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PLEASE SCROLL DOWN FOR ARTICLE
Evaluating the Image Quality of Closed Circuit Television Magnification Systems Versus a Head-Mounted Display for People With Low Vision

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In this research, image analysis was used to optimize the visual output of a traditional Closed Circuit Television (CCTV) magnifying system and a head-mounted display (HMD) for people with low vision. There were two purposes: (1) To determine the benefit of using an image analysis system to customize image quality for a person with low vision, and (2) to have people with low vision evaluate a traditional CCTV magnifier and an HMD, each customized to the user’s needs and preferences. A CCTV system can electronically alter images by increasing the contrast, brightness, and magnification for the visually disabled when they are reading texts and pictures. The test methods was developed to evaluate and customize a magnification system for persons with low vision. The head-mounted display with CCTV was used to obtain better depth of field and a higher modulation transfer function from the video camera. By sensing the parameters of the environment (e.g., ambient light level, etc.) and collecting the user’s specific characteristics, the system could make adjustments according to the user’s needs, thus allowing the visually disabled to read more efficiently.

Keywords: closed circuit television, head-mounted display, low vision, magnifier system

Introduction and Background

Visual impairment includes blindness, low vision, and functional vision deficits (Carney, Engbretson, Scammell, & Sheppard, 2003), and it is a globally prevalent issue in both adults and young populations (Alabdulkadera & Leat, 2010). Visual impairment is not correctable with glasses, contact lenses, or surgical intervention, and it interferes with normal everyday functioning. It has been well established that people with vision impairment have an increased risk of depression compared to those without impaired vision. Studies conducted largely in the United States have found that up to one third of all people with vision impairment report clinically significant depressive symptoms (Rees et al., 2010; Scott, Smiddy, Schiffman, Feuer, & Pappas, 1999). The World Health Organization estimates that over 135 million people are visually disabled and nearly 45 million people are blind. Without effective intervention, the number of people with low vision will increase significantly by 2020. This not only has significant implications for productivity but also poses a large burden on current rehabilitation services (Wong, O’Connor, & Keeffe, 2011). Visual impairment is a global concern that is likely to become more significant as the standard of medical care improves and average lifespans increase. Low-vision aids can improve the quality of people’s lives (Binns et al., 2012). Rehabilitation assistants develop rehabilitation plans for individuals and recommend appropriate low-vision aids. The result of assessing residual visual functions is the detection of functions that can be improved with the use of optical devices (Samuel, 2006).

Assistive technology for the visually impaired involves low-technology and high-technology devices. Low technology refers to any apparatus that is either non-electronically based or is a simple battery-operated item. Examples include magnifiers, rulers with Braille-embossed numbers, battery-operated toys, and tape recorders. High technology involves sophisticated systems that are electronically based, such as powered wheelchairs, environmental control systems, closed-circuit televisions, Braille note takers, optical character recognition systems, screen readers, and speech synthesizers (Olson & DeRuyter, 2002).

The particular needs of the low-vision population related to the image quality of reading magnification systems become more and more important, so this article discusses electronic low-vision devices known as Electronic Vision Enhancement Systems (EVES), which are a type of closed circuit television (CCTV). Such systems consist of a direct cable link between the camera imaging system and the monitor viewing system (in contrast to....
of Red-Green-Blue (RGB) color components to chromaticity coordinates was used to determine how faithfully colors were being reproduced by the CCTV monitor, (2) the Modulation Transfer Function (MTF) was used to evaluate image quality in terms of the sharpness of the image and image contrast, and (3) a comparison of image contrast and sharpness across the screen from the center to the edges was used to determine image quality across the screen. The larger magnification range and shorter response time are also the important items for system design to optimize image quality and customize the system for each user. The first step is to convert the input image from the most popular RGB model to other common color models. The objective is to use individual color components as the source image for extracting features. A chroma meter can measure the coordinate values \((u, v)\) in the Commission Internationale de l’Eclairage (CIE) chromaticity diagram (Chiou, Lin, & Chen, 2009) and the illuminance of an image’s colors exported from CCTV equipment. The trichromatic coefficient can point out the proportions of the light quantities of RGB colors in the color of a pixel, and the summation of the trichromatic coefficient is 1 (Shei & Lin, 2012).

