Appearance Enhancement for Visually Impaired with Projector Camera Feedback

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Abstract—Visually impaired is a common problem for human life in the world wide. The projector-based AR technique has ability to change appearance of real object, and it can help to improve visibility for visually impaired. We propose a new framework for the appearance enhancement with the projector camera system that employed model predictive controller. This framework enables arbitrary image processing such as photo-retouch software in the real world and it helps to improve visibility for visually impaired. In this article, we show the appearance enhancement result of Peli's method and Wolffshon's method for the low vision, Jefferson's method for color vision deficiencies. Through experiment results, the potential of our method to enhance the appearance for visually impaired was confirmed as same as appearance enhancement for the digital image and television viewing.

Index Terms—Projector Camera System, Model Predictive Control, Visually Impaired

1 Introduction

Low vision and color vision deficiencies (CVD, be known as color blindness) are not minor visual impairment and both of vision problems are improvable with projection based augmented reality technique in the real world. ”Vision 2020 The Right To Sight” reports 153 million people are visually impaired other than caused by uncorrected refractive errors in the total of 314 million people of visually impaired in the world[1]. The main cause of blindness and low vision was cataract except uncorrected refractive errors and many elderly people suffering for its disabilities.

Peli et. al.[19] proposed digital image enhancement techniques that enhance high-frequency components as aid for visually impaired for central scotoma or cataracts. Wolffsohn et. al. [21] examined the combination of generic edge detection and image processing to enhance the television viewing of the visually impaired. Both of techniques are effective to improve visibility for low vision viewer and applicable for the sight assistance in our life environment with the real time capturing by the video camera. However, users are tied down in front of the video monitor and it is not suitable for the situation in the daily life such as reading news paper, books and watching picture. Head mount display (HMD) might be useful, but its resolution is not sufficient to recognize the detail of picture and text in the publications. Additionally, to wear HMD or special optical device (such like SOPHie) in the daily life scene gives big strain and makes user suffer in terms of quality of life.

In this paper we propose projection based appearance enhancement technique for the visually impairment to achieve better environment. In the our method, projector camera dynamical feedback system was used. The system overlays compensation pattern onto publications and make appearance to enhance as same as image enhancement result of Peli's and Wolffsohn's method. Additionally, we describe how the visibly is improved for low vision viewer from the comparison of the final appearance with referenced appearance that given from Peli's and Wolffsohn's methods. This technique is applicable not only for the low vision but for the CVD as well. CVD is the inability to perceive differences between some of the colors that trichromat can distinguish. There are main three types of disabilities called anomalous trichromatism, dichromatism and monochromatism. Anomalous trichromatism is caused by peak sensitivity shift for one of fundamental cones and it is classified as protanomaly and deuteranomaly. Dichromatism is caused by the lack of one of fundamental cones and it is classified as protanopes, deuteranopes or tritanopes and it depending on whether fundamental cone is missing. Monochromatism is very rare but it is most severe case that total inability to distinguish colors. The number of CVD population has sex and race difference since it arise from genetic strain, 8% of Caucasian males, 5% of Asiatic males and 3% of African-American and Native-American males are have CVD, but below 0.1% for all race of women[**?**]. We focus attention on the nature that the apparent colors of publications are changeable with colored lighting and attempt visually improvement for CVD viewer by the projector camera dynamical feedback with Jefferson's method[24]. In this paper we describe how our approach is effective for CVD viewer from the appearance simulation used Vischeck algorithm, and propose automatic parameter tuning for Jefferson's method as well.

2 Related Work and Contribution

2.1 HMD for Visual impairment

Head Mounted Display (HMD) has been using as poplar device for the Augmented Reality technique and it has two main type of video see-through and optical see-through from it optical structure [18]. The video see-through HMD has great capability for the enhancement or annotation for visual impairment since it completely replaces the human sight with small video displays attached in front of eyes. However, to realize wide field of view, hight resolution and high dynamic range display are still hard and these problems make frustration for user in the daily life use. Since the optical see-through HMD shows real world sight in optically, we can see true scene directly with human vision system. From the aspect to assist for the visual impairment, the optical see-through HMD is useful but precise registration that can overlay edge line onto the real scene is still hard without strict support. The size and weight of both type of HMDs are becoming small and light but it makes much more suffer than eye glasses.

