TansuBot: A Drawer-type Storage System for Supporting Object Search with Contents' Photos and Usage Histories

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Abstract— **In spite of IT innovation, people cannot get rid of non-creative tasks of searching daily-use objects at home. This paper presents a drawer-type storage system for supporting object search, "TansuBot". By using this system and a smart device (e.g. smart phone), a user can review the photos of contents stored in the system. In addition, the system can present candidate drawers where the searching target object may be stored based on preliminary information such as usage histories. Concretely, LED blinking and pop-up actions (pushing drawers forward) are used for display. To realize these supports, a stacker crane type wall-moving robot is equipped at the backside of storage. The robot has a movable camera and mechanisms to push a drawer forward. For easy installation to a home, storage efficiency and cost reduction should be considered in the design of the instrument. Especially for cost reduction, this paper presents an approach to use wooden parts for main mechanisms. This approach also contributes to user-friendly presence and appearance of the instrument. This paper reports about the development of a prototype and an experiment to evaluate the functions for supporting object search. The results of the experiment prove the importance of the functions realized by the system; displaying contents' photos on a smart device and showing candidate drawers to investigate. The outcomes indicate that those functions have positive effects on reduction of searching time and mental burden.**

I. Introduction

As our life become more affluent, we must deal with numerous objects in daily lives. In an industrial or commercial environment such as factories and drug stores, some specialists organize the objects carefully. On the other hand, in a home environment without such specialists, objects are generally not well organized. Now "searching objects" is one of the most stressful tasks at home. Therefore, some people are highly interested in home-storage and decluttering. In fact, many empirical guide books are published and have a large sale[1][2]. In spite of long-term stress from home-storage problem, no clear engineering or technical solution has been developed yet.

For example, people cannot find an object while he or she is in a rush; especially a daily-use small object such as stationery and a PC-related item is troublesome. This is because, even if people define the position for the object to be stored, it is difficult to keep it in the place, and sometimes the object disappears behind other objects. Moreover, in a house where several residents live, it is not practical to decide the definite home positions of all objects. It is also difficult to obligate all the residents to follow the rules. Thus, sometimes it is very tough work to find an object that other people have moved before.

There are a substantial number of previously proposed systems to support object search at home. Some of them use RFID tags[3][4][5][6][7][8] or AR Markers[9] for identification of objects. In these systems, objects can be managed accurately; however, all objects must be attached with tags individually. When introducing those systems into home, a user must attach a tag even to tiny objects, and the tag sometimes makes a user feel uncomfortable to use the object. There are some tagless systems that use images of overhead cameras installed at the ceiling of a room[10][11][12]. However, those systems need high-resolution cameras or pan-tilt-zoom movable cameras to observe small objects. These cameras are expensive to be introduced into a home. In addition, those systems cannot detect an object occluded by other objects. In contrast, egocentric vision[13][14][15][16] can effectively provide information about objects to a particular user. Those systems are not so expensive but these instruments restrict the user's activities and make the user to feel bothersome because the user must wear these instruments all of the time.

It is possible for a system with cameras to solve these problems by concentrating the operation target in a single instrument such as a shelf with drawers. For example, BoxFinder[17] and DrawerFinder[18] use a few cameras installed at the top of a shelf. Those cameras take photos of contents stored in the shelf whenever a user accesses to the contents of the drawers. However, it's not an easy task to take a clear photo of contents while the user is accessing to the shelf dynamically. Those cameras cannot monitor the whole space of a drawer because there is at least small overlapping between the shelf and the drawer. By installing multiple cameras at every drawer[19][20], very clear and accurate photos can be taken; however, a large number of cameras cost very much.

In this research, we propose a storage system to support search for small daily-use objects at home; "TansuBot" (Fig. 1). The name of "TansuBot" derives from the name of Japanese traditional drawers for clothes; "tansu". In this system, the main structure is a drawer-type (tansu-type) shelf. The system monitors objects with a movable camera. Every time a user accesses the shelf, the system collects contents' photos and usage histories. By using the collected information, the system can support object search. This approach needs no tag to be attached with on each object. In addition,

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Fig. 1. The prototype of TansuBot.

the system can take the contents' photos automatically and stably. The system is very compact and easily introduced into home because it comprises only one shelf and supplemental equipment installed at the shelf. Authors develop a prototype of the system and evaluate its effectiveness for users' object search support.

