Interactive Bookshelf Surface for In Situ Book Searching and Storing Support

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ABSTRACT

We propose an interactive bookshelf surface to augment a human ability for in situ book searching and storing. In book searching support, when a user touches the edge of the bookshelf, the cover image of a stored book located above the touched position is projected directly onto the book spine. As a result, the user can search for a desired book by sliding his (or her) finger across the shelf edge. In book storing support, when a user brings a book close to the bookshelf, the place where the book should be stored is visually highlighted by a projection light. This paper also presents sensing technologies to achieve the above mentioned interactive techniques. In addition, by considering the properties of the human visual system, we propose a simple visual effect to reduce the legibility degradation of the projected image contents by the complex textures and geometric irregularities of the spines. We confirmed the feasibility of the system and the effectiveness of the proposed interaction techniques through user studies.

Categories and Subject Descriptors

H.5.1 [**Information interfaces and presentation (e.g., HCI)**]: Multimedia information systems—*Artificial, augmented, and virtual realities*

General Terms

Design, Human Factors

Keywords

Projection-based mixed reality, smart bookshelf, book searching and storing support

1. INTRODUCTION

When searching for a book (including magazine, notebook, photographic album etc.) in a physical bookshelf, people usually browse the titles printed on the book spines as a clue for the search. However, in some cases, the information on the spine is not sufficient for the search. For example, it is difficult to search for a particular issue of a magazine from a series of titles of the same magazine, because normally the same title is printed on their spines. Furthermore, some books are too thin to have spines. In such cases, the search task becomes burdensome as every book needs to be taken out from the bookshelf to look for details such as those printed on the book cover until the desired one is found. For efficient book search, the books should also be stored in a proper order. In a library, professional librarians continuously organize the stored books according to the library classification system. However, it is difficult to do the same in an ordinary office or home due to time constraints.

We propose an interactive bookshelf surface to augment a human ability for such in situ book searching and storing. To support the book searching task, we propose to optically superimpose the cover images of the stored books on the book spines by projected imagery (Fig. 1(a)). When a user touches a shelf edge, the cover images of books that are stored nearest to the touched position are projected onto the neighboring spines. We believe that an efficient in situ book search can be accomplished by this support because the user can view the cover images, which show richer information than the spines, without removing the book from the bookshelf. To support the book storing task, we propose to brighten the place where a book should be stored by projecting a spotlight (Fig. 1(b)). The spotlight is projected when the user brings the book close to the bookshelf, and thus it can be stored at the proper position and order of the stored books can be easily maintained.

This paper presents sensing and displaying methods as basic technologies to make a normal bookshelf surface interactive. For the sensing method, we employ a 1-D range (area) sensor and a video camera to record book information, such as the position in the bookshelf and the cover image, while a user removes/stores the book from/in the bookshelf in the usual manner. When a user touches a shelf edge, the touch position is also detected in the same sensing scheme. The sensing method does not require any identification tags to be attached on the books, and users do not need to wear/hold any special input devices. For the display method, we propose a visual effect to reduce the legibility degradation of the projected image contents by the complex textures and geometric irregularities of the book spines. In general, most

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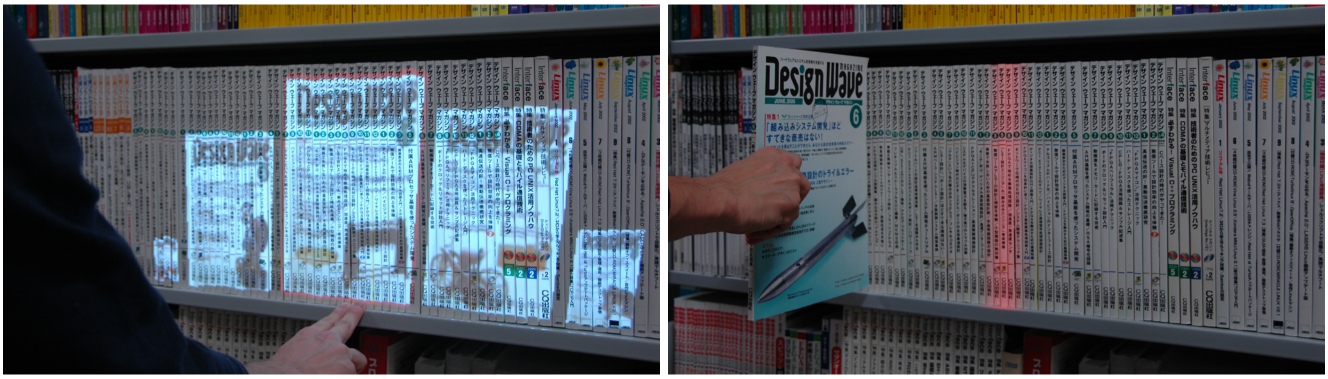

(a) (b)

Figure 1: Proposed in situ book searching and storing support: (a) book searching support by projecting the cover image of a stored book onto the spines, (b) book storing support, in which when a user brings a book close to the bookshelf, a spotlight is projected onto the place where the book should be stored.

everyday surfaces other than book spines are also not suitable for projection because of the same photometric and geometric reasons. Therefore, an appropriate image correction technique is needed when researchers attempt to make such everyday surfaces interactive. This paper proposes a simple solution, by taking into account properties of the human visual system (HVS).

