Portable Information Security Display System via Spatial PsychoVisual Modulation

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***Abstract*—With the rapid development of visual media, people prefer to pay more attention to privacy protection in public situations. Currently, most existing researches on information security such as cryptography and steganography mainly concern transmission and yet little has been done to keep the information displayed on screens from reaching eyes of the bystanders. At the same time, the reporter just stands in front of the screen during traditional meetings. Limited time, screen area and report forms, which inevitably leads to limited information. As a result, we design a portable screen for assisting the reporter to present any information in a new form. In some public occasions, the reporter can show private content with important information to authorized audience while the others can not see that. In this paper, we propose a new Spatial PsychoVisual Modulation (SPVM) based solution to the privacy problem. This system uses two synchronized projectors with linear polarization filters and polarization glasses, and a camera with linear polarization filter the metallic screen. It can guarantee the system shows private information synchronously. We have implemented the system and experimental results demonstrate the effectiveness and robustness of the proposed information security display system.**

***Index Terms*—Spatial PsychoVisual Modulation (SPVM), Display technology, Information security, Multimedia technology, Portable display.**

I. Introduction

In traditional meetings, the reporter is always standing in front of the screen, facing the audience, presenting what he(she) wants to show. Just relying on that screen can not show information vividly and enough, even though the reporter has wonderful speech skills or adds interesting gestures into the speech for enhancing the emotions expression. It is undeniable that limited area of screen can only show limited information. What's more, the concept of privacy is playing an important role in our daily lives. In many important occasions like company meetings, the privacy protection is highly required. With the two concerns stated above, this paper introduces an information security display system based on the Spatial Psychovisual Modulation (SPVM). SPVM is a novel display technology which exploits the psychovisual redundancy in high definition (HD) display. It is evolved from the Temporal PsychoVisual Modulation (TPVM) [1], which makes use of the redundancy in high refresh rate instead. TPVM exploits the redundant frames to provide different contents to different observers simultaneously [2]. The so-called atom frames are broadcasted at a speed several times higher than that the HVS can recognize. And the viewers can use their own display synchronized shutter glasses to temporally weight the atom frames. Through various glasses, people can see various images on the same screen at the same time.

There are so many stream liquid crystal displays such as LCD and LED provide HD resolution of 2K or UHD resolution at 4K in the current display market. However, the resolution limit of human eyes is limited. Human eyes just be able to distinguish 300 pixels per inch (PPI) under normal viewing condition at most [3]. In most instances, people view the display screen from a distance farther than ideal and this generally makes more redundancy in pixel exhibition capacity . Taking the advantage of the resolution difference between those modern multimedia display devices and the human eyes ingeniously, SPVM can provide different information to specific users simultaneously [4]. In the SPVM system, different users can be divided into two groups by polarization. The polarization based 3D display always has interlaced screen which means that the odd and even scan lines are polarized into different directions. The interlacing certainly divides the screen into two parts. Through broadcasting different images x_1 and x_2 from the odd and even lines independently, it is possible to show different contents to different audiences. [5] Similarly, we can also use two movie projectors combined with a pair of polarizer in a SPVM system.

Based on the technology of SPVM and inspired by the 2D/3D simultaneous display system, we designed an information security display system. The system based on the polarization type 3D cinema system in which two projectors are used to broadcast the images for left and right eyes simultaneously with a pair of polarizers. As shown in Fig.1, one can clearly see the structure of the system. In this system, we preprocess the display signal for each projector to ensure that authorized audiences can see private information with polarization glasses while the others can see different contents with naked eyes. What's more, another innovation is that we change the traditional fixed screen into a portable screen [6]. We have to admit that it is a new challenge

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and an improvement to the traditional mode of meeting or speech. In fact, the system can be a good achievement of portable speech assistance and privacy information protection.