The cost of the system is also an important factor to realize smooth introduction into home. To reduce manufacturing cost, we adopt a design approach of using wooden parts in the main mechanisms. There is an example of using wooden parts as the main structure of a robot arm[21]. The approach also contributes to user-friendly presence and appearance of the instrument. In this paper, we discuss how to utilize effectively wooden parts in mechanical structures.

The framework of this paper is as follows. Section II mentions required functions and the basic configuration of the system. Section III explains the development of a prototype, focusing on the design to realize easy introduction. Section IV describes an experiment to evaluate functions to support object search. Section V concludes this paper.

II. TansuBot for object search support

This section defines the required functions of the system and describes the basic configuration of the system. This system must be implemented with three basic functions described below:

(1) Recording time and a location of an opened drawer at each time the user accesses a drawer
(2) Shooting photos of contents in drawers automatically
(3) Accumulation of these information and support user's object search

When function (2) is implemented, the photo should be taken soon after the user accessed the drawer because the contents changes frequently. If possible, the system should take a high-resolution photo of whole area in each drawer because the user can recognize each content more easily. To realize function (3), the system should give users information for search efficiently. For example, a smart device (e.g. smart phone) is efficient tool to give users the information. Users can periodically access the information with the smart devices. In addition, each drawer of the system should have a simple displaying device. Such displaying device can easily point out a specific drawer.

Those functions are combined into two main searching supports. Fig. 2 shows example stories by those two supports.

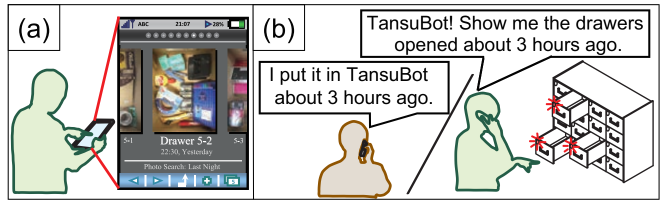

Fig. 2. Example stories of how to use TansuBot.

These supports are expected to make users' object search more efficient.

(a) Search by photos: A user can browse the contents' photos with a smart device. The system provides not only current photos but also photos of contents' histories.
(b) Displaying candidate drawers: If a user has some information preliminarily such as "the object has been used about 3 hours ago", the system can indicate the candidate drawers where the target object may be stored. The system has two methods for displaying target candidate drawers; one is by LED blinking and the other is by a pop-up action. Pop-up means pushing drawers forward and opening it. When the number of candidates is large, the LED blinking method is preferable because it is troublesome to close many pop-up drawers. Surely, the pop-up method seems to be more interactive for users.

Fig. 3 shows the configuration of the system to realize those functions and supports mentioned above. Each drawer has an LED for displaying and an open/close detect switch. A wall-moving robot is equipped on the backside of the shelf. This robot is a simplified version of an industrial stacker crane[22]. It has an extensible arm where a camera is placed at the end. When taking photos, the camera is inserted into the upper space of each drawer by extending the arm. The extending motion of the arm is also used for the pop-up function. That means the arm pushes each drawer forward.

This system has web server. It is used to give information to users via web browser on smart devices.

III. Design for TansuBot prototype

In this section, design of a prototype is discussed. Particularly this section focuses on how to realize primary functions and on how to introduce the instrument into home smoothly.

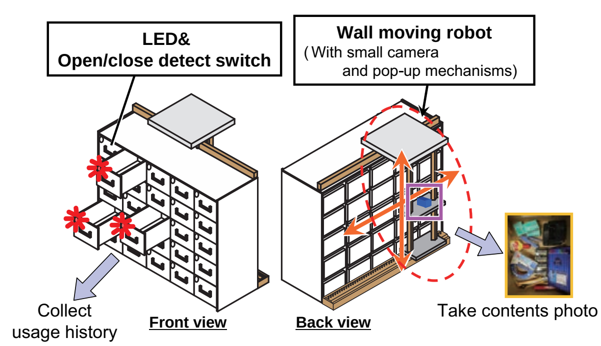

Fig. 3. Total system configuration of TansuBot.