2. RELATED WORK

Researchers previously tried to support a user's search for a physical document with PC interfaces (mice, keyboards, and monitors). Kim et al. proposed tracking documents over time on a physical desktop using an overhead camera [6]. The tracked documents are automatically linked to the corresponding electronic documents, which are stored on a PC. The user can easily locate the desired document in physical stacks by performing a keyword search. Strata drawer supports document search in a physical drawer [9]. A camera is mounted facing downward in the drawer. When a user places a document in the drawer, it is automatically photographed. The user can then browse pictures of documents in the drawer with PC interfaces. In these systems, a user must move to the place where the desired document exists after searching for it on a PC.

Projection-based mixed reality (PBMR) technologies have been applied to support book search in a bookshelf. Butz et al. and Castro et al. proposed book searching support systems in which a spotlight is projected onto the spine of the searched book, so that the user can easily find it [4, 5]. Pinhanez et al. also proposed a book searching support system in which they projected arrows that guided the user to the location of the searched book, instead of using a spotlight [8]. Löchtefeld et al. proposed to apply a handheld projector for book searching support in which a spotlight is projected onto the searched book in a bookshelf when the user directs the projector toward the book [7]. Because a PBMR system superimposes an application interface directly onto areas very close to where the search activities are occurring, the user's attention can be more easily attracted. Hence, the user can take out the searched book immediately after it is found. However, the previous works assumed that the user first uses PC interfaces to search for a desired book (e.g., keyword search), then the user moves to the bookshelf in which the augmentation is projected.

This paper assumes a different user scenario, in which the searched books include those that cannot be located by a keyword search, such as photo albums or handwritten notes. We design a book searching interaction that does not require any PC interfaces. The user performs a book searching task only in front of the bookshelf. In addition, as described in the previous section, we propose to support the book storing task, which has not been considered in previous works.

3. SYSTEM CONFIGURATION

Figure 2 shows the system configuration. A video camera (640×480 pixels, 30 fps) is placed beside the bookshelf (0.9 m×2.2 m), so that it observes the front of the bookshelf. A time-of-flight 1-D range (area) sensor (28 ms/scan, 0.36 deg of the angular resolution) is placed at the upper left corner of the bookshelf, so that its sensitive plane is parallel to the front plane of the bookshelf. Note that we define the front plane as containing the shelf edges of the bookshelf. A projector (2000 ANSI Lumens, 1024×768 pixels) is installed on the ceiling, so that it projects images onto the spines of the stored books without disturbing the user's natural actions. A PC (CPU: 2.44 GHz, RAM: 2 GB) controls all the equipment. A local book information database (LBID) is prepared on the PC. The system also accesses another online book information database (OBID) via the Internet.

The 3-D world coordinate system (WCS) is defined such that its original point corresponds to one of the range sensors, and the XY plane corresponds to the sensitive plane, which is parallel to the front plane of the bookshelf. The intrinsic and extrinsic parameters of the video camera ($\mathbf{I_c}$ and $\mathbf{E_c}$, respectively), as well as the 2-D homography matrix between the front plane of the bookshelf and the projector screen coordinate system (PSCS) ($\mathbf{P_h}$), are calibrated in advance based on the DLT (Direct Linear Transformation) method [12]. Note that the intrinsic matrix ($\mathbf{I_c}$) and the extrinsic matrix ($\mathbf{E_c}$) are 3×3 and 3×4 matrices, respectively. The homography matrix ($\mathbf{P_h}$) is a 3×3 matrix.

