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REAL TIME OPTICALLY-PROCESSED FACE RECOGNITION SYSTEM BASED ON ARBITRARY MOIRÉ CONTOURS

Rafael A. Andrade †
Bernard S. Gilbert III *
Don Dawson*
Chris Hart *
Samuel Kozaitis †
Joel Blatt (blatt@pss.fit.edu), MEMBER SPIE *
* Department of Physics and Space Science
† Division of Electrical and Computer Science and Engineering
Florida Institute of Technology, 150 West University Blvd, Melbourne, FL 32901-6975

ABSTRACT

A real-time diffraction based optical processed 3-D shape recognition system has been built and demonstrated. The system uses an Ar-Ion laser interferometer to project variable spatial frequency structural illumination on 3 dimensional targets which are viewed by a camera. The video data is mixed with a computer generated mask (converted to RS-170 video) and the resulting output video signal is sent to a Liquid Crystal Television (modified to function as a Spatial Light Modulator) which is illuminated by a He-Ne laser. The video mixing process, based on a commercial Chroma-Key circuit, generates an arbitrary moiré pattern which is a function of the 3 dimensional shape of the target (indicated by the distorted structured illumination) and of the computer generated mask. As an example, the output pattern could be a 1 dimensional Fresnel Zone Plate (FZP[1]) when the shape of the object is recognized. In this case, the laser illuminated zone plate produces a bright line focus at the predicted focal distance for the correct target, a reduced intensity line focus for a damaged target, and no output for a totally different target. The result is a mixed video-optical processing system that could be used for real-time quality level sorting or other automated inspection requirements.

Other types of diffractive masks are simulated with the goal of increasing the area of target inspection and recognizing and discriminating between different targets with a single mask. Limitations and improvements in the current system are discussed.

Keywords: optical processing, 3-D shape, moiré contours, face recognition

1.0 INTRODUCTION

High speed target recognition systems can be divided into three classes: All digital, all optical, and hybrid optical and digital. In reality, all optical systems involve some analog signal processing and switching, but in this paper, digital processing refers exclusively to computer processing. High speed digital processors have been used for near real-time target recognition systems, but because of the large amounts of data in images, much interest has been shown in all optical or hybrid digital-optical systems. In order for a hybrid digital-optical system to function optimally, rapid computer processing is ordinarily necessary. In a number of systems, a majority of the information is computer rather than optically processed. However, in order to achieve real-time processing, it would be ideal to minimize the computer processing and maximize the optical.

We have designed a real-time system that utilizes optical rather than computer processing techniques to achieve target recognition. The real-time feature of this system relies on the diffracting properties of video generated patterns displayed on a liquid crystal TV (LCTV) acting as a spatial light modulator (SLM). Spatial Light Modulators (SLMs) are increasingly being relied upon for optical

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processing[2,3]. An SLM is the single most important element that can enable real-time or near-real-time two dimensional data processing by spatially modulating a two dimensional optical signal. As a result, the light wave itself becomes the information carrier [4,5]. For the system presented in this paper, we used a Radio Shack LCTV since it compares favorably with many SLMs at a much lower cost[6]. The fairly large size of our optical processing system is a function of the SLM pixel size and spacing, but if a higher quality SLM were used, a very compact and reliable high resolution system could be built.