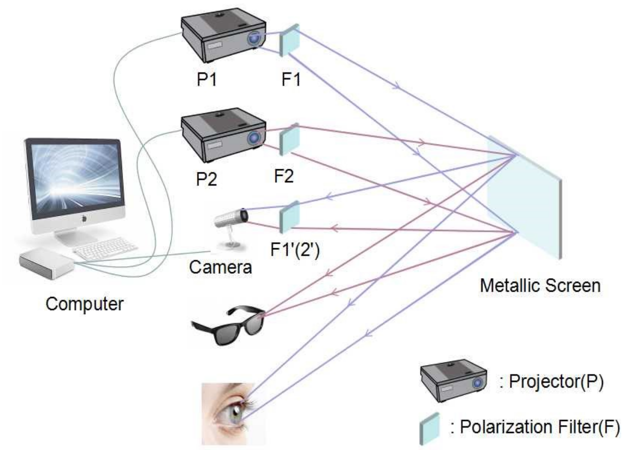


Fig.1. The structure of the system.

II. ALGORITHM FOR DERIVING THE DISPLAY FRAMES

A. Spatial psychovisual modulation

In this system, we first define the three views. The glasses-free view is defaulted as Y_0 and the two display frames for the projectors are denoted as X_1 and X_2. We supposed a pair of images X_1 and X_2 are broadcasted in the even and odd lines on the same screen simultaneously. Using a pair of polarization glasses matched to the even lines, we can see glasses-aided view X_1. Supposing the projectors are perfectly matched, clearly the normal view Y_0 can be calculated as

$$Y_0 = X_1 + X_2. \tag{1}$$

The idea of broadcasting two images using interlaced polarization was also applied to LG's "DUAL PLAY" system. Essentially, it is a simultaneously screen sharing form for audience with two types of polarization glasses matched to even and odd lines of the screen respectively [7]. However, with this naive technique, audiences without the polarization glasses can only get a meaningless and blurry view combining two views X_1 and X_2. The key idea of SPVM is that we not only consider the images of X_1 and X_2 but also think of the meaningful normal view Y_0 for the glasses-free viewers.

The modulation weights of the viewing glasses are from 0 to 1 corresponding from completely transparent to totally block. Besides, any display signal should not be negative. So we can have a general SPVM system expressed by nonnegative matrix factorization (NMF) [8] as follows:

$$Y_k = \sum_{i=1}^{2} X_i W_k^i \tag{2}$$

$$\begin{aligned} subject\ to\ & 0 \le W_k^i \le 1 \\ & X_i \ge 0, i = 1, 2 \end{aligned}$$

In the system, there are two projectors, so the NMF equation can be simplified to the problem with k = 2. To derive the display frames and the weights, we will have to solve the following linear system with nonnegative constraints:

$$\begin{bmatrix} Y_0 & Y_1 & Y_2 \end{bmatrix} = \begin{bmatrix} X_1 & X_2 \end{bmatrix} \begin{bmatrix} W_1^0 & W_1^1 & W_1^2 \\ W_2^0 & W_2^1 & W_2^2 \end{bmatrix} \tag{3}$$

The weight factor W can be set to 1 by making the viewing glasses polarized in the same direction as the polarization glasses lay before the projector. If we want to set the W to be 0, we just need to turn the polarization glasses into another direction (90 degree for linear polarization or change into another glass for circular polarization), so that all the lights from the specific projector are blocked [9]. By tuning the mismatch between the polarizers, we can set the weight W to any value belong to the range of [0,1]. Considering the fact that both lightness and weight [10] cannot be negative and are bounded, the above equation amounts to the NMF problem as indicated in TPVM . However, solving NMF directly requires a lot of computation which is out of the question for the practical system we are aiming to develop in this work. Moreover, for those consumer level inexpensive polarization glasses, only two polarization directions are provided, i.e. let the light complete pass or complete blocked. Therefore, a quick solution to the weights of LC glasses in the dual-subtitle system is as follows:

$$\begin{bmatrix} W_1^0 & W_1^1 & W_1^2 \\ W_2^0 & W_2^1 & W_2^2 \end{bmatrix} = \begin{bmatrix} 1 & 1 & 0 \\ 1 & 0 & 1 \end{bmatrix} \tag{4}$$

Then we arrive at the linear least-square problem :

$$\min_{X_1, X_2} \{\|Y_0 - X_1 - X_2\| + \|Y_1 - X_1\|\} \tag{5}$$

Again, solution of this least square problem involves matrix inversion which is also of high complexity. Fortunately, we further find a heuristic solution to the problem as:

$$\begin{cases} X_1 = Y_1 \\ X_2 = Y_0 - X_1 = Y_0 - Y_1 \end{cases} \tag{6}$$

In this case, we can simply choose the display frames X1 and X2 respectively.