4. SENSING STORED BOOK INFORMATION

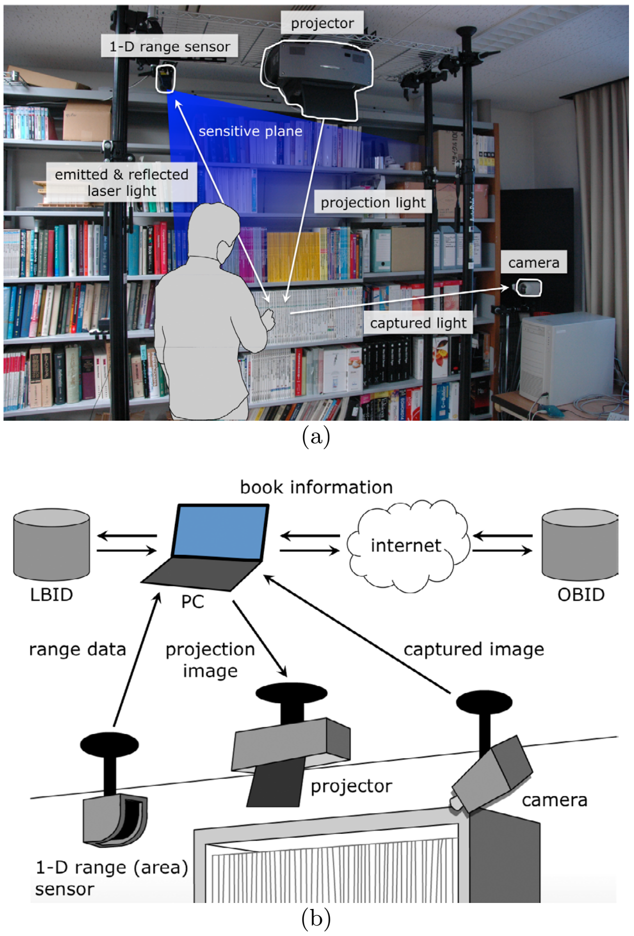

Figure 2: Prototype system: (a) overview, (b) data flow.

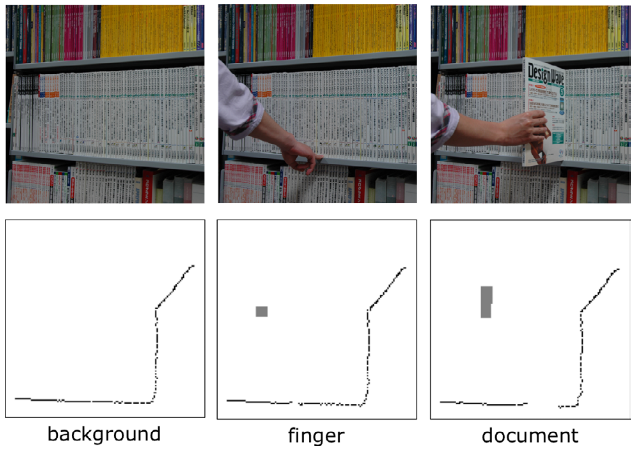

Figure 3: Background subtraction of range data: (top) measured scene, (bottom) captured range data (dot: background, box: intrusion).

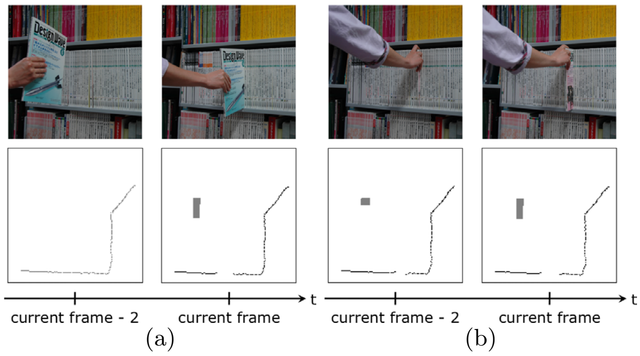

Figure 4: Discrimination between storing and removing of book: (a) storing, (b) removing.

The 1-D range sensor and video camera record the stored book information (such as the position in the bookshelf and the cover image) while a user removes/stores the book from/in the bookshelf in the usual manner. When a new book is stored in the bookshelf, the information is saved in LBID. Note that in this study we assume that the user does not take out or store multiple books at once.

4.1 Position Measurement of Stored Book and User's Finger

The system measures the position of a stored book in the bookshelf using the range sensor. Since a user manipulates the system by touching the shelf edge, the system also measures the position of the user's finger. It is necessary to distinguish between the stored book and the user's finger, as well as to measure their positions while they are crossing the sensitive plane.

We apply a simple background subtraction technique to the captured range data in order to extract consecutive points of the intrusion data (Fig. 3). After this, the system decides that the object crossing the sensitive plane is a book, if the number of the consecutive point N^r is greater than a threshold T_b^r (i.e., $N^r > T_b^r$). In the same manner, when N^r is between T_{fmax}^r and T_{fmin}^r (i.e., $T_{fmax}^r > N^r > T_{fmin}^r$), the object is recognized as a finger. From a preliminary experiment, we found that the process worked well when T_b^r, T_{fmax}^r, and T_{fmin}^r were 15, 10, and 2, respectively. The book position in the bookshelf (X_b, Y_b, Z_b), as well as the finger touch position (X_t, Y_t, Z_t) in the WCS, is calculated as the average position of the consecutive points of the intrusion data.