2.2 See-through Optical Processing

Recently, several see-through optical processing devices are developed and attempted to enhance the capabilities of the human vision system. Nayar et. al.[17] proposed programmable imaging concept that used digital micro-mirror device (DMD) in the optical path and the DMD controls the luminance and direction from scene. They showed the capability of high dynamic range imaging, optical image processing such as feature detection and object recognition. This technique is applicable for human vision system and it gives a user significant control over the radiometric and geometric properties of the system[**?**]. However, the resolution of real scene for the user is restrict with the resolution of DMD since real scene is observed via DVD reflection. Wetzstein et. al.[15] proposed the another way for the see-through optical processing that used Liquid Crystal Display (LCD) in the optical path call SOPhIE. The resolution of the real scene is not depend on the modulating device and it is easy to extend color image processing with color LCD panel. These approaches have ability to enhance the capability of human vision system but folding same problems as well as HMD since these are definable as a kind of optical see-through HMD that used subtractive method of optics.

2.3 Projector-Based AR technique

To get tied down special devices is not acceptable in the daily life in therms of quality of life. From this point of view, the projector based AR technique is suitable since the user is freed from wearing device. The system for this technique, we need convention video projector and camera but those are not expensive at present. The final style for commercial product of projector based human vision system enhancement technique is supposable as like desk light or room lighting that means replace of lighting systems currently we using. In the beginning, projector based AR technique aimed radiometric and geometric compensation for the non-plane neither uniform reflection screen such as dome screen, textured wall, etc. In this projector based AR technique, there are two main trends of adaptive and enhancing. For the adaptive method, projector camera feedback is proposed to control the appearance dynamically[9]. It enables make the scene to another appearance such as the appearance of globe to soccer ball. The closed-loop photometric adaptation[10] improved response speed for the appearance control. In [10], it enabled free positioning of projector camera system with co-axial optics. For the enhancing, double modulation display technique is proposed.

The projector-based AR technique is also attempted for high dynamic display [12], appearance enhancement [11]. This approach is similar with photometric adaptation in terms of equipments configuration at a glance. However, it has new novelty that enables enhance the real environment optically and it gives super visibility that not achieved for the poor quality of printing media or limitation of human vision system. The application of this technique is not only for printing media, but also optical microscope [13]. The dynamical feedback is also possible for the appearance enhancement [11], [13] and this realtime processing make sense for human vision support of visually impairment in the daily life. Therefore, we used this realtime appearance enhancement for visually impairment but the techniques described in [11], [13] have a problem for visually impairment since those have no reference input. The precise control is required in the application for visual impairment especially against for CVD. Our main contribution is adoption of reliable control theory for the projector camera system and it enabled precise control for arbitrary image processing. Thanks to its versatility, conventional property of appearance enhancement techniques are applicable and it enabled appearance enhancement for visually impaired in the real world. In the follow section, we describe about adaptation of model prediction control for the projector camera feedback system.

3 Projector Camera Feedback

3.1 Model Predictive Control

The Dynamic Adaptation algorithm [10] can be explained as one of Model Predictive Control (MPC) [14] that commonly used in the process industries such as chemical plants and oil refineries since the 1980s. This control method is including a model for control object and manipulation value is decide by using of this model. Its idea is simple and reasonable way when we have known the system response.

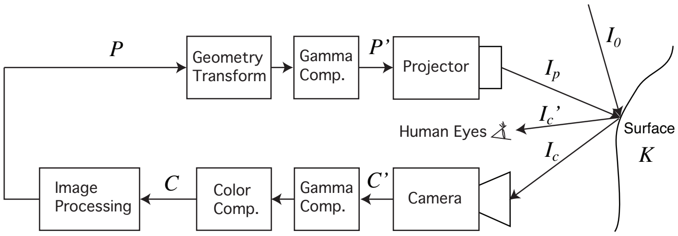


Fig. 1. Previous System Diagram

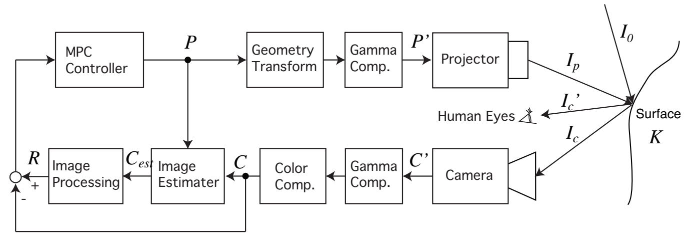


Fig. 2. System Diagram with MPC controller

By using of model prediction $y_M(t)$ that includes input $u(t)$ and measurement $y(t)$, estimation of output $y_P(t+1)$ is given by

