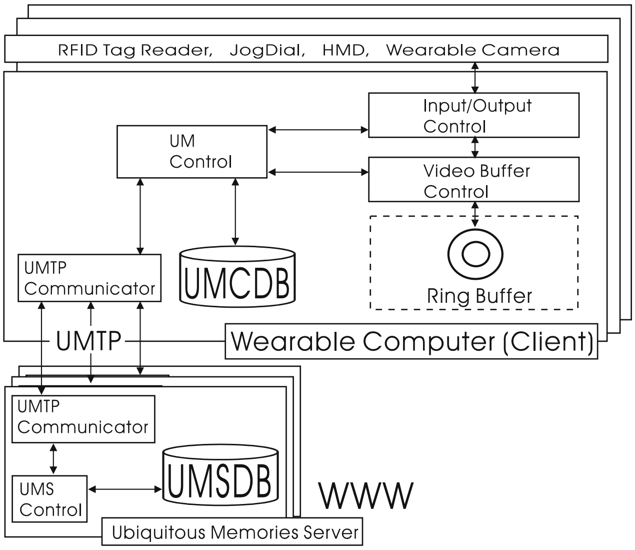


Fig. 4 System architecture

referring to a video. A "GID" is an identification number of a group. Members who are in a certain group can share their experiences with each other. A "TIME" is a time when an event was linked with an object by a user. A "List Data" includes information about videos that has been associated with an OID object. Table 3 describes an actual example of transportation message and data.

3.2 User operation

The *Ubiquitous Memories* system has five operational modes: ENCLOSE, DISCLOSE, DELETE, MOVE, and COPY. There are two basic operations and three additional operations for changing the mode. A user can select one of the following types:

ENCLOSE: By selecting the ENCLOSE operation and thus, an object sequentially, the user encloses his/her experience into an object. In this mode, the functions of "absorb" and "run in" are sequentially operated. Strictly, the ENCLOSE operation is composed of an OENC operation and a CENC operation. The OENC operation enables the user to enclose his/her experience just after the experience has occurred. The CENC operation is employed to enclose a user's experience that has occurred after he/she wanted to enclose the experience. The procedure for an externalization of memory is shown as follows:

Table 2 Type of transportation message and data

Identification	Message Type
Message	OID, UID, AT, GID, TIME, (Command)
Data	(Video Data)/(List Data)

Table 3 Example of transportation message and data

Identification	DATA
Message	0B8BE72400000009, 1000, 1, 9001, 20030909101231, OENC
Data	data.avi

STEP 1: A user changes a mode to ENCLOSE (OENC/CENC) by using a jog remote controller.
STEP 2: The user then touches an object.
STEP 3: The user selects a permission level from "private," "group," or "public." If he/she chooses "group", he/she must select one group from the registered groups.
STEP 4: The system accumulates a video including his/her experience in the UMCDB when the user selects the private level. If the user selects a group/public level, the system accumulates a video in both the UMCDB and the UMSDB.

DISCLOSE: The user can disclose his/her experience from a certain physical object. In this mode, the "Run out" function and the "Emit" function are sequentially operated. The procedure for recollection of memory is shown as follows:

STEP 1: A user changes a mode to DISCLOSE by using a jog remote controller.
STEP 2: The user then touches an object.
STEP 3: The *Ubiquitous Memories* system gives the user his/her experiences, which have enclosed into an object, as a list.
STEP 4: The user selects one of experiences from the list by using the jog remote controller.
STEP 5: The system discloses a video of his/her experience from the UMCDB/UMSDB.

Using additional operations, the user can operate his/her experiences in the real world in a similar way as files in a PC by using the "DELETE," "MOVE," and "COPY" operations.

4 Basic experiments and results

We conducted two experiments to evaluate the performances of the *Ubiquitous Memories* system [20]. The experiments clarified the "succession of the principle" and the "comparison of mechanisms." Note that we employed a stand-alone type *Ubiquitous Memories* system for the experiments to get clear experimental results of a base mechanism of the proposed system. The two experiments are detailed as follows:

• *A succession of the encoding specificity principle*: We must confirm the succession of the encoding specificity principle in the *Ubiquitous Memories* system. Cognitive researchers have known that the principle is one of the strong cognitive functions for memorizing and recalling numerous contextual events in everyday life. The aim of the first experiment is to find out how much effect the system design has on maintaining contextual events. We conducted the experiments with the following two conditions:

Condition 1: A recorded video, which is associated with a physical object, does NOT include an context related to the object.
Condition 2: A recorded video, which is associated with a physical object, includes an context related to the object.

