

An Easy Paging Operation for Reading Three Dimensional Virtual Book via Leap Motion

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Abstract: This paper proposes a new easy paging operation that is a kind of improved swipe motion to be able to tie plural pages together for reading a 3D virtual book by applying augmented reality technology. Our previous system could display a virtual book by using 3DCG and could capture human hand motions via Leap Motion that is a very small and reasonable contact-less sensor, and it could make users the operational feeling such as a paper book on a PC, for the first time. However, this system had a problem that it is difficult for many users to learn the paging operations because the recognition accuracy of the Leap Motion is not enough to distinguish each fingers correctly, and then, it requires very complex hands and/or fingers form to control the 3D virtual book. To cope with the difficulty, the new function is added to our previous system. As a result, it could be achieved that paging with tying plural pages together for reading the 3D virtual book by using the contact-less sensor becomes easy while all of previous functions can be used together. Our improved software that can use the new operation is presented, and its effectiveness is discussed.

Keywords: E-book, Augmented reality, contact-less motion sensor, 3DCG, WebGL, THREE.js

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I. Introduction

Nowadays, paper books still have some advantages even though electronic books have explosively spread. For example, it is easy to read contents written in separated pages, to feel physical thickness, to tie plural pages together, and to transform paper shapes or viewing angles. These advantages cannot be seen in almost all of the current electronic books. On the other hand, electronic books have different advantages. For example, tablets with high quality display can be used reasonably, a lot of text information can be stored in smaller spaces, retrieving contents is easier than paper media, and managing and supplying data on the Internet is possible. Which is better, paper books or electronic books? On this topic, there have already been various investigation research for comparison between paper media and electronic media as the following.

R. Kobayashi and A. Ikeuchi have investigated a comparison between electronic media (iPad) and paper media for legibility and understanding contents conducted on 36 subjects[1]. As a result, it is found in subjectivity evaluation that iPad is almost equal to paper media in legibility performance, however, paper media is still better than iPad in understanding contents.

Similarly, K. Takano et al. have investigated a comparison between paper books and electronic books including iPad, Kindle and laptop computer for legibility in reading short stories conducted on 26 subjects[2]. As a result, it is found in subjectivity evaluation that both paper media and iPad are faster to page than Kindle and laptop computer, however, there are no significant differences for a recognition load, and finally, paper media got the highest evaluation.

Furthermore, according to a study of J.M. Noyes and K.J. Garland, the evaluation that paper media is more legible than electronic media is supported statistically[3]. It can be said that the level of understanding contents is changed by body senses with difference of media. Therefore, electronic books have to approach the quality of paper books using evolution of computer technologies as much as possible.

Originally, paper books are handled with transformation in three dimensional (3D) space variously as shown in Figs. 1(a),(b). In contrast, the current electronic books are only displayed in two dimensional (2D) space as shown in Fig. 2, though it looks 3D image. Therefore, electronic books have almost no advantages such as paper books mentioned above. To cope with this difficulty, an enhanced text reader system that has operational feeling of paper media, called MaSSText, has been proposed on our previous research[4][5]. As a result, the way to imitate paper transformation in 2D has been able to be achieved, however, it was not real transformation in 3D.

The performance of three dimensional computer graphic (3DCG) technologies has already improved dramatically, and it can be operated on reasonable personal computer (PC). It can be said that 3DCG is enough

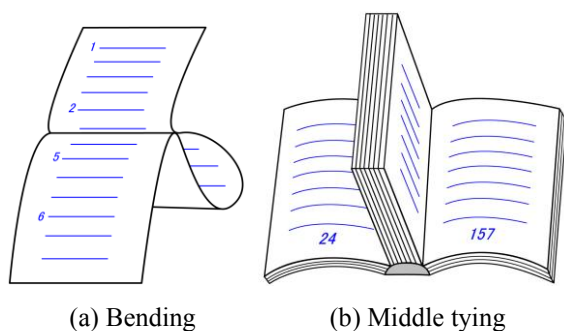


Figure 1: 3D Transformations in Paper media



Figure 2: Paging Operation in 2D e-book

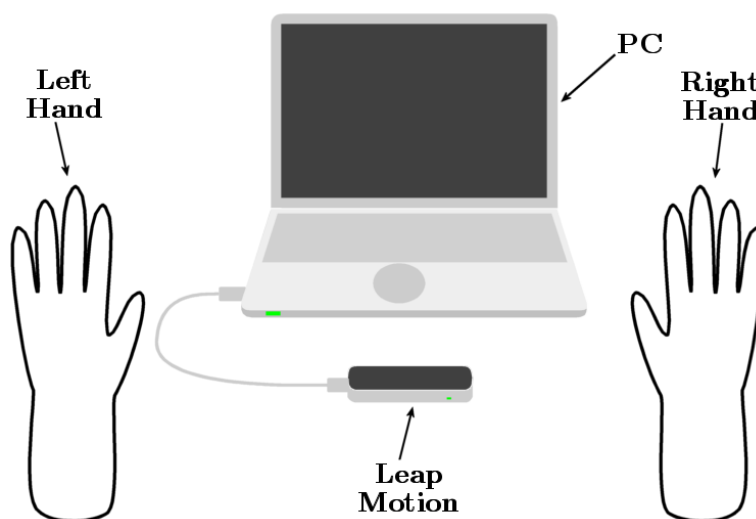


Figure 3: System Configuration

to apply to electronic books, however, there is no application such as a book style in 3D even though there are so many animations and/or game applications by using 3DCG.

To solve this problem, a 3D text reader by applying augmented reality (AR) technology has already been proposed on our previous research[6]. This system displays a book by using 3DCG and captures human hand motions via Leap Motion that is a very small and reasonable contact-less sensor, and it could make users the operational feeling such as a paper book in a PC, for the first time. As a result, it could be achieved to read contents written in separated pages, to understand physical thickness, to tie plural pages together, and to transform paper shapes or viewing angles, that are some of the advantages on paper books. However, this system had a problem that it is difficult for many users to learn the paging operations because the recognition accuracy of the Leap Motion is not enough to distinguish each fingers correctly, and then, it requires very complex hands and/or fingers form to control the 3D virtual book.