4.2 Discrimination between Storing and Removing of Book

After detecting that a book has crossed the sensitive plane, the system discriminates whether it is stored in or removed from the bookshelf. To achieve this, the system refers to background subtraction results of both a past range sensor data and a past captured image. When the number of intrusion pixels N^i in the background subtraction result of a captured image is grater than a threshold T_b^i (i.e., $N^i > T_b^i$), the system decides that there is a book in front of the bookshelf. If there is no object crossing the sensitive plane in the past range sensor data and there is a book in front of the bookshelf in the past captured image, the system decides that the book is being stored in the bookshelf. On the other hand, if there is an object crossing the sensitive plane

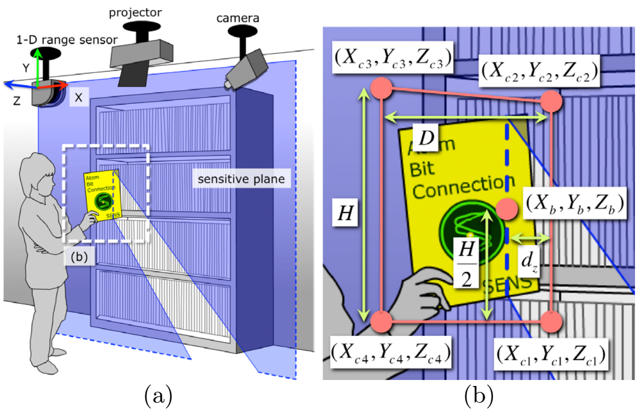

Figure 5: Acquisition of the cover image of a stored book: (a) overview and (b) magnified view.

in the past range sensor data, the system decides that the book is being removed (Fig. 4). From a preliminary experiment, we found that the process worked well when T_b^i was 3,000 and when the system referred to the past background subtraction results of 2 frames before the current frame.

4.3 Capturing Cover Image Being Stored Book

When detecting a book is being stored in the bookshelf through the process described in 4.2, the system extracts the cover image from the captured image in the following manner (Fig. 5). Note that the depth and height of each row of the bookshelf (D and H, respectively), and the distance of the front plane of the bookshelf from the sensitive plane of the range sensor (d_z) are measured in advance.

First, the system computes the 3-D positions of the four corners of a rectangle that is parallel to the YZ plane of the WCS, so that it covers the detected book. The width and height of the rectangle correspond to D and H, respectively. The positions of the four corners $(X_{ci},\ Y_{ci},\ Z_{ci})$ $(i = 1, 2, 3, 4)$ in the WCS are calculated as:

$$(X_{c1},\ Y_{c1},\ Z_{c1}) = (X_b,\ Y_b - H/2,\ Z_b - d_z), \quad (1)$$

$$(X_{c2},\ Y_{c2},\ Z_{c2}) = (X_b,\ Y_b + H/2,\ Z_b - d_z), \quad (2)$$

$$(X_{c3},\ Y_{c3},\ Z_{c3}) = (X_b,\ Y_b + H/2,\ Z_b + (D - d_z)), \quad (3)$$

$$(X_{c4},\ Y_{c4},\ Z_{c4}) = (X_b,\ Y_b - H/2,\ Z_b + (D - d_z)). \quad (4)$$

Then, the rectangle is transformed from WCS to the 2-D camera screen coordinate system (CSCS) by perspective transformation as:

$$h \begin{bmatrix} x_{ci} & y_{ci} & 1 \end{bmatrix}^t = \mathbf{I_c E_c} \begin{bmatrix} X_{ci} & Y_{ci} & Z_{ci} & 1 \end{bmatrix}^t, \quad (5)$$

where $(x_{ci},\ y_{ci})$ represents the positions of the four corners in the CSCS. The system then extracts the quadrangle region from the captured image and rectifies it. Figure 6(a) and (b) show the captured and extracted images, respectively. The final image contains the book's cover image.

The extracted image contains not only the cover image, but also the user's hand and possibly a cluttered background. In addition, the contrast and resolution of the extracted cover image are low in general. Therefore, the system searches for a higher quality image from an OBID, such as Amazon.com, and copies it to the LBID. At the same time, other

Figure 6: Book cover image acquisition: (a) captured image by the camera, (b) extracted image, (b) image feature matching, and (c) higher quality counterpart of the captured image from OBID.

book information, such as title, name of the author, and (if a magazine) volume of the issue, is also copied to the LBID. The search is performed based on image feature matching (Fig. 6(c)). We apply SURF (speeded up robust features) that are robust for the scale change of the image [1]. An example of the higher quality version of a cover image found by the search is shown in Fig. 6(d). In case that there is no digital counterpart in the LBID, the captured cover image itself is copied to the LBID. In our current prototype, we implement an OBID by ourselves with small number of book data (< 100) and thus the image search is performed in real-time. Even when we use a public OBID, the search can also be performed in a reasonable query time (around 1-2 s) with a large scale image search technique proposed in the computer vision research field such as [11].