If the *Ubiquitous Memories* system succeeds in the encoding specificity principle as an applicable augmented memory system, then the results show that the *Ubiquitous Memories* system's memory augmentation naturally support a user to recollect an event related to a physical object. Also, the results represent that it is hard for the user to recollect an event that is not related to a physical object. On the other hand, if the *Ubiquitous Memories* system does not succeed the encoding specificity principle, the user can employ all physical objects like a memorandum when the objects enable him/her to recollect any events easily. Otherwise, the *Ubiquitous Memories* system might not be employed as a novel memory externalization strategy at all when the user is difficult to recall any events by all objects.

• *Recollection efficiency of memory externalization strategies*: We must compare the *Ubiquitous Memories* system with other memory externalization strategies. In terms of memory externalization, each strategy has a unique mechanism to memorize events and to recall events. Investigating these mechanisms is an important point necessary for evaluating the *Ubiquitous Memories* system.

The second experiment aims to find how the *Ubiquitous Memories* system is different from other strategies and what memory strategy shows the most effective performance. We therefore focused on the following two directions for this experiment:

Investigation 1: An investigation of a mechanism for the *Ubiquitous Memories* system by comparison with other memory externalization strategies
Investigation 2: An investigation of an effectivity for the *Ubiquitous Memories* system by comparison with other memory externalization strategies.

In investigation 1, we investigated what kind of mechanism the *Ubiquitous Memories* system contains by comparisons with conventional memory externalization strategies, for instance, a memorandum and a photo album. If the mechanism of the *Ubiquitous Memories* system is similar to mechanisms of conventional strategies, a user can use the proposed system easily like doing with conventional memory externalization tools. If not, the user might have to additionally practice operations for the *ubiquitous memories* system. In investigation 2, we investigated an effectivity of the *Ubiquitous Memories* system for memory externalization by comparisons with conventional strategies. If the proposed system has better performance than the conventional strategies, this study suggests a novel and useful memory externalization strategy.

4.1 A succession of the encoding specificity principle

4.1.1 Experimental methods

This experiment was conducted at the Nara Institute of Science and Technology (NAIST) in Nara, Japan,

Fig. 5 Reference display for experiment 1

among graduate students of the Information Science Department. Seventeen Japanese test subjects participated in the experiment.

The experimental trial used pairs of an object image and a video in a trial (Fig. 5). We set a notebook PC under laboratory conditions. An object image and a video pair were displayed on a PC monitor. The linked video is replayed automatically when the subject clicked the displayed image. For example, the subject watched a video about "playing dolls" just after he/she clicked the image of a doll (see Fig. 5). The experiment contained 20 trials. In ten trials, each object in the displayed image was contained in the linked video. In the other ten trials, each object and the video had no semantic relationship. In the experiment, each trial was alternately performed. Test subjects could watch a video two times in each trial, and then, the subject could proceed to the next trial immediately.

After the subject finished all trials, there was a 3-min delay period. During this delay period, the Japanese test subjects had to read an international scientific journal paper and translate out loud 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. Eleven 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 min. 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.