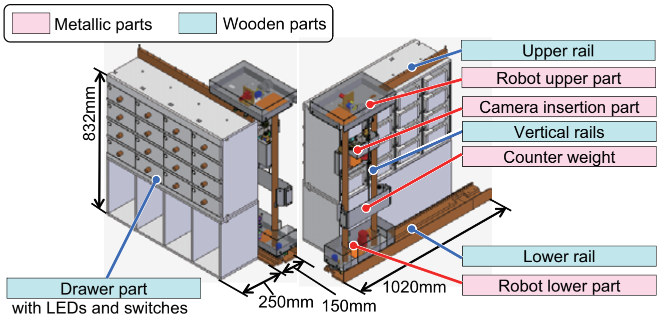

Fig. 4. The framework of TansuBot prototype.

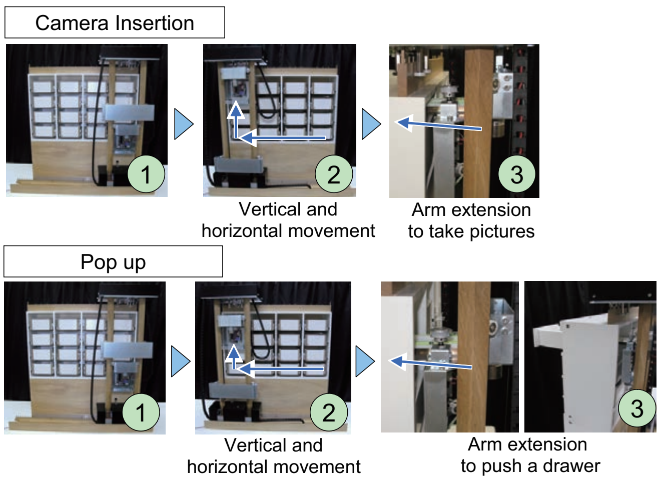

Fig. 5. Sequential snapshots of robot motions.

A. Overview of the prototype

Fig. 4 shows the framework of the prototype. The wall-moving robot consists of camera insertion part, upper part, lower part, a counter weight and vertical rails. The robot moves horizontally guided by the upper rail and the lower rail. The camera insertion part moves vertically with a wire winch mechanism, and the part is guided by the vertical rails.

Fig. 5 shows the sequence of robot motions. First the whole robot moves horizontally and the camera insertion part moves vertically. After that, for taking photos the extensible arm is extended and the camera is inserted into the upper space of each drawer. When it executes a pop-up action, the arm pushes the backside of each drawer forward.

B. Design for keeping storage efficiency

For introducing the instrument into home easily, two points should be considered mainly: keeping storage efficiency and cost reduction. First, design for keeping storage efficiency is discussed. The instrument needs a robot action space as shown in Fig. 6. The space has two types; one is the space where the robot moves horizontally on the backside of the shelf, and the other is the upper space of each drawer where the robot inserts the extensible arm with the camera. The more space the robot requires, the less space is available for storage; that is, the storage efficiency decreases. For this reason, the robot action space should be as small as possible.

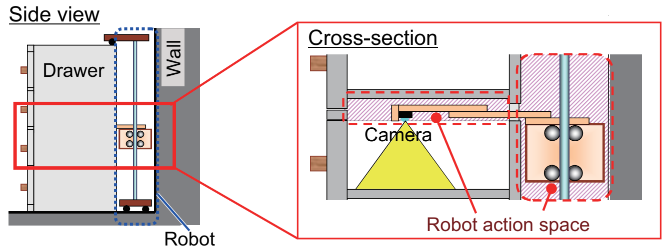

Fig. 6. Robot action space.

The structure of the extensible arm is the most important element to save the space. To decrease the space where the robot moves horizontally, the length of the arm needs to be short in the contraction state. In contrast, the arm needs to have an enough stroke to take photos of whole area inside a drawer. The arm should be thin because the thinness contributes to decrease the space for inserting the camera. Fig. 7 shows the structure of the extensible arm satisfying these requirements. This arm consists of four steps of extension rails made of POM (polyacetal), and the rails slide over each other. This arm extends by pulling wires in the same way as extension-ladders[23]. When the arm contracts, it uses the force of constant force springs (Constons). The structure realizes both downsizing in the contraction state and enlargement of the arm stroke. Despite of the difficult requirements, the designed structure is concise and compact. This structure reduces the proportion of the robot action space to total space. As shown in Fig. 8, the proportion is 53%; it is lower than that of the instrument without this structure (66%).