4.4 Recognition of Removed Book

The system updates LBID when detecting a book is being removed from the bookshelf through the process described in 4.2. First, it obtains the position of the removed book in the bookshelf and its cover image through the processes described in 4.1 and 4.3. Then, it searches for the book over LBID, using the position and the cover image as queries. In particular, it applies image feature matching to several books that are located around the obtained position, in order to recognize the removed book. The range of the search is defined as the measurement precision of the stored book position. The precision is verified later.

5. BOOK SEARCHING AND STORING SUPPORT TECHNIQUE

Based on the sensing techniques described above, we propose the following in situ book searching and storing support techniques.

5.1 Book Searching Support: Projection of Cover Image onto Book Spine

As described at the beginning of this paper, when searching for a book in a bookshelf, people usually browse the titles printed on the book spines (that sometimes does not contain sufficient information) as a clue for the search. In such cases, people have to take out and check every book from the bookshelf until they find the desired one. We propose to support the book searching task by projecting the cover image of a stored book onto its spine. The cover image contains richer information than the spine in general.

The process flow of the proposed book searching support system can be described as follows. First, a user touches the shelf edge to specify a book. The system then searches for a book stored nearest to the touched position in the LBID. Next, the cover images of not only the specified book, but also of four neighboring books (two each on the left and right) are projected onto the spines above the touched position (Fig. 1(a)). The order of the projected cover images correspond to the stored order in the bookshelf.

The projected cover images are changed as the user slides his (or her) finger across the shelf edge. The system stops projecting any cover images when a user releases his (or her) finger from the shelf edge. The position of the user's touch as well as that of each stored book, which is measured and saved in the LBID, is not always correct because of the measurement error of the range sensor. Therefore, the projected cover image does not always correspond to the book stored nearest to the user's touch position. However, even if it is not correct, the user only needs to take out the neighboring books from the bookshelf to confirm their cover images, which are stored within the error range.

5.1.1 *Continuously Resizing Effect: A Visual Effect Based on Motion Transparency*

The color (reflectance) or the texture of a book spine varies among different books. In addition, not all of the books are aligned parallel with the shelf edge. In such cases, the spines are not suitable for projection. The projected cover images are photometrically disturbed and geometrically deformed, and consequently their legibility is significantly degraded.

In the research field of projector-camera cooperative systems, various geometric registration and radiometric compensation methods have been proposed to resolve this issue [2, 3]. However, these techniques require rigorous calibrations every time the projection scene is changed. A dark environment is also assumed in these techniques although a bookshelf usage scene is generally bright under room lighting. Furthermore, the processes generally require time (at least a few seconds). Therefore, they are not suitable for a dynamic scene, such as that in a bookshelf, where books are often stored and removed. On the other hand, we only consider geometric registration and use 2-D homography transformation using the calibrated homography matrix $\mathbf{P_h}$, so that the projected cover image is geometrically correct if it is

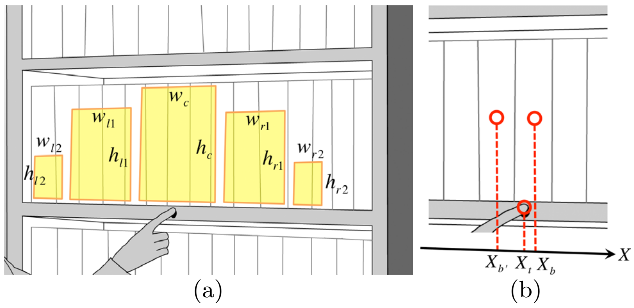

Figure 7: Continuously resizing effect: (a) overview, (b) X_t, X_b, $X_{b'}$ (magnified view).

projected onto the front plane of the bookshelf. Additional online calibration processes are not needed. However, the front plane does not always correspond to the book spines, so the projected image is possibly deformed.

This paper proposes to apply a visual effect to reduce the legibility degradation of the projected image contents. We call the effect as continuously resizing effect in this paper. The effect dynamically changes the size of each projected cover image, according to the distance of the user's touch position from the book of the cover image. The size of the projected cover image is the largest when the book is just above the user's touch position (i.e., the specified book), and continuously decreases as the distance increases (Fig. 7(a)). The same kind of effect is applied in the Dock of Apple's Mac OS X. The width w_j and height h_j $(j = r2, r1, c, l1, l2)$ of each projection image are:

$$w_j = m_j D, \ h_j = m_j H, \tag{6}$$

where m_j $(0 < m_j \leq 1)$ represents the magnification coefficient. The notations $r2, r1, c, l1$, and $l2$ represent the books from the right to the left, so that c corresponds to the specified book. Then, the magnification coefficient of the specified book m_c is computed as:

$$m_c = cos\theta, \ \theta = \frac{1}{5}\pi n, \ n = \frac{X_t - X_b}{X_b - X_{b'}}, \tag{7}$$

where $X_{b'}$ represents the x-coordinate position in WCS of a book second nearest to the touch position ($X_b > X_t > X_{b'}$ or $X_{b'} > X_t > X_b$) (Fig. 7(b)). Therefore the absolute value of n is less than $1/2$, and consequently that of θ is less than $1/10\pi$. The sizes of the other projected cover images decrease according to the cosine law as follows:

$$m_{r1} = cos(\theta - \frac{1}{5}\pi), \ m_{r2} = cos(\theta - \frac{2}{5}\pi), \tag{8}$$

$$m_{l1} = cos(\theta + \frac{1}{5}\pi), \ m_{l2} = cos(\theta + \frac{2}{5}\pi). \tag{9}$$