$$y_P(t+1) = y_M(t+1) + Error(t) \tag{1}$$

Where

$$Error(t) = y(t) - y_M(t) \tag{2}$$

for considering of estimation error. In the MPC algorithm, reference trajectory

$$y_R(t+1) = \alpha^t y(t) + (1-\alpha^t) r(t+1) \tag{3}$$

is used for control stability against modeling error. Since $y_P(t+1) = y_R(t+1)$, we get control input for step $t+1$. Where α^t and $r(t)$ are tuning parameter and desired value for step t. The Dynamic Adaptation is corresponding with this algorithm at the condition of $\alpha^t = 0$ and $Error(t) = 0$. Fortunately, projector camera feedback is stable without these terms in case of irradiance compensation since control error is decreasing step by step. However, its error is critical for the appearance enhancement and we have to consider these terms in the appearance enhancement.

3.2 Negative Feedback for the Enhancement

Amano et. al. proposed appearance enhancement technique with projector camera feedback [11]. The diagram is shown in figure 1. In this diagram, all property have 3 color components of R, G and B channel, and now we think about for a single pixel relation. The environment light $I_0 \in \mathcal{R}^3$ and projection light $I_p \in \mathcal{R}^3$ is mixed and reflected on the surface $K \in \mathcal{R}^{3\times3}$. This reflection

$$I_c = K(I_p + I_0) \tag{4}$$

is captured by camera and the system get an image

$$C = M{C'}^{\gamma}_{c}, C' \propto I_c \tag{5}$$

via the gamma and color compensation. Regarding of lambert reflection, we can expect an irradiance that observed by user $I_c' \approx I_c$. Where M is the color mixing matrix between camera and projector color spaces. After the image processing, the system projects compensation light P with correct scaled irradiance on to the same point with the captured pixel from projector by using of the geometrical transformation and gamma compensation. The remarkable point is the projection light I_P is never diverge with proper image processing includes gain control. However, it is not easy to reach desired appearance since to estimate final result is decided with many times iteration of this feedback. Moreover, this feedback model is not robust since this model not includes projection error nor capture error. In other words, the problems are this system has no reference image for desired appearance neither not employed negative feedback that considered control error.

Against for these problems, we propose new feedback approach that shown in fig. 2. By using projection pattern, the estimated physical surface reflectance is written as

$$\hat{K} = diag\{C./\{(C_{full} - C_0) \odot P + C_0\}\}. \tag{6}$$

Where C_{full} and C_0 are images those are captured images under maximum power (white light) and minimum power (turn off) projections, ./ and $\odot$ are meaning component wise division and multiplication respectively. Note, however, those non-linear response features of C and P are compensated with the module of "Gamma Comp.". Based on K, the true appearance that under the white light projection is given by

$$C_{est} = \hat{K} C_{white}, \tag{7}$$

where $C_{white} = (1,1,1)^T$. Since this true appearance, we can get reference image for negative feedback loop via arbitrary image processing.

3.3 MPC for Appearance Enhancement

To apply MPC algorithm, we use projector camera response model

$$C_M(t+1) = \hat{K}(t)\{(C_{full} - C_0) \odot P(t+1) + C_0\}, \tag{8}$$

where $P(t), C(t) \in ([0,1],[0,1],[0,1])^T$ are normalized projection pattern and captured image at the step t. Image prediction that considered model error is written by

$$C_P(t+1) = C_M(t+1) + Error(t) \tag{9}$$

where

$$Error(t) = C_M(t+1) + C(t) - C_M(t). \tag{10}$$

As for the reference trajectory, we used

$$C_R(t+1) = \alpha C(t) + (1-\alpha) R(t+1) \tag{11}$$

that employed constant tuning parameter since projector camera response is stay flat for $t \geq 0$. Where $R(t+1)$ is reference image that given by image processing result based on true appearance. From the control law $C_P(t+1) = C_R(t+1)$, we get manipulating value

$$\begin{aligned}
&P(t+1)\\
&= \hat{K}(t)^{-1}(1-\alpha)\{R(t+1)-C(t)\}./(C_{full}-C_0)\\
&-\hat{K}(t)^{-1}\{\hat{K}(t)-\hat{K}(t-1)\}./(C_{full}-C_0)\\
&+\hat{K}(t)^{-1}\hat{K}(t-1)P(t)\\
&\approx \hat{K}(t)^{-1}(1-\alpha)\{R(t+1)-C(t)\}./(C_{full}-C_0)+P(t)
\end{aligned} \tag{12}$$

with an approximation of $\hat{K}(t) \approx \hat{K}(t-1)$. This approximation is employed to avoid near zero division when $\hat{K}(t-1) \approx 0$ that leads unstable control. This approximation is sufferable since image prediction eq. (9) is including modeling error.