The SLM is illuminated by a low power He-Ne laser, and the resulting diffracted beam falls on a video camera or detector array. The video pattern sent to the SLM is obtained by mixing a computer generated video mask signal with the video image of a structurally illuminated target. The mask is designed such that the video mix forms the correct Fresnel Zone Plate (FZP)[1] or diffraction grating in the SLM when the correct structurally illuminated target is seen by the input camera. A variable resolution video moiré system[7] is used to generate a set of structurally illuminated images of the desired target. This set of images and the desired arbitrary output moiré are computer processed off line to generate a mask image, which, when converted to composite video, can be recorded on video tape to be mixed with the video image of a structurally illuminated target to produce the desired output moiré. Several diffraction recognition masks will be demonstrated and/or simulated, including an FZP and a tilted conventional diffraction grating, which generates a series of spots when the target is recognized. If the output FZP[8,9] moiré video signal is sent to a coherently illuminated SLM, a bright, real-time, "target recognized" signal appears at the Fresnel focal plane. With either diffractive mask, if the target camera views a structurally illuminated incorrect target, either there is no focusing of light at the output detector (for the FZP) or the spot pattern is incorrect, reduced in intensity, or absent (for the diffraction grating). The result is a system that could be used for real-time target recognition, quality level sorting or other inspection requirements.

2.0 THEORY OF OPERATION AND EQUIPMENT SETUP

Arbitrary moiré masks are generated by differencing the phase of the desired pattern and the phase of the projection grating distorted by the 3-D shape of the reference object. This difference uniquely identifies the intensity of every point on the generated mask, making it usable for creating the desired moiré when mixed with an object whose distorted grating pattern matches the reference's distorted grating pattern. The moiré pattern generated by a different object will vary in phase by the phase difference of the two grating patterns distorted by the objects.

The difference in the distorted gratings seen on the two objects will determine the difference in the resulting moiré patterns. By uniquely picking the output moiré pattern for one object, the custom mask will have a unique but different fixed pattern for the second object. In general the second pattern will not have the useful recognition properties that the chosen pattern for the first object has. Thus to test for recognition of multiple objects, a custom mask for each object is generally required. These custom masks could be presented sequentially in time or in parallel in space. The parallel recognition of say one of a set of three objects could be achieved by having the optical system generate three side by side replicates of the viewed object, and have the custom mask designed so that the left pattern recognized object one, the center pattern object two and the right pattern object three. If the camera views a structurally illuminated object one, a line focus or other desired output will be generated by the live mix of the triple object video signal with the left pattern.

The system can be divided into two parts: the filter grating (mask) generating system, and the optical processor. The mask generating system captures the desired face contour images, contains the desired output image, and computes the filter grating that will be video-mixed in real-time with an input contour image. The video moiré system[6] basically consists of a Michelson interferometer grating projector and two TV cameras to view an input and reference surfaces from symmetric angles. The video signals

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from these cameras are fed to a video mixer. The modified and unmodified video output from the mixer are delivered to two monitors and to a Macintosh Iici with a Data Translation frame grabber board and a Scion RS-170 video output board, which is used to collect and store data in the form of images and to generate the required video recognition mask.

To recognize an object a mask must be created for that object. The Michelson interferometer generates and projects variable spatial frequency gratings on an input and reference surface. Therefore, the gratings on the input will look distorted unless the input is flat. Five images of these distorted gratings on the input object are captured by manually shifting the reference (and input object) gratings by $\pi/2$, four times. Video images of the shifted gratings along the reference surface allows precise adjustment of the phase shifts. A total of five images are captured (each one with a phase difference of $\pi/2$ from the previous one) and later used to compute a phase mask[7]. The filter grating is produced by combining (using a computer program) this phase information and the desired FZP. Obviously, the generation of the filter grating requires computer processing. Then, the filter grating image is converted to composite video and sent directly to the video mixer. This filter grating produces the desired real-time Fresnel zone plate when mixed in live video with the structurally illuminated input object. In other words, if the test object matches the correct input, the Fresnel zone plate moiré output pattern is produced. Figure 1 illustrates the video and optical parts of the mask generating system.