Namely,

\[
X = 0.619R + 0.177G + 0.204B \\
Y = 0.299R + 0.586G + 0.115B \\
Z = 0.000R + 0.056G + 0.944B \\
u = X / (X + Y + Z) \\
v = Y / (X + Y + Z)
\]

According to the above description, the \(u\) and \(v\) components are taken as the coordinate values of a chromaticity diagram (Figure 1).

Therefore, the chromaticity coordinate values of the colors from all points of the CCTV output image can be measured by comparing the standard color chart chrominance values with the three primary colors taken by the CCTV equipment, so as to quantify the color display’s capability. The color deviation can be obtained by scanning the two-dimensional plane of the CCTV image, so as to evaluate the color output characteristics of the CCTV equipment.

The recorded values and calculated numerical values of the digital image are used to draw the CIE coordinate graph. The MTF is the most widely used scientific method of describing lens performance. It is a measure of the transfer of modulation (or contrast) from the original image to the output image. It measures how faithfully the output image is reproduced in detail from the original. The image is analyzed using the MTF, and the figure shows the frequency response of focusing, slight defocusing, and complete defocusing. The pattern of bright and dark lines can be used for imaging quality evaluation.

\[
MTF = \frac{I_{\text{max}} - I_{\text{min}}}{I_{\text{max}} + I_{\text{min}}} \tag{3}
\]

where \(I_{\text{max}}\) and \(I_{\text{min}}\) are the brightness and darkness of the fringes.
The sharpness of the image can be determined by spectrum analysis. A sharp image has good high frequency response, and a blurred image has good low frequency response. Within each range, the pixels of optimum bright and dark fringes are analyzed and computed statistically for comparison (Lin, Wu, Ho, Lee, & Yeh, 2009). The mathematical expressions for the contrast of image center and edge are given by

\[
C_c = \frac{I'_{cb} - I'_{cd}}{I'_{cb} + I'_{cd}} \quad (4)
\]

\[
C_e = \frac{I'_{eb} - I'_{ed}}{I'_{eb} + I'_{ed}} \quad (5)
\]

where \( C_c, I'_{cb}, \) and \( I'_{cd} \) are contrast values between brightness and darkness of image center, gray scales of brightness, and gray scales of darkness, respectively, while \( C_e, I'_{eb}, I'_{ed} \) are contrast value between brightness and darkness of edge of image, and value of gray scales of optimum brightness and darkness, respectively. From the above calculation, the image with the best contrast in the high frequency domain is focused correctly.

Prototype

For the display, a smaller screen pitch and higher resolution was required to provide a sharper image and higher contrast. The picture size followed the standard length to width ratio of 4:3, and the resolution of the screen could be set as 1024 \( \times \) 768, 1280 \( \times \) 1024, or 1600 \( \times \) 1280. The low-vision video magnifier (W: 35.6 cm D: 43.2 cm H: 37 cm) with 24 in display can obtain a magnification range from 2.3x to 50x. The view of field is 11 in x 11 in, optical sensor size is 1/2.3 in, and response time is 25 ms (rise time \( t_r \) + fall time \( t_f \)). A head-mounted projection liquid-crystal display (LCD) was used as the portable CCTV display (Figure 2).

A high-resolution CCTV camera displayed file images on the screen, and a pair of ultralight virtual reality glasses were connected to the CCTV to display the magnified images on a digital magnifying blinder screen. There were three optional display modes: Color, black-and-white, and positive and negative. The system was composed of a CCTV system and a HMD, which displayed images on a pair of ultralight virtual reality glasses that replaced the traditional screen and displayed the magnified images to the eyes authentically. There was a power supply that provided the user with an optimized environment that was easy to use and comfortable to wear. The port could be easily connected to a computer (with an additional frequency converter) or a television screen. Thus, the problems of inconvenient carrying, white-on-black reflections, and screen flicker could be solved.

**Fig. 1.** The measurement of the coordinate values of \( u \) and \( v \) components in a CIE chromaticity diagram of this system.

