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DEVELOPMENT OF AN OBJECTIVE METHOD OF RESPIRATORY PROTECTIVE MASK LENS FOGGING: DATA ACQUISITION AND IMAGE PROCESSING PROOF OF CONCEPT

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A method that objectively related video image gray scale characteristics to Snellen visual acuity was conceptualized, developed, and evaluated in this investigation as a first step towards development of an objective measure of respirator lens fogging. Seven image processing techniques, including region of interest selection, image filtering, thresholding, removal of border objects, removal of small objects, filling of image holes, and particle detection were applied to images captured on-line with a miniature video camera through goggles with different levels of visual acuity. The image processing sequence was used to assess correlations between image particle counts and known visual acuity scores. A LabVIEW program was developed to determine Snellen visual acuity based on the presence or absence of circles from the processed images. The developed image processing and analysis application correctly identified 20/20, 20/50, 20/70, and 20/300 Snellen visual acuity conditions on a consistent basis. Following adjustments to the image thresholding techniques during image processing, program identification success improved for all acuity conditions. These findings indicate that an objective method has been established that can be used to quantify changes in visual acuity due to mask lens fogging.

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PREFACE

The work described in this report was authorized under Project No. 62262255200. This work began in January 2002 and was completed in November 2002.

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1. INTRODUCTION

Fogging of the optical lenses of a protective respirator is influenced by factors such as environmental conditions, moisture trapping within the mask face piece, work intensity, airflow dynamics within the face piece, and the optical surface of the lenses. Respirator lens fogging can be defined as the condensation of water vapor on the internal surface of the lenses to such a degree that vision becomes impaired.

The methods used today by the military mask development community for quantifying mask lens fogging rely on subjective observations of fogging during controlled environmental tests and from field reports of lens fogging during uncontrolled operational testing.(1) Using such procedures to quantify mask lens fogging has several drawbacks. The most significant drawback is that the data relies heavily upon the subjective opinions of both test personnel and test participants. Even though subjective testing may be able to document fogging that is readily apparent, it lacks the detail necessary to quantify thin films of water vapor that can be formed on lens surfaces that are treated with anti-fog coatings. For example, after coating lenses with a hydrophilic substance, condensing water vapor will form as a continuous film on the optical surface. Viewing through the lenses will be unaffected until the water film becomes uneven in thickness, resulting in distortion of vision due to refraction. However, the naked eye may or may not be able to notice the formation of such a film and its true effect on vision may not be apparent from a test of visual acuity. Thus, the usefulness of human use mask lens fogging tests in the design of mask lens optics, optical treatments, or mask internal flow dynamics that prevent fogging is questionable.

Prior work conducted by the Health Safety Laboratory (HSL) in the United Kingdom related fogging of eye protective goggles to a fogging resistance score but not to visual acuity.(3) The current effort attempted to expand and improve upon the work of the HSL by developing a technique for objectively quantifying fogging of military respirator lenses using visual acuity as a measure of performance. This could be accomplished by relating characteristics of a captured video image to Snellen visual acuity. The idea was that the pixel gray levels in the video image would change as fog formed on a mask's lenses. In theory, we believed that these changes in the gray levels could be related to Snellen visual acuity.

2. METHODS

2.1 The Image Acquisition System.

A miniature, charged-coupled device (CCD), black and white video camera (30mm (W) x 30mm (H) x 26mm (D), 92° Field-of-View) was placed in the left eye-socket of a metal headform. A Pentium computer with National Instruments IMAQ Vision Builder 6.0 and LabVIEW 6.1 software was used to acquire and process images captured from a PCI-1407 data acquisition board (National Instruments). A target image was placed in front of the headform so that the entire image was within view of the camera. Several different targets were used to assess the ability of the data acquisition system to discern different gray intensities and image shapes based on varying levels of visual acuity. Variances of the target image included a bulls-eye shape, shapes such as squares, triangles, and stars, groups of lines of varying thickness and spacing, several video test patterns, and large, medium, and small circles of varying gray intensities.. Two photography lights (Lowel Pro-Light, Lowel-Light Manufacturing, Inc.) with 125 W halogen bulbs supplied the lighting. The lights were placed on each side of the headform at the same height as the headform and were aimed toward the ceiling and were adjusted to obtain minimal shadowing of the video image. Figure 1 shows a schematic of the layout of the image acquisition system.