In this research, a new easy paging operation that is a kind of improved swipe motion to be able to tie plural pages together is proposed to cope with the difficulty. Our software that can use the new operation is presented, and its effectiveness is discussed.

II. System Configuration

Leap Motion that is one of contact-less hand motion sensors is used in this research as shown in Fig. 3 because it is very small and reasonable[7]. HTML5 and Javascript with WebGL are used for constructing this system because high speed 3DCG using GPU on multi-platforms can be used easily and immediately if web browsers are only available. Note that THREE.js (R75)[8] as a Javascript library for WebGL and Leap.js (V0.6.4)[7] as a Javascript library for Leap Motion are used together. Our software has been checked on the Internet Explorer 11, the Google Chrome, and the Firefox using a laptop computer, Panasonic Let's note S10 that has Core i7/2.7GHz and Windows 7 (64bit/SP1).

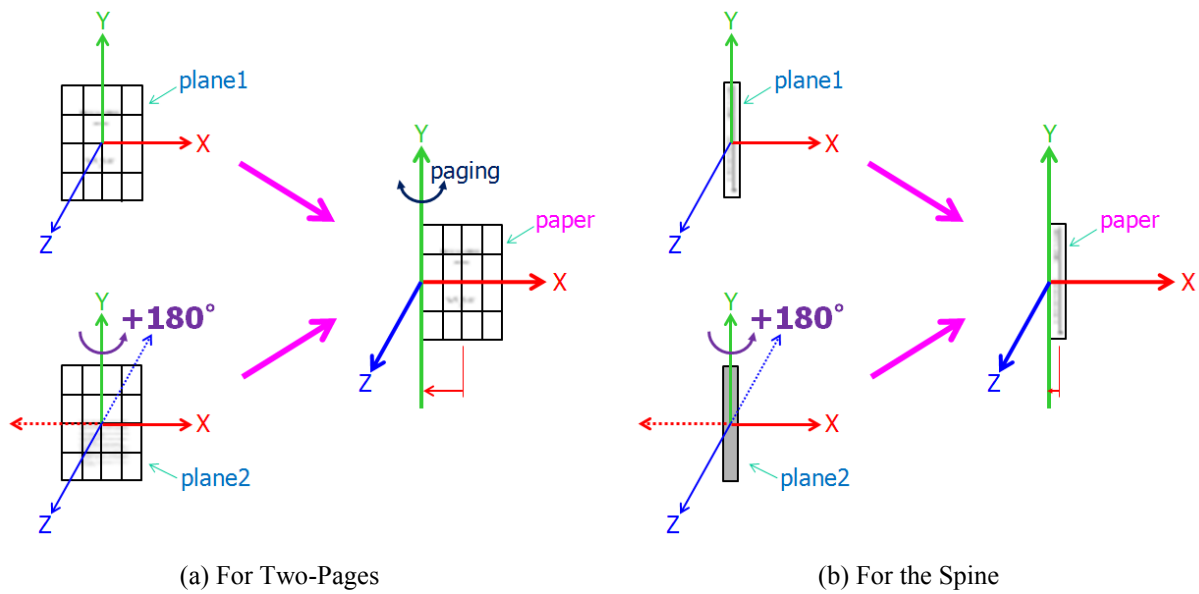


Figure 4: Double-Sided Paper Space

III. 3D Virtual Book Construction Method

3.1 Transforming PDF to Image File

Basically, 3DCG does not assume that long texts and/or books are displayed. Therefore, a PDF including texts is transformed to image files per page using Cube PDF that is a free software for creating image files with continuous file numbers[9]. In this research, the resolution of these image files is set to the minimum setting, 72 [dpi] that is 595×842 [pixel] for the Japanese A4 size papers. Note that the resolution can be changed according to the user's requirement.

A set of pages (each image file) is represented by

$$\{ p_1, p_2, \dots, p_{max} \mid max \geq 2 \} \quad (1)$$

where the index numbers 1, 2, ..., max denote page numbers. Note that max denotes the end page that is an even number. The p_i ($i = 1, 2, \dots, max$) has each image data, including width, height, positions, rotations and scales in 3D space.

3.2 Creating Double-Sided Paper Space for Two Pages

A double-sided paper space for two pages is created by using the set of pages (Eq. (1)) as shown in Fig. 4(a). First, plane1 and plane2 that are 2D surfaces using the plane mesh that is a function of the THREE.js are prepared. Second, an odd page is set to the plane1 and an even page that is the next of the odd page is set to the plane2 by using the texture mapping method respectively. Third, rotate Y-axis of the plane2 to 180 degrees. As a result, both plane1 and plane2 become one double-sided paper space because both origins are set to the same zero position in 3D space when initializing. Finally, both plane1 and plane2 are managed by a set of paper object. In addition, translate Y-axis of the paper object to the left side of plane1 (the right side of plane2). As a result, only rotating Y-axis can make the paging operation.

A set of papers (each double sided paper space) \mathbf{P}_i is represented by

$$\mathbf{P}_i = \{ p_{od}, p_{ev} \mid ev = od + 1 \}; \quad (i = 0, 1, \dots, n - 1) \quad (2)$$

where p_{od} denotes an odd page and p_{ev} denotes an even page that are included in Eq. (1), and n denotes the maximum paper number that is $max / 2$. The \mathbf{P}_i has its own positions, rotations, and scales in 3D space that include those of p_{od} and p_{ev} relatively. Therefore, controlling only \mathbf{P}_i 's 3D parameters can change two pages together.

