Limpid Desk: See-Through Access to Disorderly Desktop in Projection-Based Mixed Reality

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ABSTRACT

We propose *Limpid Desk* which supports document search on a real desktop with virtual transparentizing of the upper layer of a document stack in projection-based mixed reality (MR) environments. In the system, users can visually access a lower layer document without physically removing the upper documents. This is accomplished by projecting a special pattern of light that is calculated to compensate the appearances of the upper layer documents as if they are transparent. In addition, we propose two types of visual effects for users to cognize the progress of the transparentizing of real documents and to recognize the layer number of the virtually exposing document, and excecute psychological tests to confirm the intuitiveness of these effects. This paper also presents an intuitive document search interaction in the proposed system.

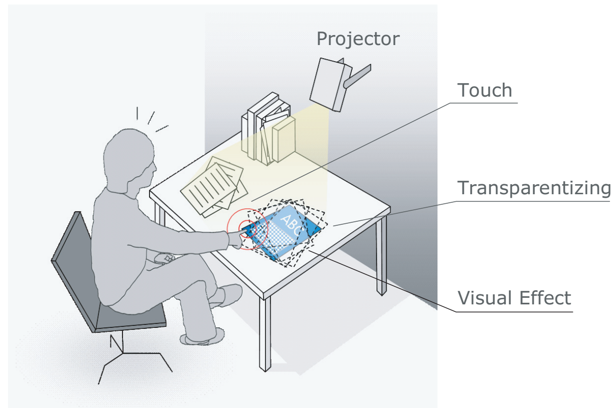


Figure 1: The conceptual idea of Limpid Desk

Categories and Subject Descriptors

H5.1 [**INFORMATION INTERFACES AND PRESENTATION (e.g., HCI)**]: Multimedia Information Systems. - Artificial, augmented, and virtual realities.

General Terms

Measurement, Human Factors

Keywords

Projection-Based Mixed Reality, Color Reflectance Compensation, Smart Desk, Transparentizing Documents

1. INTRODUCTION

Documents (e.g., magazines, books, papers, etc.) are scattered and in disorderly piles on a real desktop. The chaos found on the desktop makes searching of desired documents painful, and when all the documents are organized on the desktop, the desired documents can be easily found and the work handled efficiently. But most people are busy and don't have any spare time to clean up their desktops.

To support a document search task in such a situation, we propose to transparentize documents in situ on a real desktop. When the upper layer documents are opaque as usual, a person has to remove them to look at a lower layer document. But if they became semi-transparent, a user could figure out what the lower layer document was with no need to remove the upper documents. In this proposed environment, users can intuitively find the desired document even if it is hidden under the document stack.

We have been proposed an intuitive document search system, *Limpid Desk*, which utilizes a projection-based MR technology to transparentize the upper layer real documents virtually. The basic idea of the system has been proposed in the previous work [4]. Figure 1 indicates the interaction sequence of the proposed system as follows. First, a user touches a document on the desktop, and the system detects the touch. Then the upper layer document is virtually transparentized by projection, and as a result, the user can see the lower layer document without physically removing its upper documents. This paper focuses on describing a part of this sequence, or the way of producing projection images.

Recently, projectors have been exploited for virtual transparentizing of real screens [2, 3]. However, these screens were limited to convenient objects such as a refrigerator's simple white door and retro-reflective material. On the other hand, there are some works on color reflectance compensation techniques of projector-camera systems to reproduce the desired projection appearance on a real object's surface which has spatially varying reflectance properties that disturb the appearance of the projected image [1, 5, 6, 7]. We combine these two technologies for virtual transparentizing of various real documents (e.g., magazines and photos) which have complex textures.

Virtual transparentizing process is done as follows. The projection image is produced by combining surface images of lower layer documents and the desktop under the upper layer documents, which are to be virtually transparentized. This projection image is compensated and projected to the transparentized upper layer documents. In addition to this basic virtual transparentizing process, we propose two types of visual effects for users to cognize the progress of the transparentizing of real documents and to recognize the layer number of the virtually exposing document. We confirm the intuitiveness of these effects by psychological test.