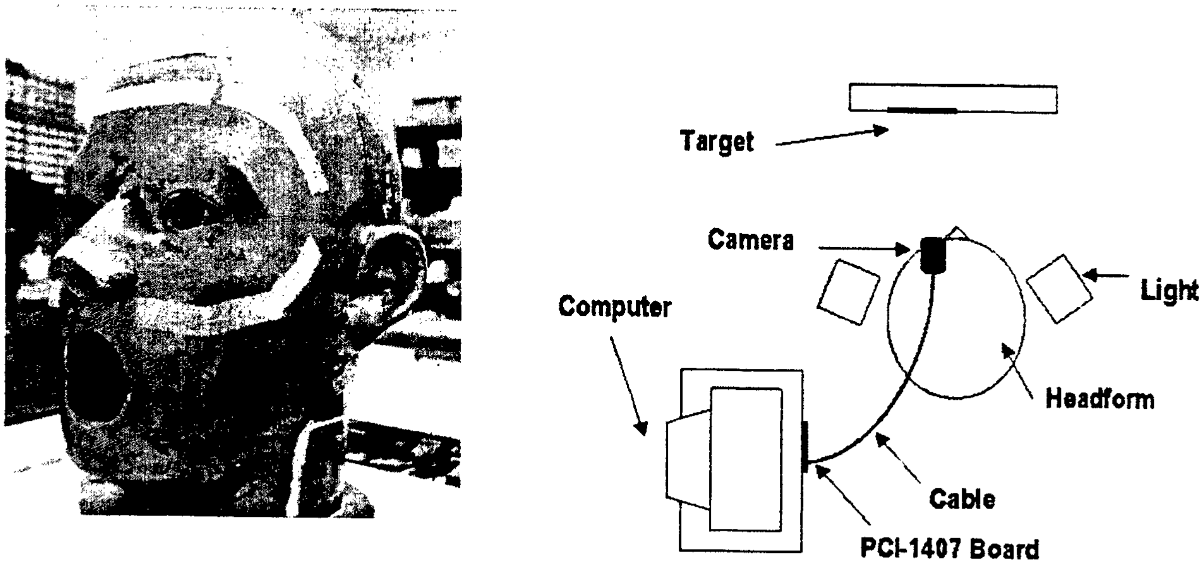


Figure 1. Camera location on the test headform and a schematic representation of the image acquisition system.

2.2 <u>Video Image Testing</u>.

Calibrated visual acuity foils (Bangerter occlusion foils) were mounted on clear safety goggles to create nine acuity conditions: 20/20, 20/25, 20/30, 20/50, 20/70, 20/100, 20/200, and 20/300 Snellen acuity, as well as an occluded lens condition. Modified goggles were placed on the headform in random order, to position an occlusion foil between the camera lens and the target image. Figure 2 displays examples of video images through the goggles for two of Snellen acuity occlusion foils. Three still video images were then captured and stored for each of the visual acuity and target image conditions.