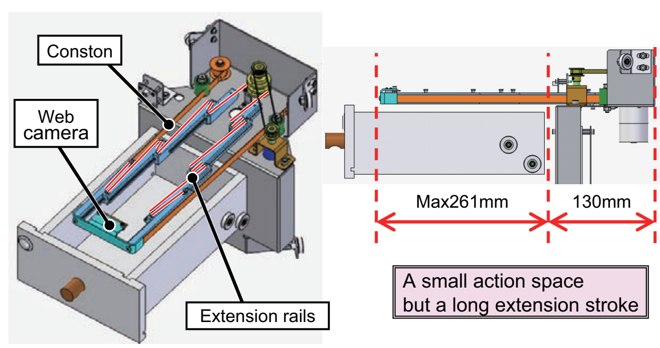

Fig. 7. The structure of extensible arm.

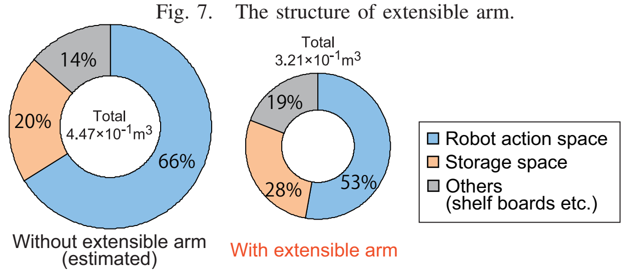

Fig. 8. Reduction of robot action space.

C. *Design for cost reduction*

As the most distinctive approach, wooden parts are used in main mechanisms to reduce the cost of the instrument. Comparing with metallic materials, wood is cheaper to realize required volume, and has characteristics: volume change via humidity, low abrasion resistance. A mechanical engineer must pay attentions to those characteristics in the design process. In this instrument, the drawer-type shelf is made of wood. The upper rail, the lower rail and the vertical rails are also made of wood.

There are some popular linear mechanisms such as (1) a sliding mechanism with a pipe and a linear bush and (2) a guide mechanism with an H-shaped rail and multiple rollers. However, these mechanisms can not be used as the guide mechanism for vertical movement because the wood expands by humidity. The expansion of a structure may cause a jamming of the guide mechanism.

Fig. 9 shows the guide mechanism used in the instrument. Six guide rollers support the camera insertion part as shown in Fig. 9-(B). A moment is generated around the wire fixed point as shown in Fig. 9-(A). By the moment, the rollers are pushed to the vertical rails whatever the position and the state of the camera insertion part are. Consequently, the camera insertion part can move stably. This structure is not affected by the expansion of the vertical rails because the camera insertion part absorbs the effect by changing its own attitude as Fig. 9-(C) indicates.

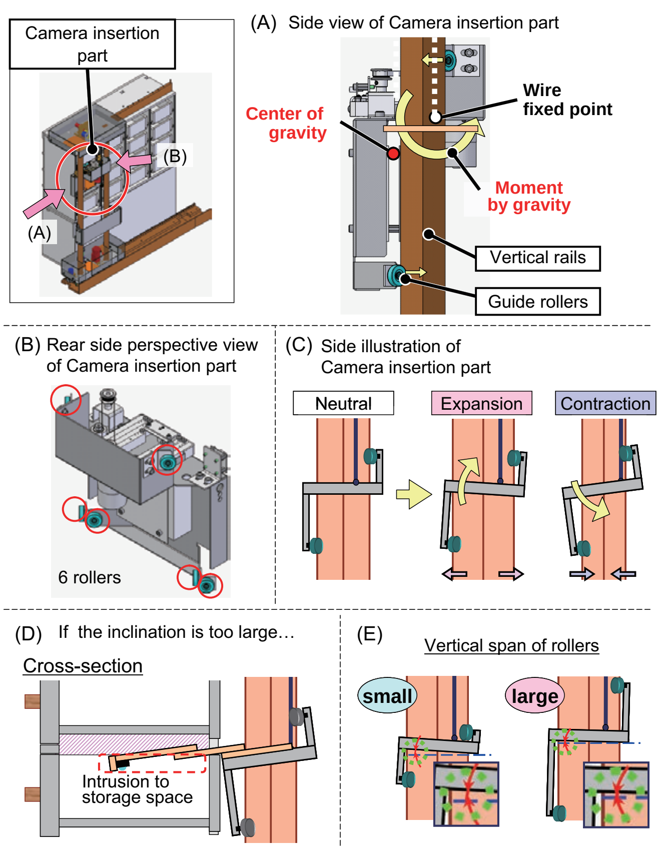

Fig. 9. The mechanism for vertical movement of the camera insertion part.