2. VIRTUAL TRANSPARENTIZING OF REAL DOCUMENTS BY PROJECTION

In this section, we present our proposed method of virtual transparentizing of real documents using a projector and a color camera. The fundamental process of virtual transparentizing of real objects is projecting the background image to the projection object. In the proposed system, the projection, or background, image is produced by combining of the surface images of the lower layer documents and the desktop under the upper layer documents that are to be virtually transparentized. Then, this projection image is projected to the transparentized upper layer documents.

We also explore the possibility of controlling the transparency of a real document. Conventional projection-based transparentizing systems have not considered the transparency of a projection object. But, the flexible transparency of a real object expands the possibility of interactions implemented on the proposed system. We realize various virtual transparencies of a real document by tuning the brightness of a projection image.

We implemented these proposed methods on the system and performed a basic experiment to confirm their operational capabilities. We overlay two documents on a desktop as in Fig. 2(a); the upper layer document is an opaque yellow paper and to be virtually transparentized. Figure 2(b) shows the upper layer document has changed to a semi-transparent yellow sheet and the appearance of this stack is ideal. We then tested whether this ideal appearance can be reproduced and the virtual transparency of the upper layer document can be controlled.

The experimental results are shown in Fig. 3. Figure 3(a1)(a2) (a3) and (b1)(b2)(b3) show the projection appearance with the projection light onto the stack and a white paper. The brightness of the projection image is tuned and the same in each Fig. 3(a1)-(b1), (a2)-(b2), and (a3)-(b3). The appearances of Fig. 2(b) and 3(a3) are almost the same, so we can say that our proposed method can realize virtual transparentizing of a real document. We can see that the brighter the projection image is, the more transparent the appearance of the upper layer document looks in Fig. 3. This indicates that our proposed method can also control the degree of transparency of a real document by tuning the brightness of the projection image.

The projection object used in the above experiment is simple yellow paper, so there is no problem with the visibility of the projection appearance. But in the real world, most documents (e.g., magazines, photos) have spatially varying reflectance properties which disturb the appearance of the projected image. We apply a color reflectance compensation method which we previously proposed in reference [7], to give a better transparent appearance. We did this so as not to reduce the visibility and readability of the projected lower layer document image on the upper layer documents that have complex textures.

The method uses a color camera to obtain an affine correlation in color space between the projection and the result captured by the camera for each camera pixel. This affine correlation can transform the desired color appearance onto a surface of a real object into a projection color value. This color calibration can be done automatically for each pixel as follows.

A color appearance is the reflected light of the object per-

(a) Projection object (b) Ideal appearance

Figure 2: Pysical outlook of documents; the upper layer document is (a) opaque yellow sheet, (b) semi-transparent yellow sheet.

Figure 3: Projection result; projecting image of the lower layer document onto (a1)(a2)(a3) the upper layer document, and onto (b1)(b2)(b3) white paper.

ceived by the human eye or the camera. Here, we set the projector as the light source, and the color camera observes the real object. When the projection intensity is represented as P_R, P_G, P_B and the response of the color camera is represented as C_R, C_G, C_B, the correlation between them can be represented as following equation in affine transformation.

$$\left[\begin{array}{ccc} P_R & P_G & P_B \end{array}\right]^t = K \left[\begin{array}{cccc} C_R & C_G & C_B & 1 \end{array}\right]^t \quad (1)$$

This equation has twelve unknown parameters in matrix K. However, if at least four correspondences between (C_R, C_G, C_B) and (P_R, P_G, P_B) are obtained, these parameters can be calculated. In the present system, we project more than four simple color patterns (e.g., red, green, blue, yellow, magenta, cyan etc.) and capture the reflectance from the projection object, or the upper layer documents. After this color calibration, we can project colored images onto surfaces taking into consideration of their reflectance. First, the (C_R, C_G, C_B) is the color of the target appearance produced by the surface image of the lower layer documents and the desktop under the upper layer documents which is virtually transparentized. Then, the color of the compensated projection image (P_R, P_G, P_B) is calculated by the Eq. 1 for each pixel of the projection image.