4.1.2 Results

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

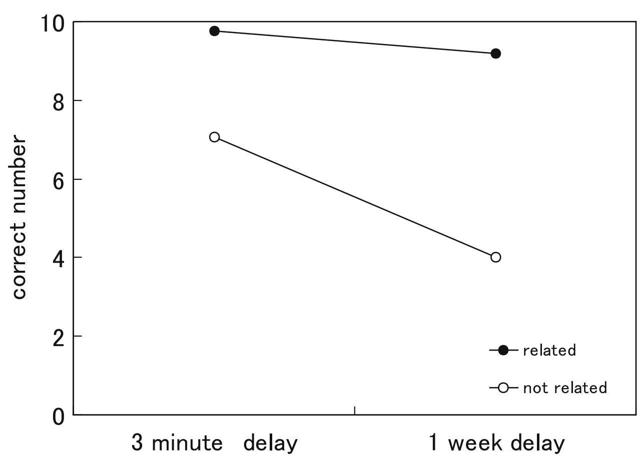


Fig. 6 Context effect

Figure 6 shows the average number of correct answers for evaluating context effect. The left side of the figure shows the average number of the correct answers in the 3-min delay questionnaires. The right side illustrates the average number of correct answers in the 1-week delay questionnaires. The black dots show the result of the questions for objects with videos containing objects themselves. The white dots show the result of the questions for objects in which videos did not contain objects themselves.

In the 3-min delay questionnaires, the average number of black dots is approximately 1.4 times greater than the average number of white dots. The results were analyzed using the variance analysis. 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 also shows a significant difference ($p < 0.0005$).

4.2 Recollection efficiency of memory externalization strategies

4.2.1 Experimental methods

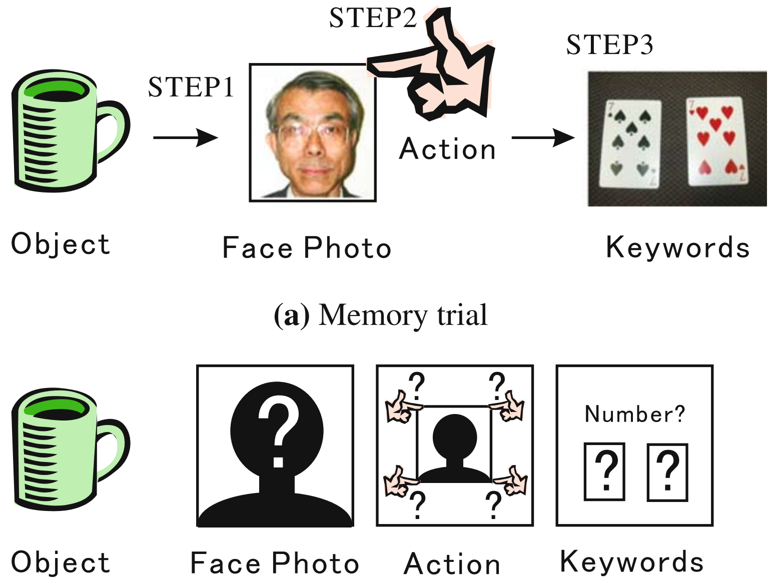
This experiment was conducted at the NAIST (Nara Institute of Science and Technology) in Nara, Japan, among graduate students of the Information Science Department. Twenty test subjects were included in this experiment.

For materials, we used ten physical objects that had no contextual relation to each other. We also used ten portraits of unfamiliar persons, and two sets of ten playing cards composed of the numbers 1–10. We conducted the experiment under laboratory conditions. One experiment was composed of a memory test and a recall test. In the memory test, the subject memorized ten trials. In the recall test, the subject answered a questionnaire.

Figure 7a illustrates an example of the procedure for the memory trial as follows:

STEP 1: The subject was first shown a pair consisting of an object and a portrait.
STEP 2: The subject then selected one of the corners of the portrait.
STEP 3: Finally, the subject was shown the predetermined pair of playing cards.

The subject was allowed to look at these numbers on the playing cards for 30 s. The subject then had to memorize the object, the portrait, the corner of the portrait he/she had pointed to, and two card numbers as an example of a real-world experience that included a time-series "narrative-type" procedure. The subject continuously tried to memorize all trials. All subjects



(a) Memory trial

(b) Recall trial

Fig. 7 Trials examples for experiment 2

had to do two experiments within the following four memory externalization strategies to evaluate a performance of each strategy:

C1: use only human memory (learn by heart)
C2: use only facial characteristics (record with a paper and a pen)
C3: refer to photo album type portraits that were used in the memory trial
C4: use the *Ubiquitous Memories* system to refer to portraits in the recall test