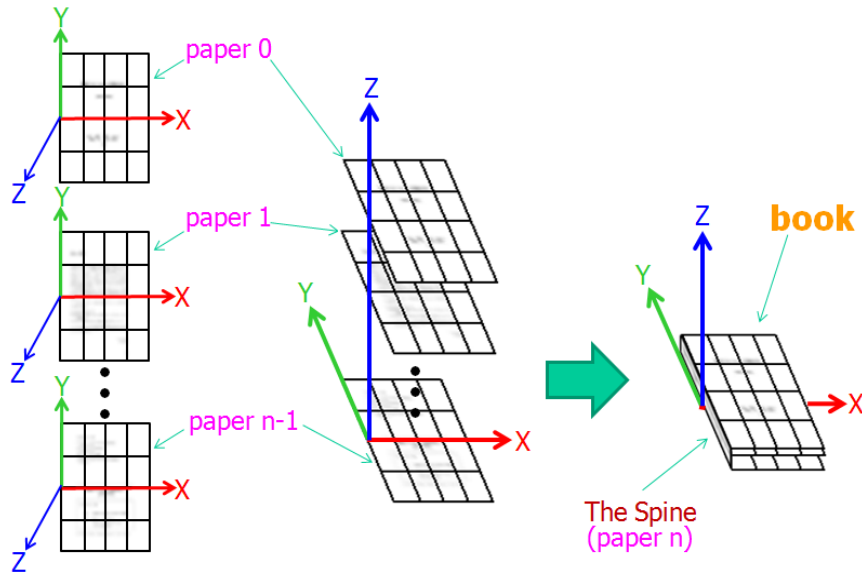


Figure 5: Book Style

3.3 Creating Double-Sided Paper Space for The Spine

Similarly, a double-sided paper space for the spine is created as shown in Fig. 4(b). In this case, the spine image is only set to the plane1 that is the front side, and paint the plane2 in gray color because the plane2 is the binding surface. Both plane1 and plane2 for the spine are managed by a set of paper object.

A set of paper for the spine \mathbf{P}_n is represented by

$$\mathbf{P}_n = \{ p_s, p_g \} \quad (3)$$

where p_s denotes the spine image and p_g denotes the gray color surface. Note that the index number n is the next number of the set of papers shown in Eq. (2). The \mathbf{P}_n also has its own positions, rotations, and scales in 3D space.

3.4 Creating Book Style

A book style is created by using the set of papers and the set of paper for the spine as shown in Fig. 5. The $\mathbf{P}_i (i = 0, 1, \dots, n - 1)$ is arranged into the width of the spine \mathbf{P}_n in equal space along the Z-axis. Both \mathbf{P}_i and \mathbf{P}_n are managed by a set of book object. The origin is located at the left end of the last paper \mathbf{P}_{n-1} .

A set of book \mathbf{B} is represented by

$$\mathbf{B} = \{ \mathbf{P}_0, \mathbf{P}_1, \dots, \mathbf{P}_{n-1}, \mathbf{P}_n \} \quad (4)$$

The \mathbf{B} also has its own positions, rotations, and scales in 3D space. Therefore, controlling only \mathbf{B} 's 3D parameters can change all of the papers and the spine together.

3.5 Paging Method

It is assumed that bending transformations do not occur in this research because this is a prototype system for creating a 3D virtual book. There are mainly three constrains:

- (1) Punch-through between papers must be avoided.
- (2) Relations of rank of papers must be maintained.
- (3) Plural papers must be able to be held together.

Figs. 6(a)–(i) show one of simple solutions for satisfying these constrains. These figures denote the book in XZ-plane (2D).