4 Appearance Enhancement for Low Vision

Peli et. al.[19] proposed digital image enhancement techniques that enhance high-frequency components to help visually impaired for central scotoma or cataracts. The appearances of original and enhanced image are simulated with contrast sensitivity function suggested that patients with moderate visual loss may have benefit by both of the techniques. The capability of proposed techniques was evaluated using image-processing simulations and patients with moderate visual loss (20/70-20/200) may have difficulty recognizing faces through video monitor. In the result, the ability to recognize celebrities from enhanced images improved for 39 of the 46 patients. Peli also applied this technique for video scene shown in television [20]. The another approach for the video scene is proposed by Wolffsohn et al. [21]. Wolffsohn examined the combination of generic edge detection and image processing to enhance the television viewing of the visually impaired. They used edge detection of Prewitt, Sobel, or the two combined, over laying its result on to image by red, green, blue or white with one to 15 times intensity for the enhancement. This examine is tested for 102 visually impaired (average age 73.8 $\pm$ 14.8 years). In the result, Prewitt filter was most preferred (44%), Green and white were equally popular for displaying the detected edges (32%). The average preferred edge intensity was 3.5 $\pm$ 1.7 times. From these study, the common process of effective enhancement for visually impaired is used edge enhancement. We attempted Peli's adaptive enhancement and Wolffsohn's filter with projector camera feedback as a representative of image enhancement for low vision.

4.1 Appearance Enhance using Peli's Method

Figure 3 shows the enhancement result with Peli's method. The original appearance of the pictures shown in (a) is enhanced to (b) with projector camera feedback, and (c) shows direct image processing result with Peli's method of (a). For this enhancement, the projector (full color XGA resolution) attached with strong tripod is placed above the picture for the appearance enhancement and the camera (full color VGA resolution) is attached on the projector. The geometrical and optical calibration for the projector camera system have been done previously with conventional methods. Because of blurring of reflectance estimation that shown in (d), the enhancement result (b) has slight blur but similar appearance is realized on the printed picture with projector camera feedback. This is caused by both of focus errors of camera and projector since reflectance is calculated with division of blurred image that include blurred projection by sharp projection pattern. Its processing speed was 12.12 flames/sec with VGA resolution IEEE1394 camera and XGA resolution projection that processed 2.4GHz cpu (Mac Book Pro Core2Duo 2.4GHz).

4.2 Appearance Enhance using Wolffsohn's Method

Along with Peli's method, Wolffsohn's method is applicable for our appearance enhancement technique since the proposed method employs reference image. For the adaptation, we just implemented Wolffsohn's algorithm for the image processing part as like as conventional static image processing. This versatility is one of the big benefit of our framework. Figure 4 show the enhancement result by Wolffson's method. The edge of original appearance (a) is detected with Prewitt filter and this result is overlayed with Green color (b) as same as for the edge enhancement that shown in [21]. This algorithm has been proposed for enhancement for television images to benefit the visually impaired but it might be assist to understand the complex scene in the printed picture.

5 Color Management for CVD

There are a number of color convert methods have been proposed to improve CVD accessibility. The strategies are classified broadly into two categories of prepublication and post publication method. The prepublication method is useful for the design of the color assign of publications and wed design, etc. The color design guide line[7] that based on CVD model[6] is used for the guideline for the web page design. For the improvement of the CVD accessibility in the daily life, post-publication method that is the optimal color conversion for the CVD perception is necessary. Several post-publication methods are proposed[22], [23], [25]. These methods are assumed to use of human interface for the CVD user and those methods replace color mapping. This replacement makes drastic improvement for visibility of the color graphs, figures and other graphical display, but all of those method are not suitable for time consuming. Moreover, projector based color convert has limit in terms of photometric. The problem is we cannot convert pure color object since it has no reflect except limited spectrum band of object's specific color band in the theory. However there are small reflection is

(a) Original Appearance

(b) Enhanced Appearance

(c) Enhancement result of (a) by the image processing

(d) Estimation Result of $\hat{K}$

Fig. 3. Enhancement Result by Peli's Method: The original appearance of pictures under the white light envitonment (a) is enhanced with Peli's method by projector camera system (b). Its enhanced appearance is similar with (c) that calculated with Peli's method to (a) directly. However, the edge of (b) is not so sharp rather than (c) because of blur of estimated reflection of $\hat{K}$ (d).