B. Camera calibration

At the beginning of building the system, the camera calibration is a necessary step. Accurate camera calibration guarantees to handle the coordinates correctly [11]. The projection formula is as follows:

$$s \cdot m' = s \cdot \begin{bmatrix} u & v & 1 \end{bmatrix} = A \cdot [R|t] \cdot M' \tag{7}$$

$$A = \begin{bmatrix} f_x & 0 & c_x \\ 0 & f_y & c_y \\ 0 & 0 & 1 \end{bmatrix} \tag{8}$$

$$[R|t] = \begin{bmatrix} r_{11} & r_{12} & r_{13} & t_1 \\ r_{21} & r_{22} & r_{23} & t_2 \\ r_{31} & r_{32} & r_{33} & t_3 \end{bmatrix} \tag{9}$$

$$M' = \begin{bmatrix} X & Y & Z & 1 \end{bmatrix}^T \tag{10}$$

In the above equations, (X, Y, Z) is a point of the world coordinates, (u, v) is the point projection in the image plane coordinates in pixels. A is called a camera matrix, or an inner parameter matrix. (c_x, c_y) is the datum point (usually at the center of the image), f_x, f_y is the focal length in pixels. All of these parameters (f_x, f_y, c_x, c_y) will be scaled (multiplied or divided) [12]by the same scale if the image is sampled due to some factors. The internal parameter matrix does not depend on the view of the scene, once calculated [13], it can be reused (as long as the focal length is fixed). The rotation-translation matrix [R|t] is called an outer parameter matrix, which is used to describe the movement of the camera relatives to a fixed scene [14]. That is to say, [R|t] transforms the coordinates of point (X, Y, Z) into a coordinate system which is fixed relative to the camera.The real lens usually has some deformation, the main deformation of the radial deformation [15], there will be a slight tangential deformation. So the above model can be shown as follows:

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = R \cdot \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} + t \tag{11}$$

$$x' = \frac{x}{z} \tag{12}$$

$$y' = \frac{y}{z} \tag{13}$$

$$x'' = x'(1 + k_1 r^2 + k_2 r^4) + 2p_1 x' y' + p_2(r^2 + 2x'^2) \tag{14}$$

$$y'' = y'(1 + k_1 r^2 + k_2 r^4) + 2p_2 x' y' + p_1(r^2 + 2y'^2) \tag{15}$$

$$u = f_x \cdot x'' + c_x \tag{16}$$

$$v = f_y \cdot y'' + c_y \tag{17}$$

In the above equation, k_1 and k_2 are radial deformation coefficients, p_1 and p_1 are tangential deformation coefficients. The deformation coefficients are independent of the scene, so they are internal parameters and independent of the resolution of the captured image.

C. Identification and projection

In this system, we want to design a portable screen. That characteristic is very necessary for every lecturer who prefers to show more information to the audience in a totally new way. So, it is rather important for detecting the screen timely and synchronously. The light passes through the polarization filter and becomes polarized light. As known, human eyes cannot distinguish polarized light from natural. However, the camera with the corresponding polarization filter can only receive a dark screen. In other words, the computer can only get the location of the screen, and can not receive the contents from the screen. Based on this, we designed the detection and identification algorithm.

Through experimental observation, we find that the image camera received is special. It has a dark area which is approximately a parallelogram [16]. By setting the appropriate color threshold, the image can be filtered. In the experiment, we found that no matter how we placed the portable screen, the detected area is always a parallelogram(ignore the part blocked by hand). Then using the HoughLinesP function to detect outlines [17]. As expected, we could detect roughly four straight outlines, and there are two pairs of parallel lines, forming a parallelogram. Through the HoughLinesP function, we can obtain the information of each line, such as the coordinates of two points where each straight line through. Thus, we can compute the intersection of the straight lines (the four vertices of the parallelogram). With the same algorithm to calculate the coordinates of the four points.