This visual effect is designed by taking into account a HVS property, motion transparency: people perceive two planes independently when two superimposed textures are moved in different directions [10]. For example, even when the projected cover image is moved on the non-planar surface, people still perceive the deformed image as a rectangular original cover image. We choose resizing rather than simple translation considering the following two issues: (1) the movement should be sufficiently large to induce strong motion transparency, and (2) it should occur in the view frustum of a user. The cosine law is applied because it guarantees a smooth transition.

We believe that the user can intuitively recognize the projected image contents, even if the book spines are not suitable for projection, because the projected cover image moves as the user slides his (or her) finger across the shelf edge. The feasibility of the proposed effect is later confirmed through a user study.

5.2 Book Storing Support: Projection of Spotlight onto Stored Position

For efficient book search, the books should be stored in a proper order. We propose a book storing support technique, in which when a user brings a book close to the bookshelf, the system projects a spotlight onto the place where the book should be stored, as shown in Fig. 1(b).

We support the following two user scenarios. First, we consider that a user is storing a book that was stored in the bookshelf before. In this case, if the book was stored in the proper position, it should be returned at the same position in the bookshelf. The process flow of the storing support for the scenario is described as follows: first, a user brings a book close to the bookshelf. When the book crosses the sensitive plane of the range sensor, the system detects it. Next, it captures the cover image and recognizes the book by applying image feature matching between the captured image and the cover images in the LBID. Finally, the system projects a spotlight at the place where the book was stored before, based on the position data in the LBID.

As the second scenario, we consider that a user is storing a new magazine that has not been previously stored in the bookshelf. Magazines with the same title are usually stored together. The process flow of the storing support for the scenario is described as follows: first, a user brings a new magazine close to the bookshelf, so that it crosses the sensitive plane of the range sensor. Next, the system captures the cover image, and recognizes the title and the volume of the issue of the magazine, as described above. Finally, the system projects a spotlight onto the place where the magazine should be stored (i.e., next to the nearest issue of the magazine with the same title).

6. EVALUATION

The proposed techniques were implemented on the proposed interactive bookshelf. We conducted experiments to evaluate the proposed sensing methods. Then, user studies were carried out to confirm the effectiveness of the proposed book searching and storing support techniques. In the experiments, we used a single row (0.35 m in height) of the bookshelf, which was at a height of 0.95 m.

6.1 Evaluation of Sensing Techniques

6.1.1 *Measurement Precision of Book Position*

We conducted an experiment to verify the measurement precision of the stored book position. In the experiment, we stored 37 magazines with the same title (A4, 8 mm thick) in the bookshelf. The system measured their positions by applying the proposed book position sensing method. We measured the error as the distance of the measured position from the actual one. As a result, the mean error was 4.8 mm (SD = 5.6 mm), which is less than the thickness of a single magazine. Therefore, we think that the precision of the proposed sensing method is sufficient for our book searching and storing support techniques.

Table 1: Experimental conditions.

		support condition		
		w/o support & w/o effect	w/ support & w/o effect	w/ support & w/ effect
spine condition	white & planar	A	B	C
	colored & planar	D	E	F
	white & non-planar	G	H	I

6.1.2 *Error Rate of Discrimination between Storing and Removing of Book*

We evaluated the error rate of the proposed technique for discriminating between the storing and removing of books as described in 4.2. We recruited 16 participants from the local university. Each participant was requested to perform the following task: store a magazine (A4, 8 mm thick) in the bookshelf and take it out, in the usual manner. The system discriminated the action using the proposed method. As a result, all the actions could be discriminated correctly. From the result, it was confirmed that the proposed method could perfectly discriminate between a user's natural action of storing and removing a book.

6.1.3 *Error Rate of Cover Image Recognition*

In the previous experiment, the system also captured and recognized the cover image of the storing/removing magazine as described in 4.3 and 4.4. The system recognized the cover image among 37 same magazines stored in the bookshelf. As the result, the cover images were correctly recognized in all the removing actions and in 13 of 16 storing actions. The errors occurred when participants much bended the magazines while storing/removing. The problem can be solved by applying an appropriate geometric correction to the deformed cover images based on the range sensor data.