The 20 test subjects were divided into four groups of five subjects each. Group 1 did two experiments using conditions C1–C3. Group 2 took a test using conditions C3–C1. Group 3 experimented two times using conditions C2–C4. Group 4 did two experiments in conditions C4–C2. Figure 7b describes an example of the procedure of the recall trial. In the recall test trial, the questionnaire contained ten recall questions. The subjects were given one object image in each question. There were three empty boxes (portrait, corner, and card numbers) in a question. The subject then selected a portrait ID from a list having 40 portraits, marked a corner (Left-Top, Left-Bottom, Right-Top, Right-Bottom), and wrote down two card numbers. The subjects in condition C2, C3, and C4 were, respectively, allowed an additional action. The subject in condition C2 could check a recorded data of facial characteristics. The subject was given a list of ten portraits used in the memory test only in condition C3. The subject in condition C4 could disclose a portrait data directly from an object attached to an RFID tag by using the *Ubiquitous Memories* system. All subjects filled in some or all answers within 10 min. The question sequence was changed from the trial sequence in the memory test. All subjects were allowed to answer the questions in a random order.

Table 4 Recall rate

	CP (%)	CQ (%)	CR (%)	CS (%)
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

4.2.2 Results

Table 4 illustrates the recall rates taken from the 20 questionnaires. In this section, we define N, P, B, F, and "'"(apostrophe). *N* represents the percentage of errors, as follows: "N" represents no correct answers regarding a portrait, a corner of the portrait, and card numbers. P shows that the answer regarding the portrait was correct. B shows that the answer regarding which corner was pointed to was correct. F represents the answers of card numbers that were correct. X' (X is either P, B, or F) represents the answer of a question X that was not correct.

In Table 4, N (C1: 24.0%, C2: 31.0%, C3: 10.0%, C4: 2.0%, $p < 0.001$) and P (C1: 51.0%, C2: 55.0%, C3: 79.0%, C4: 94.0%, $p < 0.001$) shows a significant difference among the four test conditions (**: $p < 0.001$). Both B and F, however, do not show a significant difference in all conditions, respectively. P by C4 is, however, not 100% because of system error. Furthermore, there are the more three considerable results:

- In the sum of P'BF', P'B'F, and R'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%, $p < 0.001$). The results show that test subjects got the general influence of a mechanism in each memory externalization strategy for remembering a context of an event.
- The sum of PBF' and PBF shows the transparency in the different test conditions (C1: 36.0%, C2: 38.0%, C3: 49.0%, C4: 56.0%, $p > 0.1$). We can see no advantage for remembering action in any test conditions.
- The sum of P'BF and PBF represents the influence on the difference among the test conditions (C1: 18.3%, C2: 21.7%, C3: 28.3%, C4: 42.5%, $p < 0.05$). The *Ubiquitous Memories* system has the strongest advantage for an association between a portrait and card numbers.

5 Discussions

We need to confirm the succession of the encoding specificity principle. Figure 6 showed that the *Ubiquitous Memories* system allows users to effectively perform contextual events associated with physical objects. The user can easily recall the event abstractly by simply looking at the object because of the encoding specificity principle. The user then can recollect the actual scene of the event by using the *Ubiquitous Memories* system. The result of this experiment also means that the effect cannot be performed when an event has no contextual relations to the objects.

We also need to investigate which kind of memory externalization strategy performed best. Table 4 shows that the *Ubiquitous Memories* system was the most effective. The differences are especially clear in the result of N and P. However, both B and F do not show significant difference. These results mean that a user does not get any advantages of the ratio of remembering contexts when he/she chooses any memory externalization strategies. But the *Ubiquitous Memories* system gives the user a better support because the result of P shows that the amount of remembering contexts in the condition of C4 is better than any other conditions. In the result of PBF (C1: 13.0%, C2: 18.0%, C3: 17.0%, C4: 25.0%), C4 showed the relationship of an object associated with a portrait. Also, the sum of P'BF', P'B'F, and P'BF (C1: 25.0%, C2: 14.0%, C3: 11.0%, C4: 4.0%, $p < 0.001$) shows a good result for the *Ubiquitous Memories* system. Especially, the results of both the sum of PBF' and PBF (C1: 36.0%, C2: 38.0%, C3: 49.0%, C4: 56.0%, $p > 0.1$) and the sum of P'BF and PBF (C1: 18.3%, C2: 21.7%, C3: 28.3%, C4: 42.5%, $p < 0.05$) show that the *Ubiquitous Memories* system augments the human's capacity for remembering appendant contexts of an event.