3. VISUAL EFFECT

In addition to the virtual transparentizing method proposed in the above section, we propose two types of visual effects that are used for users to cognize the transparentizing of real documents and to recognize the layer number of virtually exposing document. We also confirm the intuitiveness of these effects by psychological test. We install the combination of these visual effects on the proposed system.

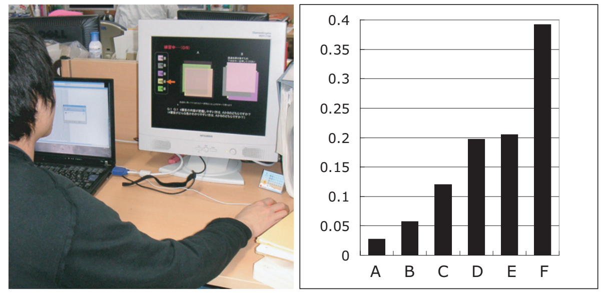
3.1 Visual Effect to Cognize Transparentizing

We adopt fadeout as the first visual effect in which the opacity of the upper layer document is gradually reduced and users can cognize the transparentizing of real documents. We conducted a questionnaire survey of seven participants who were recruited from a local university. In the experiment, we put two papers on a real desktop and virtually transparentized the upper layer paper by projection with fadeout effect. We showed this to the participants and 100% of the participants answered that they were able to cognize the transparentizing of real documents by the fadeout effect. This result confirmed the intuitiveness of the proposed first visual effect.

3.2 Visual Effect to Recognize Layer Number of the Virtually Exposing Document

In the scenario of document search, it is important for users to recognize the layer number of the displayed lower layer document in the stack, so that they can immediately take the document from the stack. To meet this need, we must show users the upper layer documents although they are virtually transparentized. Simple alpha blending which able to show both the lower and upper layer document causes a reduction of readability of the contents because they become muddled. So as not to reduce the readability so much, we propose to transparentize the upper layer documents one by one while retaining all disappeared documents' frames.

To confirm the proposed effect is the most intuitive visual effect of several types of effects, we executed a pair comparison method. We compared six types of visual effects including the proposed effect. Effect A is transparentizing of the upper layer documents without any additional effects. Effect B is transparentizing of the upper layer documents with alpha blending of all transparentized documents. Effect C is transparentizing of the upper layer documents while retaining all disappeared documents' frames. In these effects, the upper layer documents are transparentized at once. Effect D, E and F are the same as each of A, B and C, but in these later effects the upper layer documents are transparentized one by one, and Effect F is our proposed one. We executed the test by comparing each pair of objective visual effects by displaying each pair together on a PC monitor in Fig. 4(a). The participants gave a score of 1 for the effect that made it easier to recognize the layer number of the virtually exposing document and 0 for the other effect of each pair. Fifteen participants were recruited from a local university and the experimental result is shown in Fig. 4(b). This result indicates that our proposed effect is the easiest for users to recognize the layer number of virtually exposing document.



(a) (b)

Figure 4: Pair comparison method; (a)experimental setup, (b)relative scores of visual effects

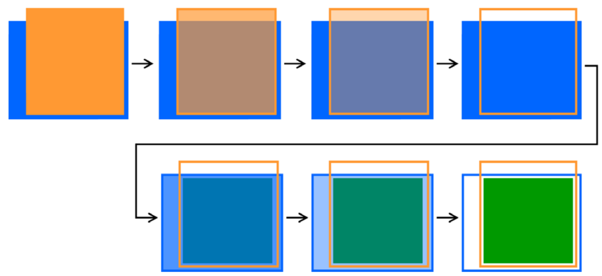


Figure 5: Visual effect; two upper layer documents are transparentized

3.3 Combination of Visual Effects

When we installed these effects on the proposed system, we combined them as shown in Fig. 5; the upper layer documents are gradually transparentized one by one, retaining the frames of the transparentized upper layer documents. The visual effect we propose in this paper is not so special but is effective for users to cognize the virtual transparentizing of real documents and recognize the layer number of the displayed lower layer document.