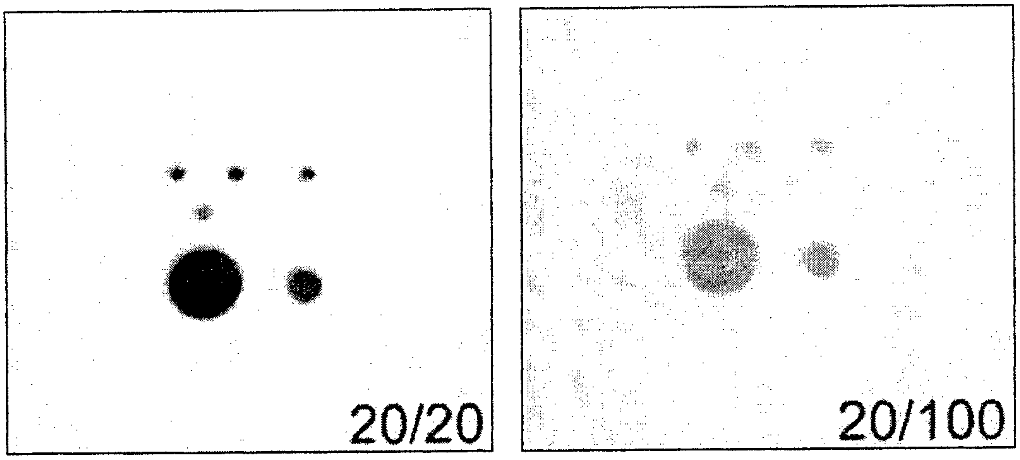


Figure 2. Video image through goggles with the 20/20 and 20/100 acuity occlusion foils before image capture and processing. Note the grayer and more diffuse appearance of the dots in the 20/100 image compared to the 20/20 image.

Captured images were analyzed using NI IMAQ Vision Builder software. Vision Builder contains a library of powerful functions for vision processing and includes an interactive environment for quick prototyping of LabVIEW applications without programming. Various processing techniques were applied to the images alone and in different combinations to assess the effects of visual acuity on gray intensity and pattern recognition of the target image. Image and line histograms were applied to the captured images of the bulls-eye pattern to determine if there were recognizable and significant differences among the various acuities. While the histograms did differ, we were unable to relate the differences to changes in acuity.

Shape matching was attempted with the square, triangle, and star pattern. With shape matching, an image was acquired with the goggles with the 20/20 acuity foil and the computer was "shown" how the shape should look for normal vision. As acuity worsened, the edges of the shape blurred and the computer no longer recognized the shape. However, the ability of the computer to recognize a shape could not be consistently related to the acuity.

A similar attempt was made to use edge detection with the line and television test pattern targets. The edges of the lines and the test patterns blurred as the acuity worsened. However, the ability of the computer to detect or not detect a given line edge could not be related to visual acuity.

Circle detection was applied to the targets containing the large, medium, and small circles. In order to use this routine, the captured images had to be converted from gray scale images to binary, or black and white, images using a thresholding technique. Initial analyses showed that some circles would disappear from these images as acuity worsened. We hypothesized that we could make specific circles disappear for a given acuity but that those circles would still be present for better acuities.

To test this idea, we adjusted the threshold level range for an image to see if we could consistently make a specific circle disappear for a given acuity. We began with the target with the large circles and looked at what threshold range would make the largest black circle undetectable with the occluded foils. Once this range was established, the range was applied to the other acuity images to verify that the large black circle was detectable. In this way, we could identify that the vision through the goggles was occluded. If the black circle were detected, vision was not occluded. If the circle were not detected, vision was occluded. This process was applied to the other acuities and the targets that had the medium and small circles. A specific threshold range and circle were selected for each visual acuity. These results led to a target that consisted of one large, one medium, and five small circles of varying gray colors. We hypothesized that small light gray circles would not be able to be detected as acuity worsened while a large black circle would be able to be detected for all but the occluded goggles. The presence or absence of a circle in the captured video image could then be related to Snellen visual acuity.

Additional still images of the selected target image were obtained for all visual acuity conditions. IMAQ Vision Builder was again used to evaluate the various image processing techniques. A sequence of image-processing techniques was determined. This sequence was applied to all captured video images in order to assess correlations between image particle counts and visual acuity. The processing sequence, or script, was converted to a LabVIEW 6.1 program using the IMAQ Vision Builder software. A LabVIEW program was developed to determine Snellen visual acuity based on the presence or absence of circles from the processed image. A simple user interface was added to the program to display the Snellen visual acuity and the acquired image.