However, an excessive change of the attitude causes an other problem shown in Fig. 9-(D). In this case, the extension arm intrudes to the storage space and may touch the contents. To overcome this problem, the vertical distance between upper rollers and lower rollers is configured to be long enough. As shown in Fig. 9-(E), the longer the vertical distance is, the smaller the inclination angle becomes. The optimal configuration of the roller distance makes the inclination angle within an acceptable range. This mechanical structure can realize stable motion regardless of volume changes in wooden material.

For the horizontal movement of the robot, a pin gear mechanism shown in Fig. 10 is used. A wooden pin rack in the lower rail is made by dowel attachment, a characteristic manufacturing process in woodworking. The pins can be exchanged because they may degrade by abrasion.

These mechanisms have been evaluated by basic movement tests. In the design of the instrument, the horizontal positioning error of the robot must be within ± 3.75[mm] to execute the camera insertion and the pop-up action adequately. In addition, the vertical positioning error of the end of the extensible arm must be within ± 4.85[mm]. It has been confirmed by the tests that this instrument satisfies these requirements. Accordingly, this instrument has enough performances to execute all the required functions.

This research introduces proactively wooden parts into the main mechanisms. The design methodology is summarized in three basic tips as follows. These tips represent the way to realize both cost-cutting and stable movement of robots while using wooden parts.

- Large volume parts should be made of wooden material preferentially.
- The effect of wooden expansion/contraction must be managed intensively in a specific mechanism.
- Wooden specific processing methods should be used proactively to exploit the advantage of wooden part.

D. *Design of electrical equipment and system software*

The instrument has three degrees of freedom: horizontal movement of the robot, vertical movement of the camera insertion part and the movement of extensible arm. Three motors and related sensors should be placed separately to realize these movements. The system should control these

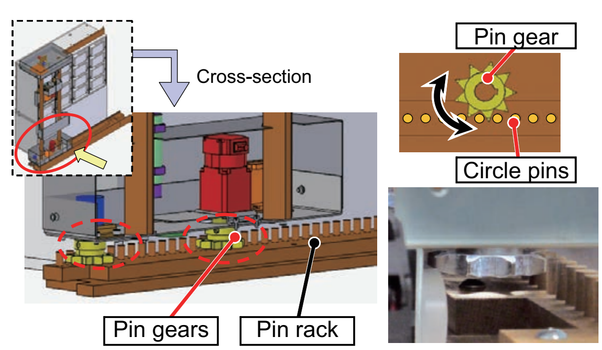

Fig. 10. Horizontal movement by pin gear.

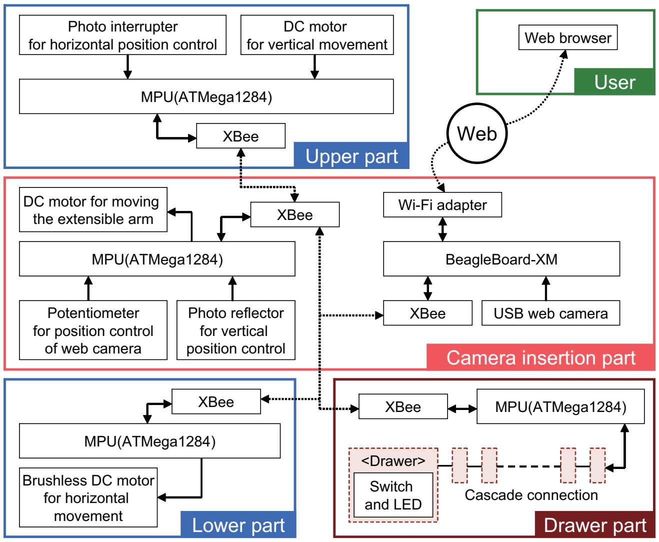

Fig. 11. System block diagram of main electrical components.

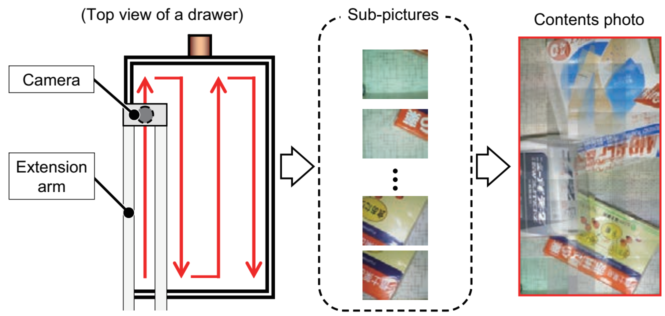

Fig. 13. Method take a contents' photo of a drawer.