**Fig. 2.** CCTV/HMD and screen connection diagram.
Prototype Technical Testing

To determine a subject’s selective adaptation to spatial frequencies and contrast, the subject looks at a grating of the same brightness for about 30 s. Then the screen is refreshed, and the subject looks briefly at the next test grating (Lin, Lue, Yeh, Hwang, & Lee, 2003). The video signals from the HMD and CCTV display device are tested and evaluated using a digital signal processing (DSP) unit. The resulting signals, including the contrast and brightness data from the HMD and CCTV display device, are transmitted from the DSP unit to the PC (Lin, 2002). The PC subsequently processes and analyzes the image data from the image capture card and the resulting signals from the DSP unit.

After the voltage signal transmission to the DSP unit, an average frame brightness value is calculated. A check is then made to determine if the image signal is over the average brightness value. The summation of image signal which exceeds average brightness value is divided by half of the number of pixels so that the average higher brightness value is obtained. Accordingly, the average lower brightness value can be obtained, so the contrast value can be calculated. The contrast value is then output to a computer.

The comparison with simulation software is used to measure the validity of the measurement and framework proposed. Real-time analysis of the image center and edge’s contrast is taken. The real-time record of each contrast and spatial horizontal frequency fx and vertical frequency fy in the diagram for the analysis of the MTF are taken. When the MTF is larger, the difference between bright and dark pixels is larger; in other words, when the contrast is larger, the black and white in the image are clearer and more distinct. Since visible light has different wavelengths, this study changed the base color of test patterns and images (Figure 3) to three primary colors (red, green, blue), and the analytical diagrams for the MTF are shown in Figure 4(A)–(C). The measurement and framework proposed by this study can achieve the same practicability and reliability as the simulation software.

Hierarchical linear modeling (HLM) was applied for data analysis. A two-level HLM model was defined by two types of regression equations (Pinquart & Pfeiffer, 2013). For comparison, the target images at specific distances captured by the lens were compared, and the highest average value of intensity within the high frequency of 70 to 90 lines/mm would be the image with the best focus, as shown in Figure 5. Then the users were given a reading task and the experiments with targets in motion.

User Testing

The user testing includes three parts: (a) The letter orientation test, (b) the reading test, and (c) the targets-in-motion test. Table 1 shows the record of the tested visual acuity values of four kinds of users with low vision, using an LCD screen and head-mounted glasses. When the head-mounted glasses used as a CCTV screen, the intensity increased and the image was free from indoor back light, but the brightness needed to be maximized and the contrast had to be positive. According to the aforesaid performance, the head-mounted glasses performed better than the LCD screen apparently. With regard to the real-time analysis of the image center and edge’s contrast, it can provide optimal image quality for the user tests.

The visual acuity test chart and CCTV captured image were displayed on the LCD screen and head-mounted glasses at the same time (Figure 6). The testers with low vision viewed the visual acuity test chart displayed on the LCD screen and through the head-mounted glasses, and then used gestures to indicate the orientation of the letters “C” or “E”. The most peripheral part of the image that the user could see was recorded and compared with the test value. The system also included a voice guidance feature, which assisted the visually-impaired users to follow the test step by step (Bengisu, 2010; Lin, Lin, Yang, Liou, & Lay, 2012).

Experimental Results

The limitation of this system is that if the camera focused on the same object for too long, the image plate of the camera would be blurred. To the user, such an image would look as if there were another duplicate, negative image on the screen. The actual data were recorded for the 21 participants of 4 different types. Table 2 shows the tested visual acuity values of four kinds of users with low vision using the LCD screen and head-mounted glasses.
Image processing with this system is comprised of the following steps:

1. Using a standardized reading test.
2. Displaying the test image on the HMD and CCTV screen and transmitting it to a DSP unit coupled to the HMD and CCTV display device in real time.
3. Calculating an average brightness value or contrast value for the test image using a computer.
4. Analyzing the reading speed, comprehension rate, average brightness, and contrast value.
5. Recording and reporting the data for all the calculated items.

When the head-mounted glasses were used as a CCTV screen, the accuracy rate was higher than 90%, the response time was shorter, and the visual acuity test values increased, but the brightness needed to be maximized and the contrast had to be positive. Then specific parameters of the environment could be obtained and their effect on the user could be analyzed.