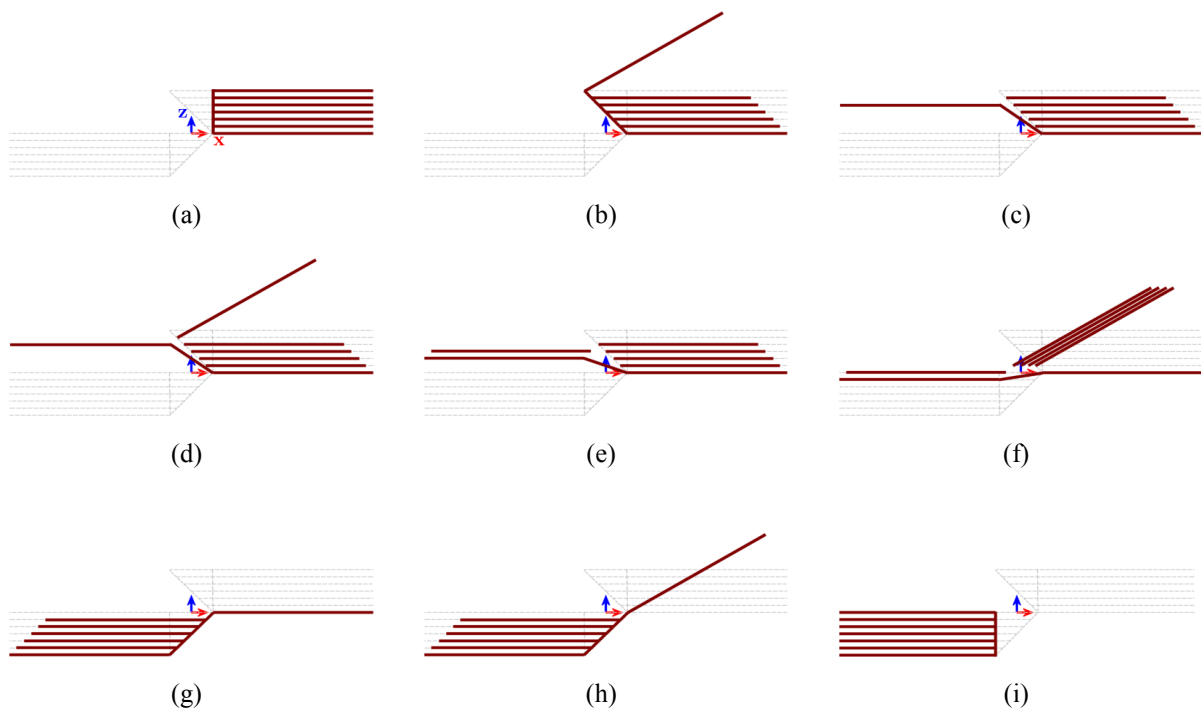


Figure 6: Paging Method

Fig. 6(a) shows the initial position (closing the book). This book position is moved to the half width of the spine in X-axis. Fig. 6(b) shows the paging for only the first paper. The spine slants at the angle of 45 degrees and the width of the spine becomes $\sqrt{2}$ times. Papers other than the last paper are moved to the connecting positions of the spine. Fig. 6(c) shows that the first paging operation is completed. The Z position of the first paper (vertical direction) is moved to the Z position of the third paper. The angle and the width of the spine are changed for connecting to the first paper. As a result, the intermediate papers other than the first paper and the last paper do not connect with the spine a little, that means the X positions of all papers do not change.

Fig. 6(d) shows the paging for the second paper. While this paging, the second paper do not overlap the others. Fig. 6(e) shows that the second paging operation is completed. The Z positions of the left side papers are moved down and the spine shape is also changed. Fig. 6(f) shows the paging with plural papers together. In this case, the Z positions of left side papers are moved down before paging starts. As a result, plural papers do not overlap both each other and the unmoved papers. Fig. 6(g) shows that the paging operation is completed, and Fig. 6(h) shows the paging for the last paper. Fig. 6(i) shows the finished paging (closing the book with reversed direction). In this case, the origin of the book is moved to the width of the spine to the left direction.

3.6 Total Paging Counter

In the existing electronic books, a paging operation from a current page to the next page is displayed by using an paper sliding animation via mouse or finger sliding/flicking operation. However, while paging, all texts in the two pages cannot be displayed together, and also plural papers cannot be paged together. In addition, when breaking in the middle of paging, the paging animation is completed immediately. As a result, all texts in not only continuous two pages but also separated pages cannot be seen/compared together.

To cope with the difficulty, an arbitrary angle of paging must be able to be stopped while the paging animation. Therefore, linking both the paging angle and the hold number to page, the total paging counter *cnt* is managed. The number of the start paper P_{start} and the number of the end paper P_{end} for holding plural papers are represented by

$$P_{start} = INT (cnt / div) \quad (5)$$

$$P_{end} = P_{start} + num \quad (6)$$

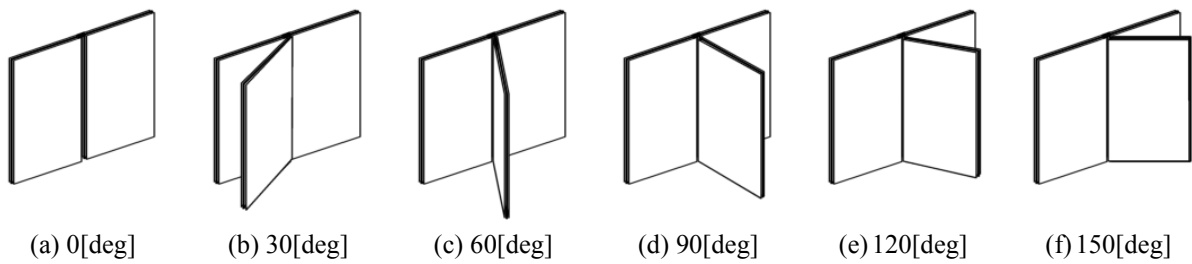


Figure 7: Sample of Paging Counter

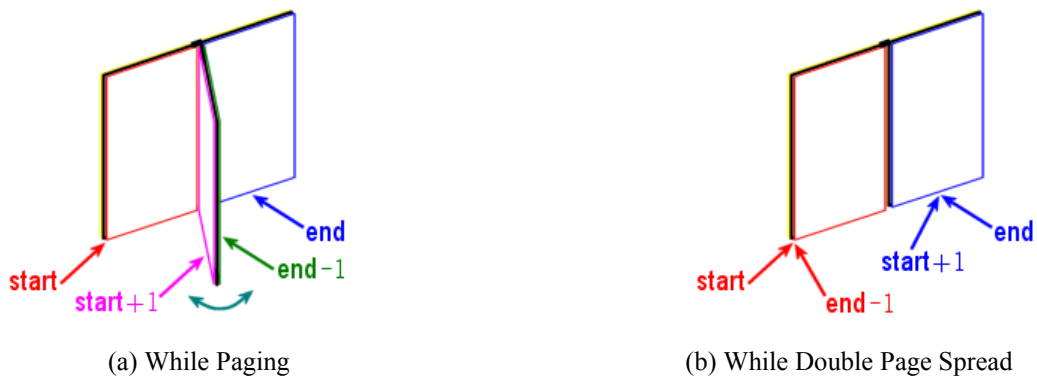


Figure 8: Visible Flag Setting

where div denotes the partition number for paging angles and num denotes the hold number to page. For example, in the case of $div = 6$ (The partition size is 30[deg]) as shown in Figs. 7(a)–(f), every time cnt advances 6, P_{start} increments. Note that when P_{start} increments, $div \times num$ is added to the cnt . In this research, div is set to 18.

3.7 Visible Flag Setting

If all background colors of all papers are set to white, it is difficult to distinguish between reading pages and the others. Processing is heavy for the way to put the shadow to the papers. For simple calculation, visible flags are used in this research. The flags are set to ‘true’ for the visible pages and to ‘false’ for the invisible pages as shown in Figs. 8(a),(b).