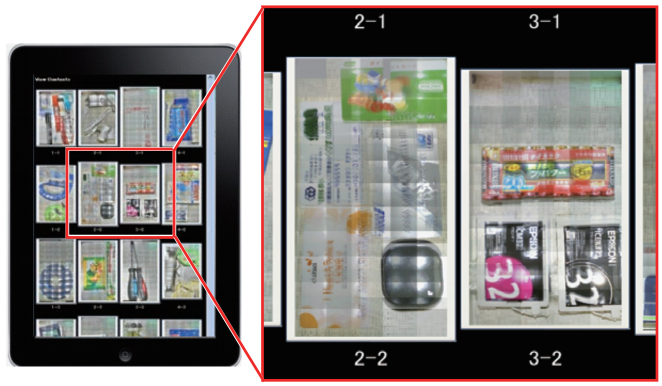

Fig. 14. Contents display on a web browser.

motors and sensors synchronously. Moreover, the system requires some information processing functions such as image processing and web service. Reduction of wiring is also necessary because the instrument has many moving parts and need to reduce its volume.

Fig. 11 shows the block diagram of the system satisfying these requirements. The system is controlled by four distributed control circuit boards with Atmel AVR microprocessors and BeagleBoard operated by Linux. Three control circuit boards control the movement of the robot and one board controls/monitors the state of drawers. BeagleBoard processes the contents' photos, makes the usage histories and provides the information as a web server. The control circuit boards and Beagleboard communicate each other with wireless communication (XBee). Thereby, the system does not need signal lines between circuit boards.

Each drawer has a circuit board with an open/close detect switch and a LED as shown in Fig. 12. The wiring between the circuit boards is realized by cascade connection. That is, the signal line is attached along only one pathway.

When the system takes a content photo in a drawer, it collects sub-pictures in various positions while moving the camera on the path shown in Fig.13-left. This is because the angle of view is limited; i.e. the camera can not take a whole-view picture of one drawer by a single shooting. When taking pictures, the system uses a light attached at the head of the extensible arm. The collected sub-pictures are connected with template matching such as Fig. 13, and the connected image is saved as a contents' photo.

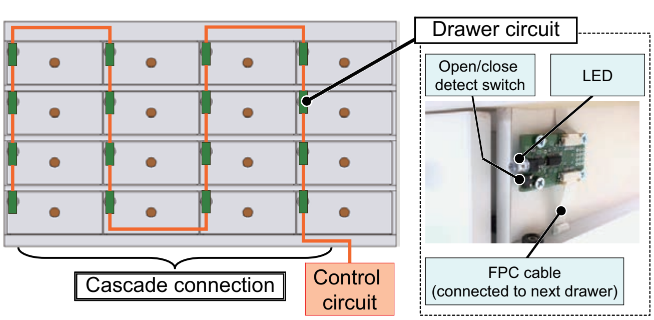

Fig. 12. Detail of circuit in drawer part.

The information such as the contents' photos and the usage histories are accumulated and accessible via network. For example, users can browse the contents' photos as shown in Fig. 14. This viewer is implemented as CGI (Common Gateway Interface). By clicking a content photo, users can operate the LED blinking or the pop-up action of a drawer.

IV. Experiment

An experiment was conducted to evaluate the effectiveness of the object search supports. This experiment examines whether the time to search a target object becomes shorter, and whether a user's mental burden decreases, by using the developed functions.

A. Experimental setup

This experiment uses 40 daily-use objects. First, the experimenter shows these objects to a subject, and the subject recognizes their characteristics. Second, these objects are stored in the drawers. After that, the subject searches for an instructed target object. In this way, the searching time is measured. The subject uses the following three ways to search the target object: (1) no support (Fig. 15-1), (2) the subject views the contents' photos with a smart device and can emphasize the target drawer with LED blinking by clicking the photo (search by photos, Fig. 15-2), (3) the subject indicates N candidate drawers by clicking a button on the smart device (displaying N candidate drawers, Fig. 15-3). The third way simulates a condition where the subject can select candidates based on preliminary information such as usage histories. In this experiment, N was configured to 3 empirically.

After the experiment, the subject answers a questionnaire. This questionnaire intends to compare the difference of the subject's mental burden among the three searching ways. The subject scores the level of (a) mental demand, (b) physical demand, (c) frustration and (d) time pressure in each searching ways, from 0 point to 10 points in 0.5 point steps.