3. RESULTS

The final method developed for image processing involved the application of seven sequential techniques. The seven techniques used were selection of a region of interest (ROI), image filtering, application of a threshold, removal of border objects, removal of small objects, filling of holes in the image, and particle (i.e., circle) detection. The ROI technique was applied to captured video images to select the area that encompassed the seven circles in the target image (Figure 3). The selected ROI defined the region of the image that was used for subsequent processing techniques and analysis. The image was then filtered to decrease shadowing and to sharpen the image (Figure 3). This created sharper boundaries between the particles and the background. A thresholding technique converted the image into a binary image to permit particle analysis. Grayscale images have pixel values ranging from 0 (black) to 255 (white). A threshold range was applied to the image so that all pixels with values in the threshold range were converted to white, while all pixel values above or below the range were converted to black, creating a binary image. This technique separated the objects from the background and made it easier to detect the circles. Border objects that may have been truncated during the digitization of the image and small objects that appeared due to shadowing were then removed from the image and small holes in the image were filled (Figure 3). Finally, particle detection was used to count the number of circles in the processed image (Figure 3).

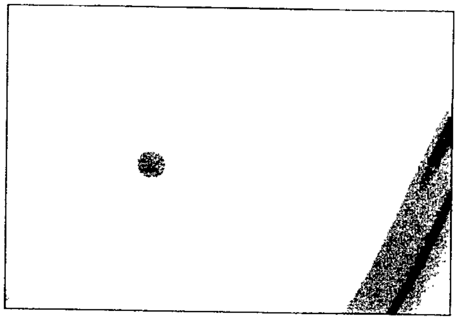
While the same sequence was used to process each captured image for each visual acuity condition, the ROI and threshold levels were different. Changing the threshold range allowed us to use the same gray intensity circles of the unprocessed image to check multiple acuities. The ROI and threshold range were set within the image-processing program. The LabVIEW program used a process of elimination to determine the visual acuity starting with the worst acuities. The ROI and threshold were set for occluded vision and the sequence was run. If no circles were detected, vision was occluded and the processing stopped. If the large, black circle was detected, the vision was 20/300 or better. The ROI and threshold were changed and the next circle was processed. If it was not detected, the acuity was 20/300 and the processing stopped. If the circle was detected, the acuity was 20/200 or better. The ROI and threshold were set and the next circle examined. This procedure continued until the 20/20 acuity level was attained.

The developed image processing and analysis application correctly identified the 20/20, 20/50, 20/70, & 20/300 Snellen visual acuity conditions on a consistent basis. However, image processing of 20/25, 20/30, 20/100, and 20/200 Snellen acuity conditions was less successful. Following additional adjustments to the image thresholding techniques during image processing, program identification success was improved to almost 100% for all acuity conditions.

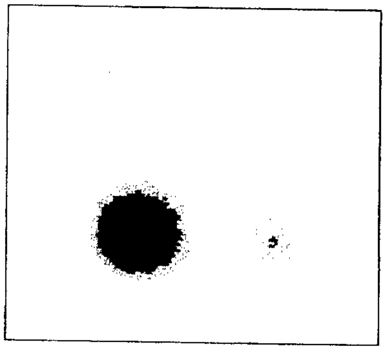
4. DISCUSSION

The goal of this effort was to establish a technique that will permit objective quantification of the impact of respirator lens fogging on vision. To that end, a method that objectively related video image gray scale characteristics to Snellen visual acuity was conceptualized, developed, and evaluated in this investigation. The theory behind the test method that was pursued was that small gray circles would become less detectable in a black and white video image as visual acuity worsened while larger black circles would be detected for all levels of acuity up to completely occluded vision. Overall, the results of this investigation proved that image pixel intensity could be used to quantify various levels of Snellen visual acuity.