In the experiment, the system showed the following two considerable results:

1. The system effectively and clearly supports users' contextual event association with physical objects by using the encoding specificity principle.
2. The result shows that the "Enclose" and "Disclose" operations, which enable users to directly record/refer to a video memory into/from an object, are effective enough to spread human memories ubiquitously in the real world.

The results in two experiments show that the *Ubiquitous Memories* system is more useful than conventional memory externalization strategies. Increasing the cognitive workload adds knowledge about how best to conduct oneself in a certain situation or in events in our increasingly complicated lives. The former result means that a user can make ubiquitous memories without special cognitive overloads using our proposed system.

6 Practical evaluation for operation

We have evaluated operationality of a system control and validity of operation classes by practically using the *Ubiquitous Memories* system in a system development process. Operationality of the system control is an important topic for a long-term use in the daily life. Therefore, an operation design is necessary to achieve an intuitive interface, which enables a user facilitate to operate with low cognitive load, for a wearable system. The design, which is not to prevent the user from activating the users' own memory, is needed in the case of operation when the user externalizes a memory and reuses an enclosed experience.

6.1 Tag operation versus jog control

In order to evaluate operationality of a system control, we have, respectively, implemented two types of controllers. One is a controller using RFID tags. We call the RFID tag for operations "operation tag." We have also

Table 5 Results of operation tags

Advantage	1. A user can operate the system by using only a "touching" action 2. The user can set operation tags at any places in the users' body
Disadvantage	1. Operation tags increase when operation classes are complicated 2. Is it difficult for the user to select an experience from enclosed experiences in an object

employed a jog remote controller (Sony, PCGA-JRH1) as the other controller.

In the test of operation tags, we set two operation tags at the side of users' head (near each ear) in the first trial. One was for ENCLOSE. The other was to operate DISCLOSE. In the second trial, we attached operation tags for ENCLOSE, DISCLOSE, DELETE, MOVE, and COPY to one size of the users' wrist.

Table 5 describes advantages and disadvantages of the operation tags. The first advantage shows a high operationality so that (1) a user does not need for paying attention to an existence of other controllers, and (2) the user can operate the *Ubiquitous Memories* system naturally. Personalizing interface is also important to control operationality by the users' oneself. On the other hand, two disadvantages arise in the case of increasing operation classes and selection of an experience from enclosed experiences. In the former case, the number of operation tags was increased when we, respectively, defined ENCLOSE, DISCLOSE, DELETE, MOVE, and COPY in each tag. The tags made the user to be confused. We had to attach labels, e.g., "ENCLOSE," to each tag. In order to improve this problem, an intuitive combination operation method such as gestures in a baseball game is necessary to suppress a number of operation tags. We found that an operation tag method was not suited for selection of an experience from experiences massively enclosed in an object.

In the test of a jog remote controller, we employed ENCLOSE, DISCLOSE, DELETE, MOVE, and COPY. A user can select all operations by using only a dial. Two actions are set at the dial to control the system. One is a "scroll" for changing an attention point in candidate operations or candidate disclosing experiences. The other is a "push" to decide a certain operation or experience. The controller had been set in a chest or pants pocket.

Table 6 shows advantages and disadvantages of the jog dial controller. We think that a jog scroll action is useful for selecting an experience from enclosed experiences in an object. The jog remote controller suppresses users' mistakes for selecting an operation so that the user selects only an operation exclusively in the jog controller. Two disadvantages, however, remain in the controller. Users' activity in the jog controller method was decreased by comparison with the operation tag method when the user operated the system by paying attention to an operation of the controller. Additionally, increasing the number of enclosed experiences in an object makes operationality of a one-experience selection worse even though the jog remote controller gave the user an easier operation than the operation tags.

In the investigation, we found that the combination between the operation tags and the jog remote controller has complemental advantages to achieve high operationality of a system control. In order to provide more useful operation to the user by using RFID tags and a jog remote controller, the *Ubiquitous Memories* system would employ the jog remote controller as the primal operation to centralize the control point. Additionally, the system would employ RFID tags as the secondary operation to externalize operational functions. Externalization of operational functions means a procedure to associate an operation with an enclosed experience before the user selects the operation. The system, for example, could operate a function that automatically deletes an experience when the user discloses the experience. The function could be supposed kind of a digital tag with a conditional valid period in order to suppress number of enclosed experiences.