(a) Original Appearance.

(b) Enhanced Appearance with Wolffsohn's method.

Fig. 4. Enhancement Result by Wolffsohn's Method: The picture in the news paper contains complex background and its visibility not good for low vision (a). The edge is detected with Prewitt filter and overlayed onto green illumination with projector camera feedback (b). The edge line in the picture is easily understandable and it gives a benefit for low vision.

existing in entire spectrum band but still hard to convert color of appearance drastically. From these reasons, we applied Jefferson's method [24] that is simple linear color convert that used in the LMS color space based on color appearance simulation for dichromats [6]. This method not make drastic color conversion but it can avoid extreme case such as Ishihara plate in the publications with minimum color modification. It is good for viewing for the natural scene since it does not make strange color such like blue colored face.

5.1 Color Modification using Jefferson's Method

Figure 5 shows color enhancement result for the CVD. The appearance of Ishihara test plates are observed under the white light environment such as (a) with the trichromatic perception. The number written in each plates are 7(top left), 42(top right), 57(down left) and 8(down right). However these numbers can not be seen with dichromatic perception (Protanope) except down right plate such like (b). This simulation is calculated from (a) with Vischeck [8]. It should be noted that the number in down right plate is featly composed with two different color and it is recognized 3 with dichromatic perception. To use of dichromatic perception simulation [6] for the reference input of projector camera feedback, we can show the appearance on the real world (c) such as like as simulated image(b). This technique is useful to check the accessibility of publishing for dichromatic perception. Jefferson's method modified the color of original appearance to (d) for the trichromatic perception with the parameter $A_P = [0.0, -1.0, 1.0, 0.0]$ and its dichromatic perception is simulated as like (e) with Vischeck. This parameter is effective for this case and it is chosen manually with cut and try. The visibility is not better compared to trichromatic vision shown in (a). However, we can see correct numbers in (e) and it is effective to avoid extreme case such as Ishihara test plates in our daily life. This color modification is applicable for the other dichromatic perceptions with each transform matrix for deuteranopes and tritanopes.

5.2 Automatic Parameter Tuning for Jefferson's Method

The essential part of Jefferson's method is channel distribution that is expressed in the formula