While paging, only six pages P_{start} , $P_{start+1}$, P_{end-1} , P_{end} and two cover pages are set to ‘true’ and the others are set to ‘false’. On the other hand, while double page spread, only four pages P_{start} , P_{end} ($P_{start} = P_{end-1}$, $P_{end} = P_{start+1}$) and two cover pages are set to ‘true’ and the others are set to ‘false’. Finally, the color of the false pages are changed to light gray ($color \times 0.9$) via fragment shader programming that is calculated on the GPU. Note that two cover pages are always ‘true’. If P_{start} , $P_{start+1}$, P_{end-1} , P_{end} can be memorized, the number of changing flags is only eight pages once.

IV. 3D Virtual Book Control Method

4.1 Whole Coordinate System

3D virtual book control method via Leap Motion is introduced. Fig. 9 shows the whole coordinate system in this research. The origin of the OpenGL is set to the origin of the Leap Motion and measurements in real space is basically used. As a result, the size of the book and the positions of hands can be treated intuitively. Paging operation can be controlled by using either left hand or right hand.

4.2 Hold Number Control Method

It is difficult to hold plural papers in the virtual space. To solve this problem, changing the roll angle of the hand is used to control the hold number as shown in Fig. 10. The left outside and the right outside of the book are set to the changeable area to hold. The hold number is proportional to the roll angle of the hand. When

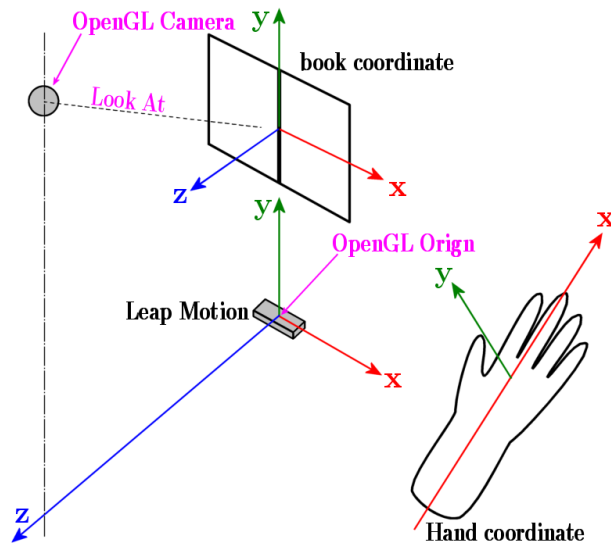


Figure 9: Whole Coordinate System

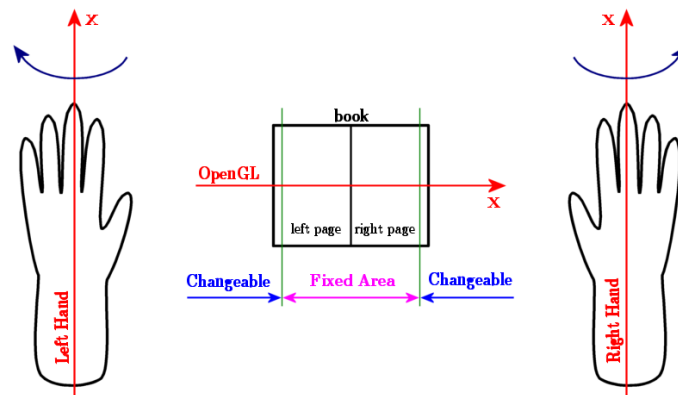


Figure 10: Controlling Hold Number

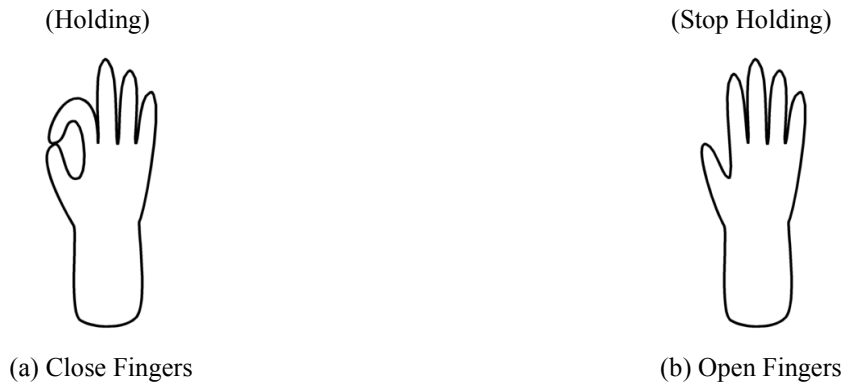


Figure 11: Holding ON/OFF

a palm faces to the bottom, the hold number is set to 1. When a palm faces to the top, the hold number is set to $n - 2$. It is assumed that the direction where the left hand and the right hand open to the outside is positive. And it is also assumed that it is impossible to change the hold number while paging.