The storage pattern of the daily-use objects was changed in each trial. That is, the subject can not remember where the target object is stored. This setup simulates a situation (i) when a user searches an object that other people put in the system or (ii) a user searches an object that the user put in the system long time ago. Subjects are 12 males and three females in their 20s to 30s. The repetition time is five in each way, thus the total number of trials per subject is 15.

B. Results

Fig. 16 shows the results of the average searching time. The average searching time of (2) search by photos or (3) displaying 3 candidate drawers is shorter than that of (1) No support. The variation in the searching time of (2) or (3) is also shorter than that of (1). There is a significant difference between the average searching time of (1) and that of (3) (Welch's t test, $t(82) = 5.20, p = 7.3 \times 10^{-7} < 0.05$). However, the difference between the average of (1) and that of (2) is not significant (Welch's t test, $t(144) = 1.354, p = 0.080 > 0.05$).

Fig. 17 shows the results of the average subjective score about mental burden. The level of (b) physical demand and

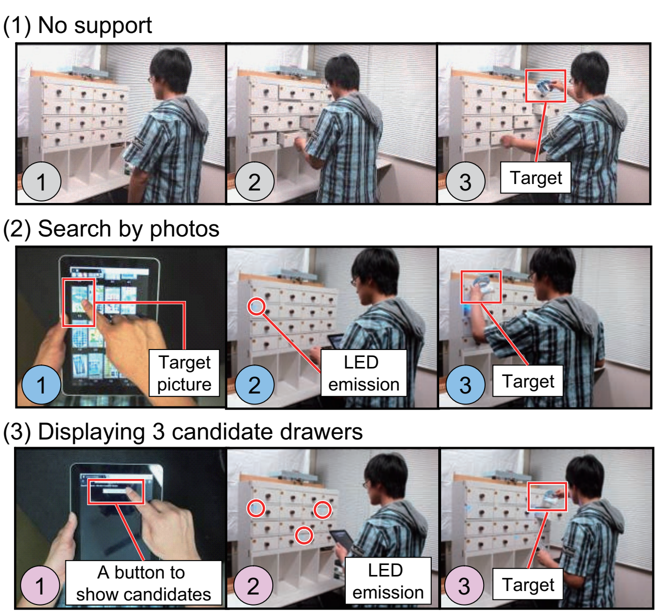

Fig. 15. Sequence of each condition in the experiment.

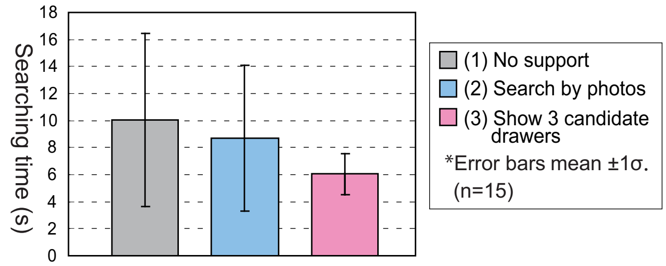

Fig. 16. Comparison of searching time.

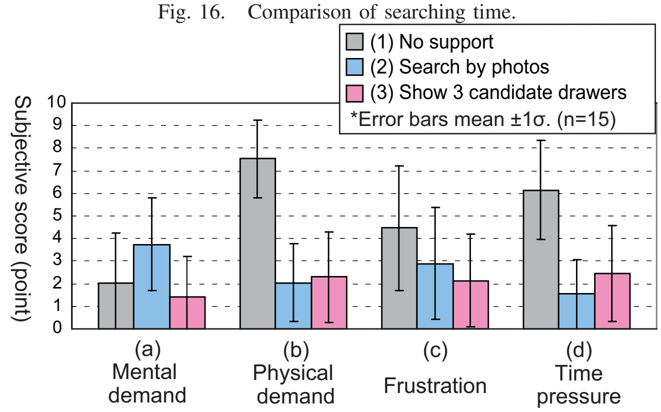

Fig. 17. Comparison of questionnaire's results.

(d) time pressure of (2) and (3) is much lower than that of (1). The level of (c) frustration of (2) and (3) is also a little lower than that of (1). The level of (a) mental demand of (2) is highest of all.