$$\tilde{C}_{LMS} = C_{LMS} + A_i \Delta C \tag{13}$$

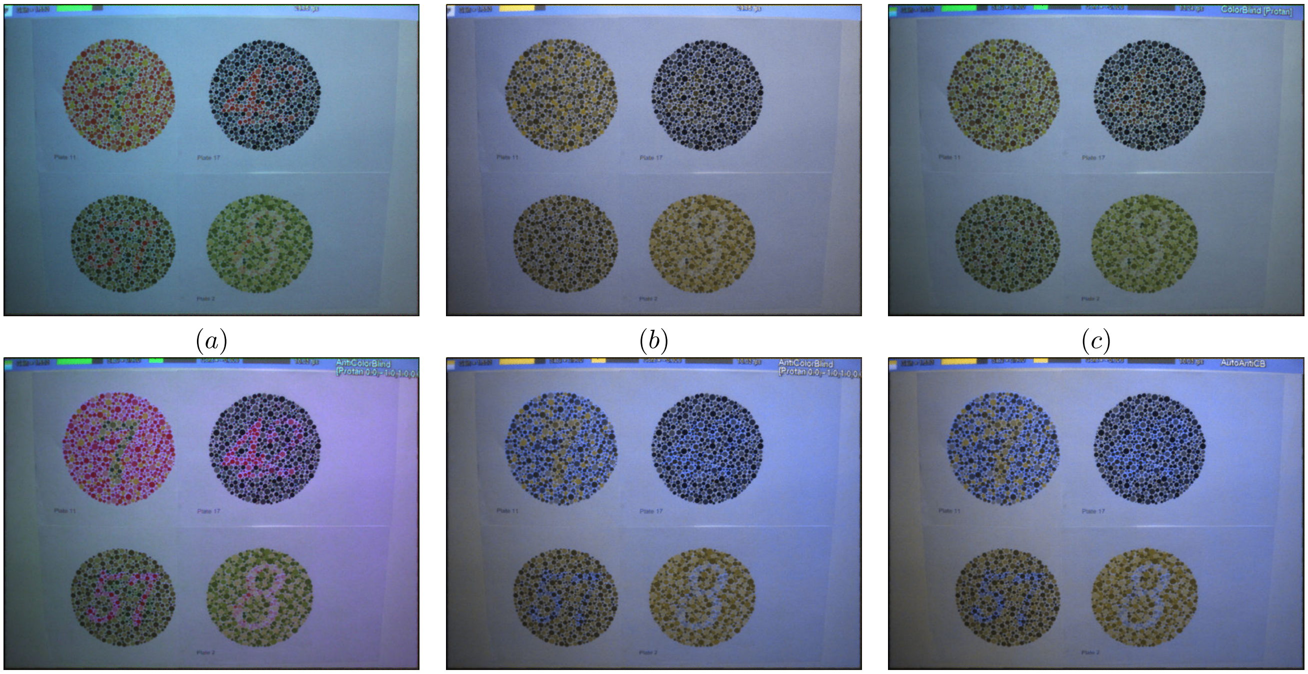
with matrix A_i. Where $\tilde{C}_{LMS}$ is converted color, C_{LMS} is original color and ΔC is the color difference between trichromatic and dichromatic perception on the LMS color space, the index $i \in \{P, D, T\}$ denotes the type of dichromat. The diagonal elements of matrix A_i is 1 for all types and the other elements are tuned with smart user inter face. However, we can understand there are no way other than to distribute ΔC to M and S channels for protanope since protanope can not unobservable L channel. In addition to this, M and S components of ΔC should be zero since protanope unobservable L channel only. Thus, the problem is how to distribute the L component of ΔC to M and S channels. From this idea, we implemented automatic tuning algorithm shown below for the protanope.

1) Extract foreground region $\mathcal{R}_f$ with background subtraction.
2) Calculate illuminance gravity $\bar{C} = (c_l, c_m, c_s)$ of original appearance in the region $\mathcal{R}_f$ with LMS color space.
3) Calculate major direction $\theta_P = tan^{-1}(c_s/c_m)$.
4) Distribute the perception difference ΔC toward to orthogonal with major direction with the matrix $A_P = \begin{bmatrix} 1 & 0 & 0 \\ gcos(\theta_P + \frac{\pi}{2}) & 1 & 0 \\ gsin(\theta_P + \frac{\pi}{2}) & 0 & 1 \end{bmatrix}$.

From this algorithm, we got similar result that shown in figure 5 (f) with (e).

6 Conclusion

In this article, we proposed new framework for the projector camera system that employed model predictive control. This framework allows us to use of conventional image enhancement techniques those developed for visual impairment for the projector-based AR technique. For the visually impaired application, we have shown the implementation of Peli's method and Wolffshon's method for the low vision, Jefferson's method for color vision deficiencies. The benefit of this framework is not only for its ability but also its configuration of equipments. Projector-based appearance enhancement is excellent with our daily life since that is replaceable with conventional lighting system. For the implementation with compact chassis, the projector camera system can be use such as like desk light. The another benefit is the cost of equipment. The convention camera and projector are applicable for our framework and those are not expensive in today. Therefore the commercialization of product is not so hard in terms of price. Through experimental results, the potential of our method to enhance the appearance for visually impaired was confirmed, but some problems still remain as future works. The one problem is blur in the enhanced result. That is caused from the estimation error of reflection on the publication and too big blur is critical for appearance enhancement of low vision. This problem is should to be solve with employ of blur model to the reflection estimation. The another problem is the range of color conversion. The proposed frame work is working well for the Jefferson's method but, it is impossible to change appearance to opposite color for the pure colored surface. This is caused by optical theory and impossible to solve with current projector camera system. However, some other suitable processing is able to consider for the color enhancement for projector camera system. We would like to keep find more effective method for color vision deficiencies other than Jefferson's method.



(a) (b) (c)

(d) (e) (f)

Fig. 5. Color Enhancement: Perception of Ishihara test plate for trichromat(a) and protanope(b). Dichromatic vision simulation for trichromat(c) and color enhance result for protanope(d) by jefferson's algorithm. With this color enhancement, protanope person can recognize the numbers for this extreme cases(e). We got same appearance by our automatic tuning algorithm(f).

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