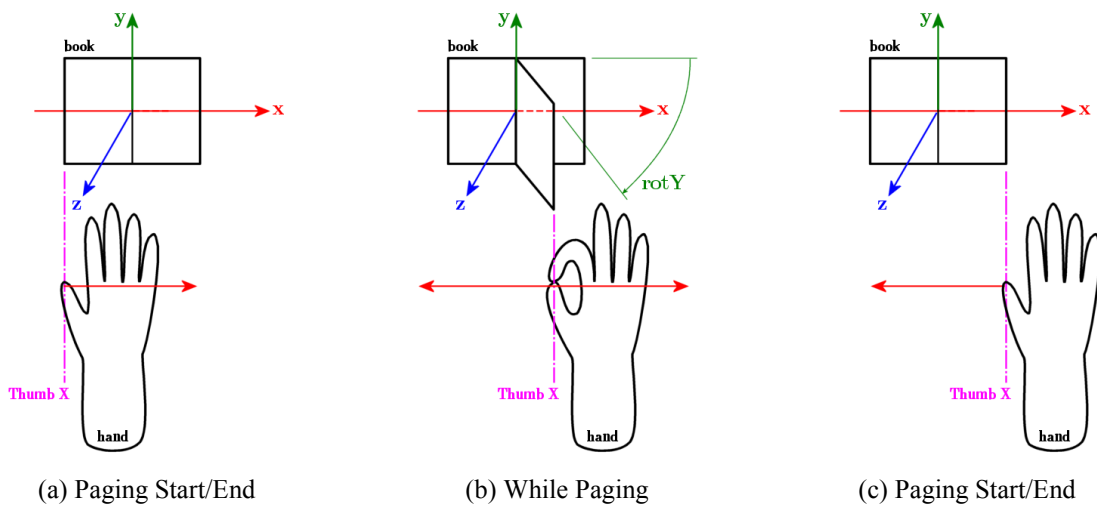


Figure 12: Controlling Paging Angle

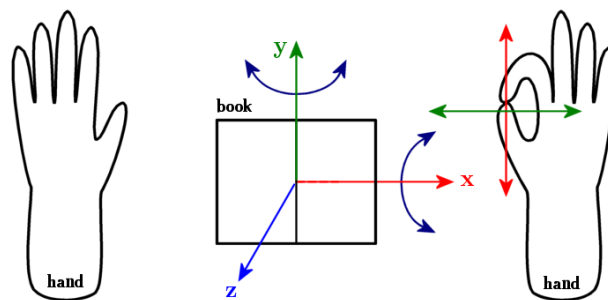


Figure 13: Controlling Book Rotations

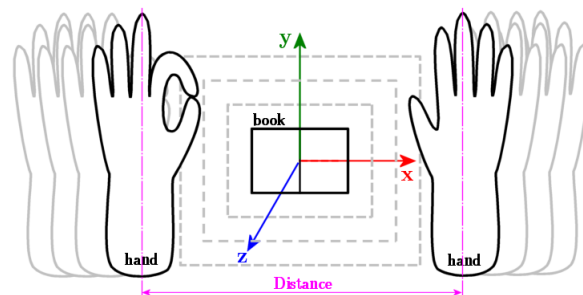


Figure 14: Controlling Book Scales

4.3 Holding ON/OFF Control Method

Paging can be controlled via holding ON/OFF control using only open or close shapes between the thumb and the index finger. When closing the fingers, it can be paged as shown in Fig. 11(a). On the other hand, when opening the fingers, it cannot be paged as shown in Fig. 11(b). Note that it is not necessary for positions of fingers to touch the book position. This is only one of trigger controls.

4.4 Paging Angle Control Method

Paging angle, that is a pitch angle of the paper(s) exactly, can be controlled via only the position of a thumb as shown in Figs. 12(a)–(c). This means that only horizontal position of the thumb can control the pitch

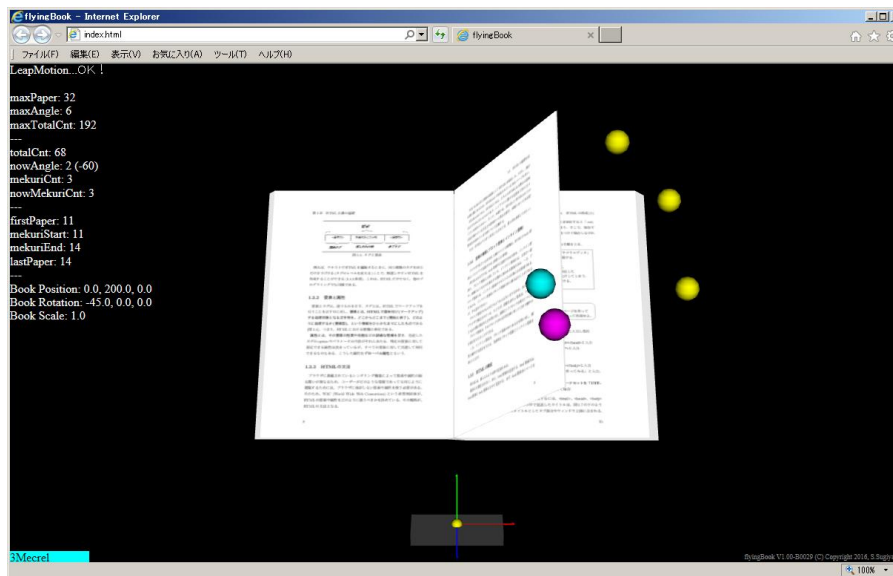


Figure 15: Our Prototype Software (The displayed book is [10])

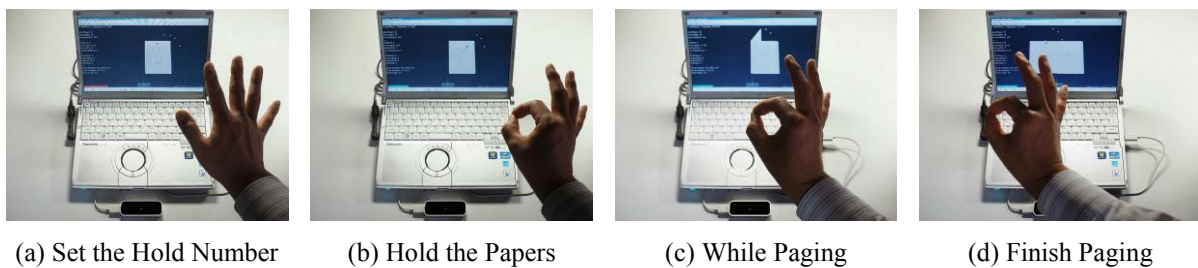


Figure 16: Experimental Result for Paging Operation

angle while closing the fingers. If each paging operation finishes, then it is necessary to stop holding (opening the fingers). Otherwise, the held current paper(s) cannot be changed to the next paper(s). This way is the same as the real paging operation on paper books.