Table 6 Results of a jog remote controller

Advantage	1. A user can select all operations with a jog remote controller 2. The controller enables the user to facilitate a selection of an experience from enclosed experiences in an object by using a dial interface
Disadvantage	1. Users' activity is reduced by frequent operations 2. Scalability of operation for selecting experiences is low

6.2 Operation classes

We have implemented ENCLOSE, DISCLOSE, DELETE, MOVE, and COPY as basic operations. In this study, we have confirmed that the operations are essential for the *Ubiquitous Memories* system in the practical test. Also, we found that more operations are needed in order to improve operationality that the user can operate with low cognitive load. An experience is related to one or more objects. Therefore, functions as multiple operations have important roles when a user wants to externalize or reorganize experiences using objects. There are two types of multiple operations. One is a sequential step operation. The user continuously operates the system using the same operation. The other is a batch step operation. The user externalizes an experience to objects or reorganizes experiences with object(s) at the same time. In this article, we only discuss the batch step operation. Necessary operation classes hereafter are shown as follows:

MULTIPLE ENCLOSE: A user encloses an experience to objects, which are related to each other, when the user touches one of the objects. For example, the user touches a bat to enclose an experience in a baseball game, and then the experience is enclosed to a glove and a uniform automatically.

MULTIPLE DELETE: If an enclosed experience in objects is not needed for the user, the user might want to delete the experience with only one-time operation. For example, the user deletes an insignificant experience in a baseball game, which includes only a vertical scene of ground, from a bat, a glove, and a uniform.

MULTIPLE MOVE: This operation is similar to the MULTIPLE ENCLOSE operation. The user moves an enclosed experience from a certain object to other objects when the user touches one of other objects. The role of the MULTIPLE MOVE operation is basically the same as the MOVE operation. For example, a mother in spectator's stands temporarily had enclosed an experience to a notebook when a son had played a baseball game. Then she moves the experience from the notebook to a bat, a glove, and a uniform to share the experience with her son.

MULTIPLE COPY: This operation is similar to the MULTIPLE MOVE operation, except for keeping an enclosed experience in a source object. For example, the user girl gets presents for her birthday from her boyfriend. She then encloses experiences of this event. The girl recalls not only the event but also all memories with the boyfriend. Therefore, she copies experiences, which are enclosed to old presents by using the ENCLOSE or MULTIPLE ENCLOSE operation, to new presents.

We had been eager to use these operations during the practical test. It is important for the user to treat experiences naturally and intuitively. Two strategies exist in order to achieve these operations. One is an advanced definition of a relation among objects. This strategy is, however, hard to employ for a relation among objects that is dynamically changed by a context of an external event. The other is to detect a relation among objects per each event. This strategy must have a function that can put candidate objects down to a set of contextually related objects.

7 Conclusions

In this paper, we have proposed a novel concept of a memory externalization system named *Ubiquitous Memories* using physical objects by implementing a prototype system. The *Ubiquitous Memories* system has been designed using a conceptual design based on human cognitive behavior via a touching operation. In order to evaluate the system, we have conducted two experiments. The first experiment confirmed the succession of the encoding specificity principle mechanism to the *Ubiquitous Memories* system. The aim of the second experiment was to clarify the characteristics of the *Ubiquitous Memories* system by comparing it with other memory externalization strategies. Experimental results show that the *Ubiquitous Memories* system is effective enough to support a memorization and recollection of contextual events in the real world. We believe that the *Ubiquitous Memories* system is helpful for stand-alone use because of the positive results of the basic experiments.

Through these experiments, we have realized that a long-term investigation of mechanisms in everyday life on a single-use or among multi-users will require a year or longer. Also, in order to accomplish these experiments, the system must have an adequate reliability for service. Based on experimental results and their considerations, we are planning to refine the next version of the *Ubiquitous Memories* system and continue practical evaluation experiments in our daily life. We therefore have already attached 2,257 RFID tags to physical objects in our laboratory as the first step toward this plan of investigation [21].

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