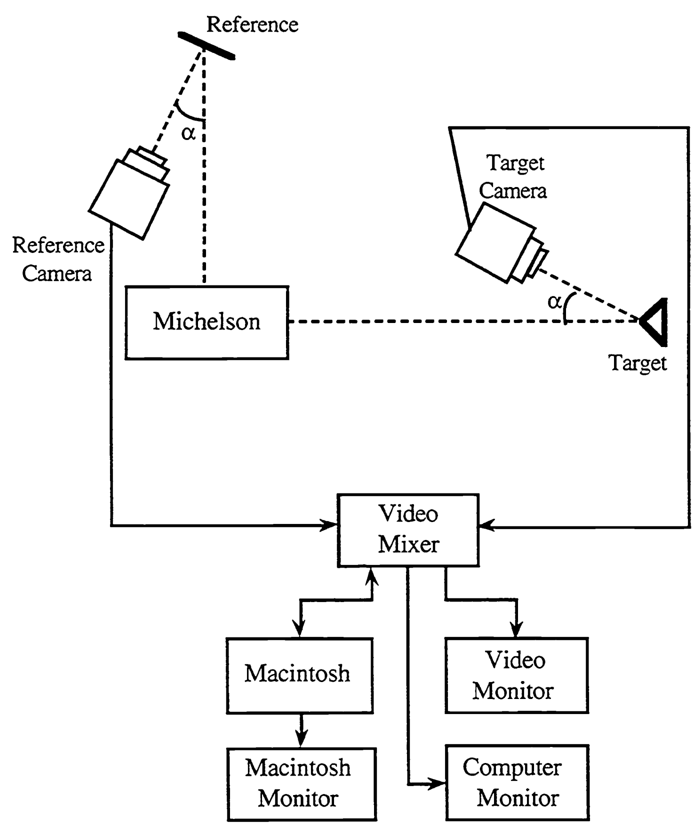

Figure 1 - Filter grating generating system

The optical processor portion of the system identifies an input object in real-time. The input to this half of the system (the output of the first half) is an arbitrary moiré interferogram in the shape of a zone plate. The output is light focused by the FZP and recorded with a detector. If the input face is not

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recognized, a zone plate is not generated and, thus, focusing does not take place. Figure 2 illustrates the optical processing system. By using a camera at the FZP focal plane it was possible to obtain images of the focal point of the zone plate. These images are shown in the next section.

The optical system relies on general diffraction theory and geometrical optics as the means for real-time optical processing. According to Fresnel diffraction, when a circular obstacle is placed in front of a point source, the construction of Fresnel zones starts at the edge of the obstacle. Then, since the optical disturbance (that is, the relation between the value of any scalar wave function at any point inside an arbitrary closed surface and the value of the wave function at the surface) is half of the contribution from the first unobstructed zone, the result is a bright spot in the center of the shadow of a circular opaque object[4]. The irradiance at the spot is very nearly the same as it would be in the absence of the obstacle. The same theory applies for a half period, one-dimensional (cylindrical) zone plate (shown in figure 3). Illumination of a FZP with parallel coherent light results in the focusing of light at a focal plane.