4.5 Parameters of the Others

Rotations and scales of the book object **B** in 3D space can be controlled by using two hands. When two hands are available on the Leap Motion, the control status is changed to the operations for controlling rotations and scales of the book. When closing the fingers of the right hand, rotations of the book can be changed via the positions of the right hand (Fig. 13). On the other hand, when closing the fingers of the left hand, scales of the book can be also changed via the distance between the left hand and the right hand (Fig. 14). Note that it is not necessary to control positions of the book in 3D space in this research because there is only one book object in the window.

V. Result on Our Previous Research

Fig. 15 shows our prototype software for displaying a 3D virtual book using HTML5 and Javascript with WebGL and a polygon of the Leap Motion on a web browser (IE11). In this figure, the book is displayed at the center of the window, the position of the Leap Motion that is also the origin of the 3D space is displayed at the bottom of the window, and five circles are displayed at the tip positions of five fingers of the right hand where the cyan circle denotes the thumb and the magenta circle denotes the index finger, and the other yellow circles denote the other three fingers. The rectangle indicator at the left bottom of the window expands and contracts according to the hold number that is set by roll angle of the hand. When the fingers open, the rectangle color becomes red that means stop holding, and when the fingers close, the rectangle color becomes cyan that means holding. This figure shows the intermediate of paging with 11 papers together.

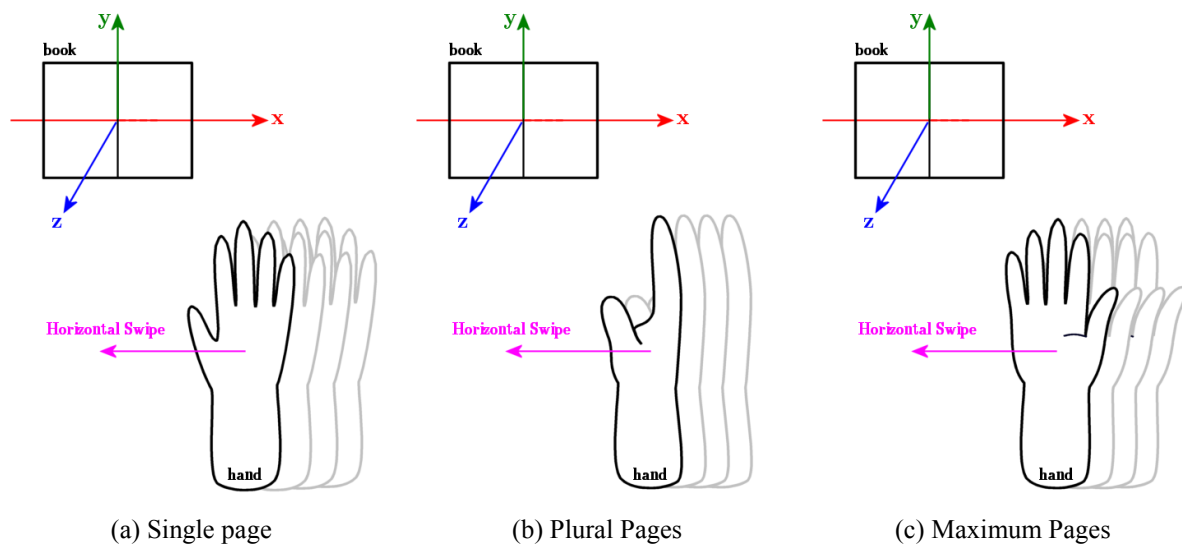


Figure 17: Easy Paging Operation

Figs. 16(a)–(d) show the experimental result for the paging operation using a right hand. Fig. 16(a) shows the state of setting the hold number by changing the roll angle of the right hand with opened fingers where the indicator color becomes red. Fig. 16(b) shows the state of holding the paper where the hold number has been set to 7 and the indicator color becomes cyan. This is the starting point of the paging. Fig. 16(c) shows the state of while paging where the paging angle changes according to the position of the thumb where seven papers are paged together while only one paging operation. Finally, Fig. 16(d) shows the state of finish paging. Note that a left hand can also control it as same as the right hand.

VI. Problems of The Interface

Paging operations by using a contact-less sensor has been achieved as shown in the prototype software of a 3D virtual book display system mentioned above, however, it is necessary to improve its interface. There is mainly three problems as the following.

The first problem is that the recognition accuracy of the Leap Motion is not enough to distinguish fingers correctly. First of all, this problem occurs in not only our software but also the checking software of the Leap Motion. Using this checking software, Leap Motion can only capture rough hand and/or finger motions almost correctly, however, it cannot capture the complicated motions such as the open/close finger forms in so many cases. When we instruct about 10 trial persons of our system to close their fingers, many of them closed both of the thumb and the index finger so that they touch around the first joints. It seems difficult that Leap Motion captures this state. On the other hand, when we again instruct the trial persons to close their fingers by touching nails both of the thumb and the index finger correctly, the results were improved, however, a half of them commented that to touch nails is so difficult.

The second problem is that inexperienced persons in the handling of sensors cannot understand the real 3D space in front of the Leap Motion. Even though positions of their fingers display on our software, they did not know where to locate their hand. As a result, a lot of trial persons could not control the 3D virtual book. It can be considered that a location marker in front of the PC or on their fingers is set to cope with the difficulty, however, the advantage of contact-less sensors disappears.

The third problem is that 3D paging operations cannot be achieved by using only current touch interface. In the case of using touch interface, not only the users can feel to touch display easily but also the software can capture the touch location easily, however, different operations more than two cannot be captured simultaneously. Therefore, it is difficult to control plural pages together and/or to tie separated pages such as paper media by using touch interface.