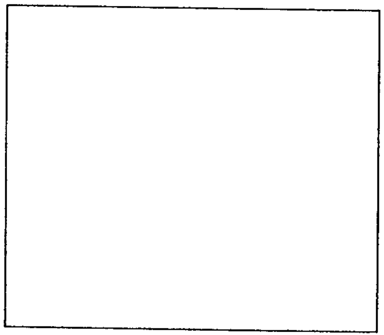
The chosen image processing techniques detected half of the Snellen acuity conditions without difficulty. With minor adjustments to the thresholding technique, program identification success for all of the tested acuity conditions improved dramatically. However, differences between the 20/25 and 20/30 acuities and the 20/100 and 20/200 acuities remained hard to detect. The ability of the program to readily discriminate between 20/25 and 20/30 may not be important in terms of functional abilities since 20/25 falls within the range of normal vision and 20/30 represents borderline normal vision based on statistical estimates of reading abilities.(2) In contrast, since the difference in functional abilities between Snellen acuities of 20/100 and 20/200 is more profound, additional emphasis needs to be placed on refining the image processing techniques to discriminate between these conditions. However, the need for this may be minimal once a pass/fail criterion for an acceptable level of visual acuity under conditions of mask lens or visor fogging has been established. Since moderate visual impairment includes the acuity range of 20/70 to 20/100, discrimination between acuities of 20/100 and 20/200 may not be needed if 20/100 becomes the pass/fail criterion.



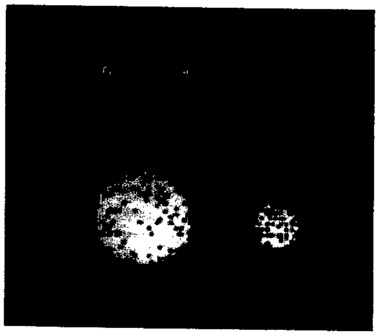
Computer captured video image



1. Selection of the region of interest (ROI)



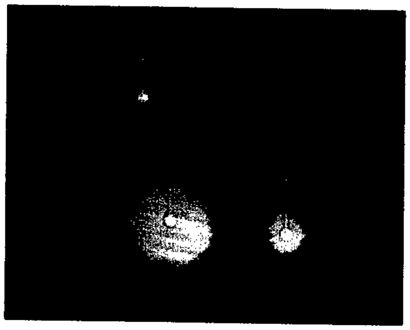
2. Filtered image (shadow reduction & sharpening)



3. Image after threshold was applied

4 & 5. Removal of border objects and small objects

6. Filling of holes in remaining objects



7. Particle detection & object counting

Figure 3. Image processing techniques applied to captured video images. The processing techniques are numbered sequentially.

Based on the findings of this investigation, additional work is needed to enhance the objective lens fogging measurement test method. Currently, work continues for refinement of the image processing techniques. In addition, a second CCD camera has been installed in the test headform and the data acquisition program has been altered to obtain a timed sequence of images from both video cameras. For this set-up, the user sets the number of images to acquire and the time between images. These changes will permit assessment of fogging patterns of an entire lens system over time. The target test image will be modified to have the seven-circle array placed in multiple locations on the target. This modification will allow the program to specify regions of the lenses where the fogging is occurring. Heating of the metal headform has been accomplished to simulate face and head temperatures. Additional headform modifications will include breathing simulation and surface wetting to mimic perspiration. Finally, testing of the upgraded system will utilize video images captured with full-facepiece respirators mounted on the headform with and without breathing simulation.

5. CONCLUSIONS

Preliminary testing showed accurate, repeatable results that suggest that an objective method has been established that can be used to quantify changes in visual acuity due to mask lens fogging. Additional progress towards establishment of a simulator that accurately mimics thermal conditions of the human head, temperature and humidity of human breath, and environmental exposure conditions in which a mask may be worn is needed before objective measurements of mask lens fogging or frosting can replace subjective evaluations.

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