Projection is also significant. It ensures that the projectors can achieve normal projection no matter how to place the screen in the space.

$$\begin{bmatrix} x' & y' & w' \end{bmatrix} = \begin{bmatrix} u & v & w \end{bmatrix} \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} \tag{18}$$

In the above equation, u and v are the original image coordinates [18], corresponding to the resulting image coordinates x and y. Besides, x = $x^{'}/w^{'}$, y = $y^{'}/w^{'}$.The transformation matrix can be into four parts:

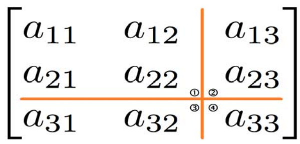


Fig.2. The four parts of the transformation matrix.

The first part represents a linear transformation, such as scaling, shearing and rotation. The second part is used to produce a perspective transformation. The third part is used to translate. From the previous transformation formula, we can get two equations as follows:

$$x = \frac{x'}{w'} = \frac{a_{11}u + a_{21}v + a_{31}}{a_{13}u + a_{23}v + a_{33}} \tag{19}$$

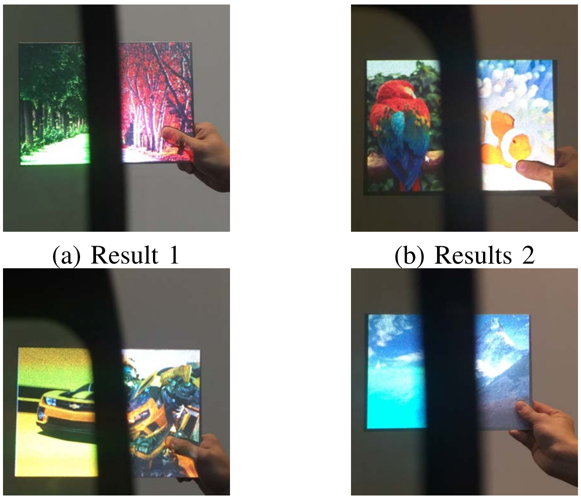
$$y = \frac{y'}{w'} = \frac{a_{12}u + a_{22}v + a_{32}}{a_{13}u + a_{23}v + a_{33}} \tag{20}$$

So, it is known that the transformation of the corresponding points can be obtained from the transformation formula [15]. Conversely, a particular transformation formula can also be transformed into a new image.

III. DESIGN AND IMPLEMENTATION OF THE SYSTEM

A. System overview

The designed information security display system is shown in Fig.1. This system is based on two synchronized projectors and one camera. As shown in Fig.3., we apply two orthogonal linear polarization filters(F1 and F2) to the pair of projectors. Assuming that F1(F2) and F1'(F2') are a pair of linear polarization filters. That means that after passing through F1(F2), the polarized light can not pass through F1'(F2'). Based on it, we apply the other linear polarization filter F1'(F2') in front of the camera. As a result, the camera can not receive



(a) Result 1 (b) Results 2

(c) Result 3 (d) Result 4

Fig.4. The results of the information security display system.

anything, it just a dark screen. By using our algorithm, no matter how to place this screen in the space, the camera can detect and recognize this screen timely and synchronously. Finally, the reporter can decide to show authorized audience private content with Spatial Psychovisual Modulation(SPVM). Note that to maintain the polarization direction of the reflection light, the metallic screen is required.

Fig.3. The projectors and their polarization filters.

B. Result analysis

Fig.4 shows the visual results of the information security display system. In the Fig.4(a), the authorized audience can see the green forest while others can see the red forest. In the Fig.4(b), the authorized audience can see a parrot while others can see a fish. In the Fig.4(c), the authorized audience can see a car while others can see a transformer. In the Fig.4(d), the authorized audience can see a sea while others can see a mountain. As the above results shown, in the glasses-aided view are completely different from the normal view. Using the special glasses, authorized users can see private information. However, unauthorized users can only see the deceptive images. By this system, privacy can be well protected.

IV. Conclusion

In this paper we designan information security display system using two synchronized projectors with linear polarization filters and polarization glasses. In the system, some authorized users can watch the private content through using the specific polarization glasses while others can just watch the unimportant information instead of the private information. The system is based on the theory of Spatial Psychovisual Modulation, which exploits the mismatch between high resolution of the modern optoelectronic displays and limited spatial resolution of the human visual system (HVS). Besides, we change the traditional forms of conference presentation, and creatively propose a portable approach. We have implemented the system and demonstrated some experimental results. We believe that this system can be used widely in various important occasions. It not only provides private information for authorized users, but also shows fake information for unauthorized users.

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