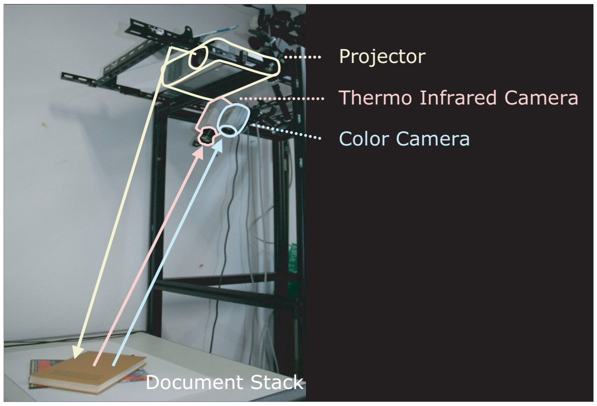


Figure 6: Outlook of experimental setup

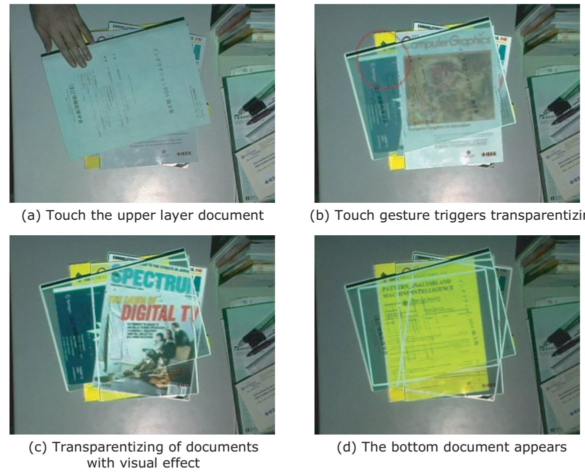


Figure 7: "Stack Browse" interaction

4. DOCUMENT SEARCH APPLICATION

Figure 6 shows the outlook of the experimental setup of Limpid Desk. The system consists of a video projector, a color camera, and a thermo infrared camera, all of which are mounted overhead and facing the desktop. This system runs on a PC workstation (Intel Pentium-4). We use a video projector (NEC MT1075J) to render images directly on document stacks, and a color camera (Sony DFW-VL500) for our color reflectance compensation method and touch area sensing method which has already been proposed in the previous work [4]. A thermo infrared camera (Mitsubishi IR-SC1) takes desktop images warmed by user's touch also used for the touch area sensing.

We implemented intuitive document search interaction techniques on the system with the proposed thermographic touch sensing method [4]. In the sensing, a user can browse and point stacked documents only by touching them without any user-worn or hand-held devices. Therefore, the user can search the desired documents onto a real desktop without a PC monitor and interface.

In the interaction, we call "Stack Browse" interaction, the upper layer documents are transparentized one by one to the bottom of the stack with the effect of a combination of fadeout and retaining of document's frame as the proposed visual effect, after a user touches the top of the document stack (Fig. 7). As a result, a user can browse all the documents in the stack by one action and after that, if the desired document is found, he/she can take the document immediately.

5. CONCLUSION

We have presented a novel document search system, Limpid Desk, which realizes see-through access to a disorderly desktop in a projection-based MR environment. In the proposed system, users can visually access a lower layer document on a real desktop without removing the upper layer documents, by virtual transparentizing of the upper layer documents. We applied a color reflectance compensation method for better appearances of virtual transparentizing of real documents that have spatially varying reflectance properties that disturb the appearance of the projected image. Our proposed simple visual effect can let users feel the transition of transparentizing of real documents and to recognize the layer number of a virtually exposing document. We implemented an intuitive, seamless and consistent interaction technique on Limpid Desk, so that users can browse all the stacked documents by their simple touch gestures. In future, we wish to develop the proposed framework to combine the virtual and physical desktop space seamlessly.

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