The reading materials are moved quickly when users read; hence, the readers saw images continuously on the screen. The speed of the target’s motion, the number of colors in the scene, the brightness of the colors in the region of interest, and the subject’s static or dynamic visual acuity are other general parameters. If the image refresh rate was the same as the reading rate, the letters would be indistinct. In order to increase the reading rate, image retention must be avoided as much as possible. As this is related to the system adjustment, a high-quality system was used. Meanwhile, an average brightness value and a contrast value, processed by the DSP unit, are displayed on a monitor in real time. Additionally, the graphs illustrating the average brightness value and the contrast value versus time are displayed in the frame in real time. According to the contrast analysis data, the contrast remained stable when the image was magnified digitally. The higher the ratio, the more transition layers from black to white, and the richer the color expression. The contrast had a critical effect on the visual effect. In general, the higher the contrast was, the sharper the image would be, and the brighter

Table 1. Comparison table and merits and demerits of students with low vision using the head-mounted spectacle screen.

<table>
<thead>
<tr>
<th>Subject condition*</th>
<th>a</th>
<th>b</th>
<th>c</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Naked vision</td>
<td>Below 0.2</td>
<td>Below 0.1</td>
<td>Below 0.2</td>
<td>0.01–0.2</td>
</tr>
<tr>
<td>Definition**</td>
<td>—</td>
<td>Max brightness</td>
<td>Max brightness</td>
<td>—</td>
</tr>
<tr>
<td>Applicability</td>
<td>Unaccustomed</td>
<td>No color</td>
<td>No color, so-so</td>
<td>Image appears far away</td>
</tr>
<tr>
<td>Concentration</td>
<td>Apparent difference</td>
<td>Apparent difference</td>
<td>Relatively free</td>
<td>So-so</td>
</tr>
<tr>
<td>Feeling</td>
<td>Like cinema</td>
<td>So-so</td>
<td>So-so</td>
<td>—</td>
</tr>
<tr>
<td>Contrast requirement</td>
<td>—</td>
<td>Maximum</td>
<td>Maximum</td>
<td>—</td>
</tr>
<tr>
<td>Contrast effect***</td>
<td>p</td>
<td>p</td>
<td>p</td>
<td>n</td>
</tr>
<tr>
<td>Other</td>
<td>Availability of larger screen</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

Notes: *Subject Condition: a = Cataract, glaucoma astigmatia, b = Optic atrophy, c = Congenital optic atrophy, d = Encephaloma caused optic atrophy.
**Relatively clear when brightness is maximized.
***Contrast effect: p = Positive, n = Negative.
the color. The high contrast was of great help for the definition, detail expression, and gradation of gray in the images.

The contrast had a more significant effect when the target image was in motion. As the dark-and-light variations of a dynamic image are fast, the higher the contrast was, the more likely the human eye would be able to recognize such a conversion process. The high-contrast products had more apparent advantages in the display of detail, definition, and high-speed target images in motion. According to the aforesaid performance, the head-mounted glasses performed better than the LCD screen (Table 3).

Most individuals with low vision prefer a white-on-black screen design. As the black background is large, the number of light rays on the screen will be smaller, and screen flicker will be reduced. However, most of the visually impaired are photophobic and sensitive to light. One defect in a white-on-black design is reflection, meaning the screen reflects other objects, and this makes it inconvenient to see photos and pictures. Therefore, negative images should be converted into positive images when viewing pictures, and it should be easy to switch them between positive and negative.

**Table 2.** Test values of students with low vision using LCD screen and head-mounted spectacle screen.

<table>
<thead>
<tr>
<th>Subject condition*</th>
<th>a</th>
<th>b</th>
<th>c</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td>I**</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of tests</td>
<td>5</td>
<td>5</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Accuracy rate</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Gesture response delay time</td>
<td>20 sec</td>
<td>12 sec</td>
<td>30 sec</td>
<td>15 sec</td>
</tr>
<tr>
<td>Extreme value of vision</td>
<td>0.1</td>
<td>0.2</td>
<td>0.1</td>
<td>0.2</td>
</tr>
<tr>
<td>Brightness requirement</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Maximum</td>
<td>Moderate</td>
</tr>
<tr>
<td>Contrast effect</td>
<td>Both p/n</td>
<td>Both p/n</td>
<td>Both p/n</td>
<td>Both p/n</td>
</tr>
<tr>
<td>II**</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of tests</td>
<td>5</td>
<td>5</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Accuracy rate</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Gesture response delay time</td>
<td>16 secs</td>
<td>10 secs</td>
<td>30 secs</td>
<td>15 secs</td>
</tr>
<tr>
<td>Extreme value of vision</td>
<td>0.2</td>
<td>0.4</td>
<td>0.1</td>
<td>0.4</td>
</tr>
<tr>
<td>Brightness requirement</td>
<td>Max</td>
<td>—</td>
<td>Max</td>
<td>Max</td>
</tr>
<tr>
<td>Contrast effect</td>
<td>Both p/n</td>
<td>p</td>
<td>p</td>
<td>N</td>
</tr>
</tbody>
</table>