C. Discussion

1) The effectiveness of searching by photos: Though the searching time reduces, the difference is not significant. The function is expected to reduce the searching time because a user needs not to open many drawers. Indeed, the level of (b) physical demand is lower when the function is used. In addition, the levels of (c) frustration and (d) time pressure drastically decrease. Therefore, the subjects must be able to search the objects without stress.

The reasons why there is no significant difference in the searching time are because of low quality of contents' photos and subjects' deficient habituation to a smart device. First, we must improve the quality of contents' photos. Especially we need to upgrade the connection algorithm of the sub-pictures. Second, we need to emphasize the information of the shape and the color in the contents' photos. That is because the information strongly influences the result of the searching time. As Fig. 18 shows, the searching time is reduced when the object has characteristic shape or bright colors.

The effects of a user's habituation can be discussed by focusing on the number of trials. Fig. 19 shows the comparison of the average searching time with (2) search by photos between trial 1-3 and 3-5. In this result, the average of trial 3-5 is shorter than that of trial 1-3, and the variance of the time of trial 3-5 is smaller than that of trial 1-3. In addition, the average of trial 3-5 is much shorter than that

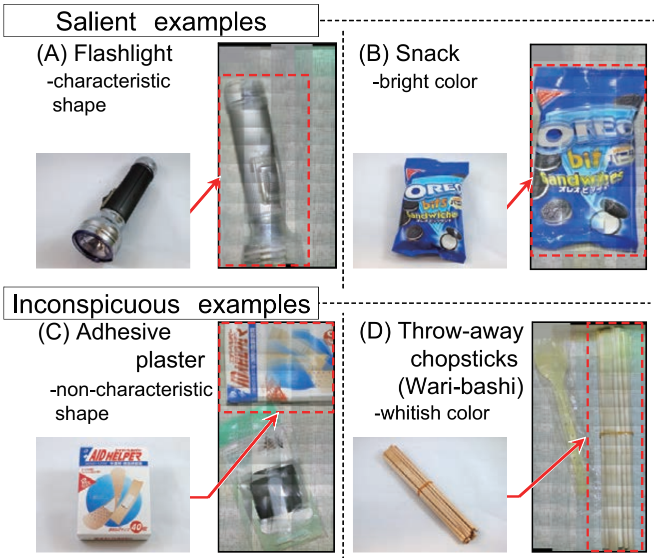

Fig. 18. Examples of positive/negative photo for object searching tasks.

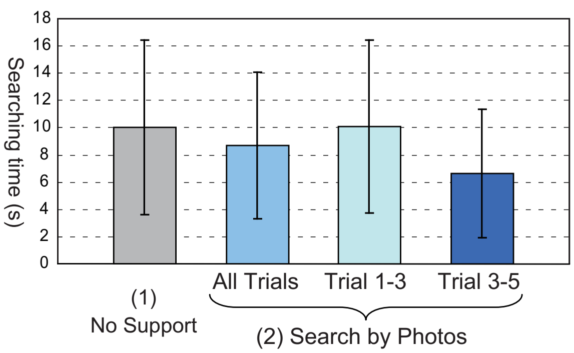

Fig. 19. Effect by habituation in the experiment.

of (1) no support. The difference is significant (Welch's t test, $t(113) = 2.25, p = 0.013 < 0.05$). Actually, more than half of the subjects do not use smart devices in their daily lives. This result shows that it is possible for a user with enough experiences of smart devices to decrease the time more effectively.

2) The effectiveness of displaying candidate drawers: The result of this experiment indicates that the function decreases the searching time. The function also decreases the variance of the time. Moreover, the function drastically decreases the levels of (b) physical demand, (c) frustration and (d) time pressure in the questionnaire's scores. Therefore, it is confirmed the importance of the function to display the candidate drawers by using some preliminary information.

V. Conclusion

In this research, we proposed a novel storage system, "TansuBot". The system takes contents' photos automatically with a movable camera and provides the functions to support a user's object search. We picked up two design criteria; keeping storage efficiency and cost reduction, to realize smooth introduction of the system into home. Through the development of the prototype, we found innovative design to satisfy those requirements. The structure of the extensible arm contributes to reduce the robot action space, and the adoption of wooden parts contributes to reduce the manufacturing cost. We evaluated the object search supports in the experiment. The positive effects on the searching time and the mental burden were examined about searching with photos and displaying candidate drawers.

Our next steps are improvement of the method to generate/display the contents' photos and development of a function to select candidate drawers based on some preliminary information.

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