6.2 Effectiveness of Searching Support

A user study was carried out to validate the proposed book searching support technique. We measured the participant's book searching time in the bookshelf with and without the support. We prepared nine experimental conditions (A, B, ..., I): three types of spine conditions and three types of support conditions (see Table 1).

Spine Condition. In the first condition, 49 magazines (A4) were stored in the bookshelf. Each book spine was white, except for the black characters of the title of the magazine. Therefore, the projected image contents were not disturbed much. In the second condition, 69 magazines (A4: 29, B5: 40) were stored. Each book spine was colored, and thus the legibility of the projected image contents was strongly degraded. In the above two conditions, the magazines were aligned parallel with the shelf edge, so that the book spines formed almost flat planes. We prepared the third condition considering that books are not always well-aligned in realistic situations. The same magazines that were used in the first condition were stored, but the depth of the spine from the shelf edge varied among the magazines (i.e., the spines did not form a flat plane). The maximum depth difference

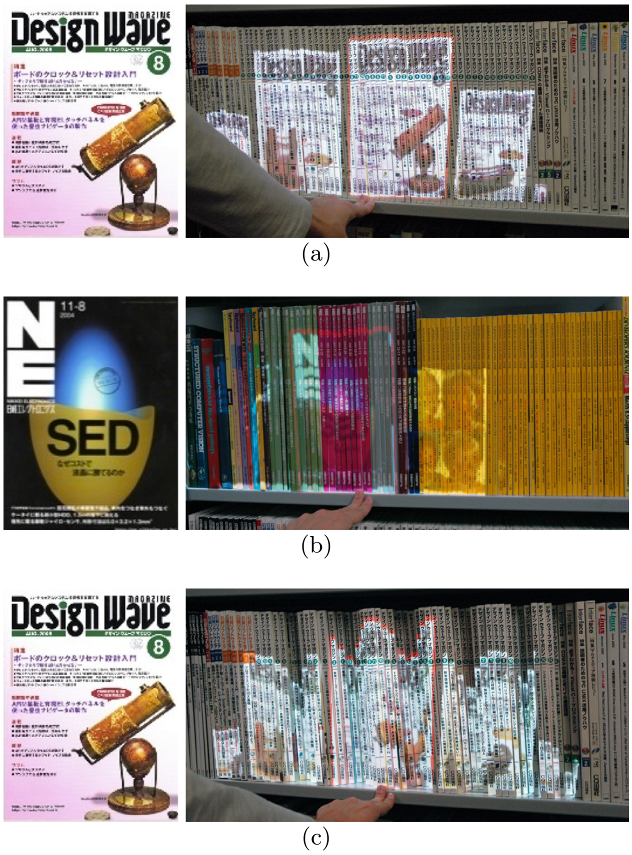

Figure 8: Original cover image (left) and its projection result (right) in different spine conditions: (a) white and planar, (b) colored and planar, and (c) white and non-planar.

of the spines was 50 mm. Figure 8 shows an overview of the three conditions. For all the conditions, the positions of the magazines in the bookshelf, as well as the cover images, were obtained through the proposed sensing methods. Note that hence not all of the measured positions of the magazines were correct, as shown in the previous experiment.

Support Condition. In the first condition, the proposed book searching support was not applied. In the second condition, it was applied without the continuously resizing effect. In the third condition, the proposed support with the continuously resizing effect was applied. The magnification coefficient m_j was fixed when the continuously resizing effect was not applied, as follows. The projected image size for the specified book is the same as the actual cover image size. The projected image sizes for the books next to the specified book are one-half of the actual sizes. Those for the rightmost and leftmost books are one-quarter the size. Thus $m_{r2} = 1/4$, $m_{r1} = 1/2$, $m_c = 1$, $m_{l1} = 1/2$, and $m_{l2} = 1/4$.

Ten students from the local university participated in the user study. Before the study, the participants were asked to use the system for a while in each condition to familiarize themselves with searching for a book in each condition. In the study, each participant performed one trial for each

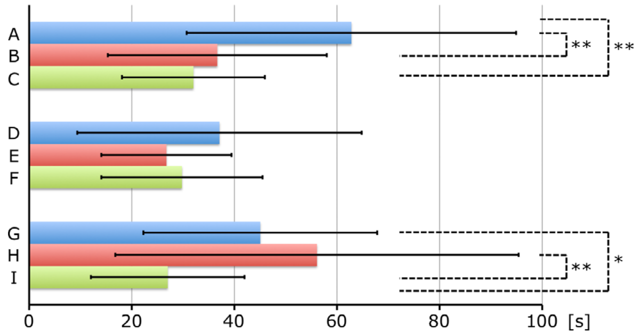

Figure 9: Mean searching time of each experimental condition ($** : p < 0.01, * : p < 0.05$).

condition in random order. In each trial, we first showed each participant the photographic copy of the cover image of a magazine stored in the bookshelf, and then asked him (or her) to search for it. At the same time, we activated a timer. We stopped the timer when the participant found the searched magazine. The illuminance of the spine of a stored magazine under the environment light in the experimental setup was approximately 200 lx. When a uniform white image was projected, the illuminance was approximately 1,200 lx.