Notes: *Subject condition: a = Congenital optic nerve compression, astigmatia, b = Retinal microvascular dysfunction, c = Congenital optic atrophy d = Abortive encephaloma caused optic atrophy, retinal detachment.

***I: Screen; II: Head-mounted display.

***Contrast effect: p = Positive, n = Negative

**Table 3.** Test results and situation analysis of students with low vision using head-mounted spectacle screen.

<table>
<thead>
<tr>
<th>Subject condition*</th>
<th>a</th>
<th>b</th>
<th>c</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Naked vision</td>
<td>Below 0.1</td>
<td>Below 0.1</td>
<td>Below 0.1</td>
<td>Below 0.2</td>
</tr>
<tr>
<td>Visual acuity value</td>
<td>increases 0.1–0.2</td>
<td>increases 0.1–0.4**</td>
<td>unchanged</td>
<td>increases 0.2–0.4**</td>
</tr>
<tr>
<td>Applicability</td>
<td>So-so</td>
<td>No color</td>
<td>No color</td>
<td>No color</td>
</tr>
<tr>
<td>Concentration</td>
<td>Apparent difference</td>
<td>Apparent difference</td>
<td>Relatively free</td>
<td>Apparent difference</td>
</tr>
<tr>
<td>Error rate</td>
<td>Below 10%</td>
<td>0%</td>
<td>15%</td>
<td>0%</td>
</tr>
<tr>
<td>Other</td>
<td>Visual field reduced</td>
<td>Visual field reduced</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>

Notes: *Subject condition: a = Congenital optic nerve compression, astigmatia, b = Retinal microvascular dysfunction, c = Congenital optic atrophy d = Abortive encephaloma caused optic atrophy, retinal detachment.

**Apparent difference, but white on black is required.
For CCTV systems for users with low vision, the screen pitch should be as small as possible, and the resolution should be as high as possible. Compared with traditional cathode ray tube and LCD screens, small and light LCD panels tend not to have distortion or curvature of field, and they are unlikely to flicker. Therefore, short-distance reading is available without causing harm to health. However, LCD panels are still inconvenient to carry. Head-mounted projection LCD glasses can solve this problem. The subjects with low vision were tested using both systems, and the results for CCTV with a general LCD screen and with head-mounted projection LCD glasses were compared. The result showed that most of the testers with low vision felt the intensity increased when they used the head-mounted glasses, as there was no indoor back light, the response time was short, and the visual acuity increased. However, the brightness needed to be maximized and the contrast had to be positive. According to the above analysis, the head-mounted glasses performed better than the LCD screen.

**Discussion and Conclusions**

Given our observation that the images blurs when the camera is focused on the same object for too long, a CCD lens of high quality phosphorescent camera should be used to eliminate blurred images. It had been tested and verified in the experiments. The users are much less sensitive to the details in moving images than in still images. The analysis data show that at high spatial frequency, the eye’s sensitivity to temporal frequency decreases, and similarly at high temporal frequency, the sensitivity to spatial frequency is diminished. This study used an optical lens and used the optical depth of field and frequency response modules to test and adjust the data, and then implemented mathematical operations using the color data to draw the CIE chromaticity diagram. The color table values were within the range of a standard color chart. However, the testers with low vision required high brightness and positive contrast. As this would cause the chrominance value to be distorted, both the contrast and brightness in higher frequency could not be satisfactory. The central display of the lens was generally better than the edge display, and the CCTV magnification was too large to influence the reading speed and reading comprehension. By sensing the parameters of the environment and collecting the user’s specific characteristics, the system could make adjustments according to the user’s needs, thus allowing the visually disabled to read more efficiently.

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**References**