VII. Proposal of Easy Paging Operation

Considering the problems mentioned above, easier operations for many users by using a contact-less sensor is necessary. Therefore, a new easy paging operation that is a kind of improved swipe motion to be able to tie plural pages together is proposed. Though the Leap Motion has a swipe operation, in this research, not

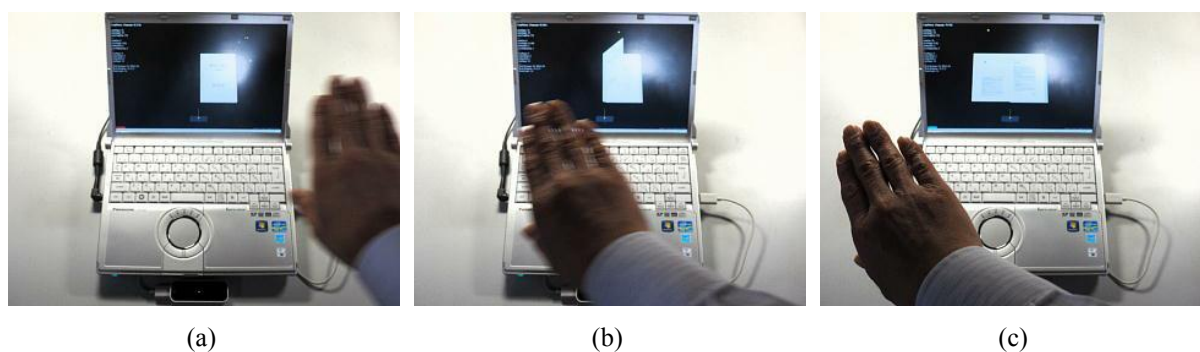


Figure 18: Swipe Operation with a page

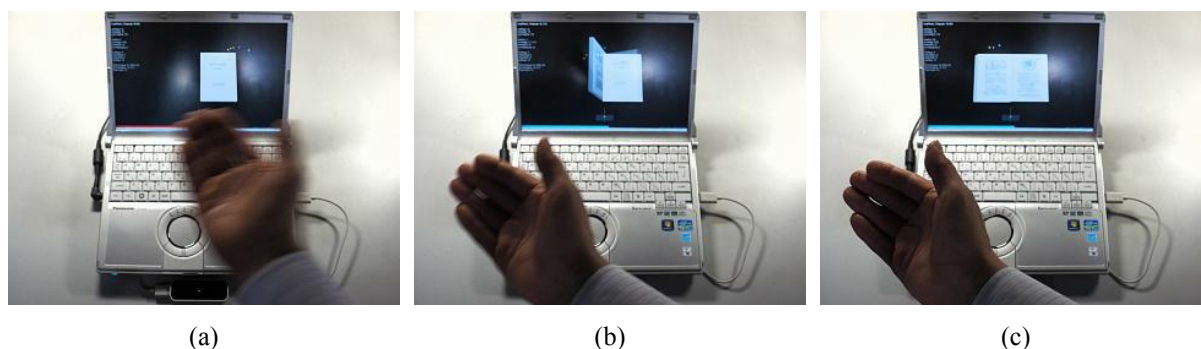


Figure 19: Swipe Operation with plural pages together

only the swipe operation but also the hold number control method are used together to control the 3D paging operation.

Fig. 17(a) shows the easy paging operation where the roll angle of the right hand is set to 0 degree (face down). In this case, when swiping the hand from right to left, one paper is only paged. Similarly, Fig. 17(b) shows the easy paging operation where the roll angle is set to intermediate angle between 1 degree and 179 degrees according to the papers as users' requirement. In this case, when swiping the hand, plural papers are paged together (only one action). In addition, Fig. 17(c) shows the easy paging operation where the roll angle of the right hand is set to 180 degree (face up). In this case, when swiping the hand, $n-2$ papers are paged together (only one action).

As a result, the easy paging operation to tie plural pages together can be achieved without thinking about the sensor measurement area strictly. This is a new paging operation which touch interface do not have. Note that all of previous functions can be used even if this new operation is added to our previous software.

VIII. Result by Using New Easy Paging Operation

Figs. 18(a)–(c) show a new result of the easy paging operation by using swipe with setting a page. Similarly, Figs. 19(a)–(c) show a new result of the easy paging operation by using swipe with setting plural pages.

Note that 3DCG is displayed later than the swipe operation because the swipe is very fast motion, however, paging animation can be completed after swiping automatically. That is, when this swipe is used, paging operation does not stop while swiping. Using both the new operation and the holding ON/OFF control together, comfortable reading can be achieved.

IX. Conclusion

In this research, the problems of our previous method proposed already were considered and a new easy paging operation has been proposed to solve these problems. As a result, it could be achieved that the paging operation with plural pages together for a 3D virtual book using contact-less sensor is easy while all of previous functions can be used together.

On the other hand, some problems are found as the following.

- (1) The memory volume of this system is very large because it uses the image files per each page. If the size of image files sets to small, the memory volume becomes small, however, it is difficult to read the texts clearly. It can be expected that the performance of GPU will be improved in the near future.
- (2) Touching a 3D virtual book with fingers in reality cannot be achieved because the Leap Motion is just a contact-less sensor, however, this paging operation can be controlled by using only the hold number, some ON/OFF controls, the positions of the hands/fingers, and new easy paging operation, instead of touching a 3D book in reality.
- (3) There is a lot of paging styles. This new method is only one of such styles and this 3D virtual book cannot display bending transformation. It is necessary to discuss the other paging style in the future.
- (4) In this research, the Leap Motion was selected for using a contact-less sensor because it is very small and reasonable. Therefore, many users who want to read our 3D virtual book can buy and can use the Leap Motion easily, however, the recognition accuracy of the Leap Motion is not enough. It is necessary to discuss and to investigate the other sensors variously.

In the present condition, there were almost no system such as our 3D virtual book control method like paper media yet even though virtual reality and augmented reality have been spread all over the world. By creating our prototype system, it can be said that the environment that argument can be advanced about 3D virtual books for the first time was made. In addition, this improved result makes users more comfortable on the reading system like paper books.

Future plans will be conducted to construct paper bending transformations, adding new functions and improving system performance, utilizing it on an absorbed display, and investigating users' evaluation of this system.

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