Figure 9 shows the mean book searching time with the standard deviation for each condition. We compared the results for each spine condition. At first, we analyzed the results of the first spine condition (i.e., A, B, and C), where the color of the spines was white. A one-way analysis of variance (ANOVA) with repeated measures showed statistically significant differences for all of the respective times ($F_{2,18} = 16.41$, $p < 0.05$). A post-hoc analysis was then performed using a Student-Newman-Keuls (SNK) test for pair-wise comparison. It showed statistically significant differences between A and B ($p < 0.01$), and between A and C ($p < 0.01$), as shown in Fig. 9. Therefore, it was confirmed that the proposed support technique could improve the book searching task, irrespective of the continuously resizing effect, when the spines were suitable for projection.

Next, we analyzed the results in the second spine condition (i.e., D, E, and F), where the spines were colored and the legibility of the projected image contents was strongly degraded. An ANOVA with repeated measures showed that there were no statistically significant differences ($F_{2,18} = 2.15$, $p > 0.05$). Therefore, it was confirmed that the proposed support technique neither improved nor worsened the book searching task when the spines were photometrically not suitable for projection.

Finally, we analyzed the results in the third spine condition (i.e., G, H, and I), where the depth of the spine from the shelf edge varied among the magazines. ANOVA with repeated measures showed statistically significant differences for all the respective times ($F_{2,18} = 12.0$, $p < 0.05$). A post-hoc analysis was then performed using a SNK test for pair-wise comparison. It showed statistically significant differences between H and I ($p < 0.05$), and between G and I ($p < 0.01$), as shown in Fig. 9. Therefore, it was confirmed that the proposed support with the continuously resizing effect could improve the book searching task in this spine condition. On the other hand, the support without the ef-

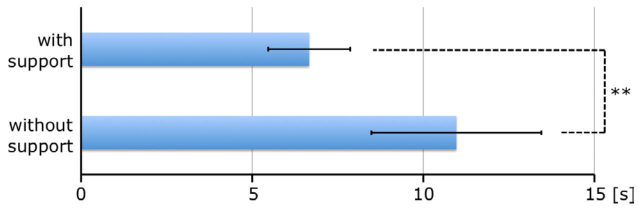

Figure 10: Mean storing time of each experimental condition ($** : p < 0.01$).

fect did not improve the task.

In summary, the proposed support technique could shorten the book searching time when the spines were suitable for projection, and even when they were not well-aligned (i.e., not geometrically suitable for projection). The continuously resizing effect was particularly effective in the latter condition. On the other hand, the proposed support technique could not improve the book searching task when the spines were colored (i.e., not photometrically suitable for projection).

Note that the difference of searching time between the conditions A and D was caused by the fact that the heights of magazines used in the condition D were lower than those used in the condition A. The lower height made the removal of the magazines easier. The difference of searching time between the condition A and G was caused because it was easier to grab the magazines in the condition G because of the varied depth of the spines of the stored magazines.

6.3 Effectiveness of Storing Support

We conducted another user study to evaluate the book storing support technique. We measured each participant's book storing time in the bookshelf under two conditions: with and without the support. A total of 47 magazines with the same title were stored in the bookshelf in chronological order. The participants attempted to store a magazine with the same title in the correct order. The time duration of each trial was measured. Eleven participants were recruited from the local university, and they performed the trial once under each condition in random order. In each trial, different magazines were stored, and the participants did not have any knowledge of them.

Figure 10 shows the mean book storing time under each condition. A paired t-test between them ($t_{10} = 4.91$, $p < 0.01$) showed that the proposed support technique could significantly shorten the time for the book storing task. Therefore, we reached the conclusion that the book storing support technique is effective in the assumed book storing scenarios.

7. CONCLUSION

We propose an interactive bookshelf surface to augment a human ability for in situ book searching and storing. This paper also presented sensing methods to achieve those interactive techniques. We applied a 1-D range sensor and a video camera to record the book information, such as the position in the bookshelf and the cover image, as well as the user's touch position on the shelf edge. In addition, continuously resizing effect was proposed in this paper, by taking into account motion transparency, a well-known property of HVS, to reduce the legibility degradation of the projected image contents by the complex textures and geometric irregularities of the spines. We confirmed the feasibility of the system and the effectiveness of the proposed interaction techniques through the proof-of-concept experiments and the user studies. As a future work, we will develop a mobile projection system and investigate its possibilities in book searching and storing support.

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