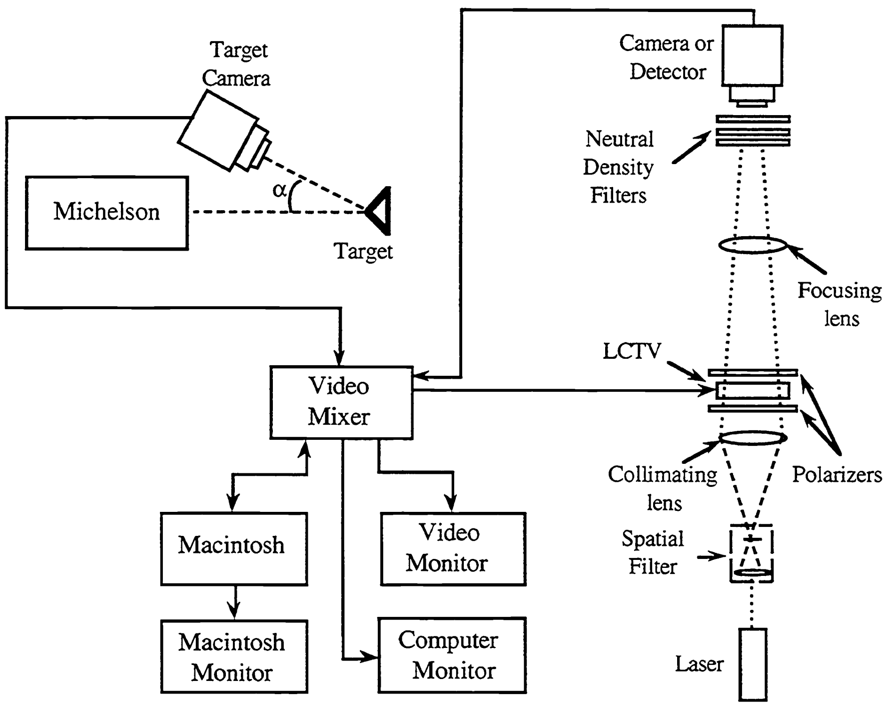

Figure 2 - Optical processor

The one dimensional calculations were carried out to estimate the theoretical distance where the bright line should be formed. The formula that gives the focal distance (**f**) of the FZP is:

$$f = R^2 / \lambda \tag{1}$$

where R is the radius of the first Fresnel zone, and λ is the wavelength of the source. According to this formula, if R = 0.4 mm, then the focal length of the corresponding zone plate would be 25.27 meters. Because of this, a focusing lens is added between the LCTV and the detector. According to geometrical optics, two thin lenses separated by a distance d will yield a combined focal length given by

$$f^{-1} = (f_1)^{-1} + (f_2)^{-1} - d(f_1 f_2)^{-1} \tag{2}$$

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where f_1 is the focal length of the lens and f_2 is the focal length of the zone plate given by equation (1).

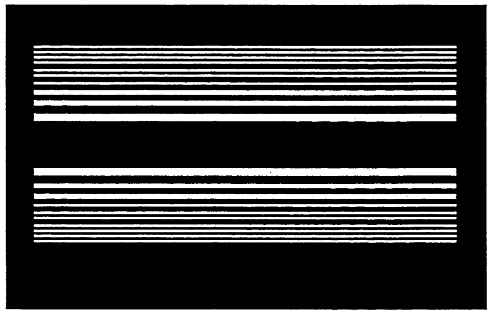

Figure 3 - Cylindrical Fresnel Zone Plate, also the desired output to the SLM

Using a lens with f = 0.5 meter and doing the calculations, the combined focal length is approximately 0.45 meters. Therefore, as long as the zone plate is present, focusing of light will occur at a distance predicted by equation (2). If the zone plate is absent, focusing will occur at the focal length of the lens.

Our video mixer produced circular FZPs that "jittered" on the LCTV. Therefore, we considered one-dimensional (cylindrical) FZPs which were stable when compared to the circular FZPs. Because the focal distance is directly proportional to the square of the zone plate's radius, the smaller the zone plate, the smaller the focal distance. However, the pixel size of the Radio Shack LCTV is a limiting factor when considering a small zone plate (pixel size $\approx$ 330 μm). A higher quality SLM would provide better resolution, better contrast, less pixel noise, and shorter focal distance.

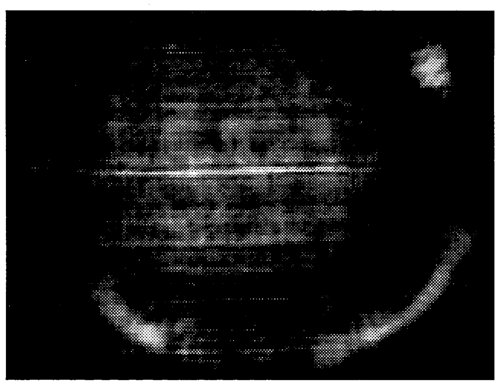

Figure 4 - Output at the CCD camera with computer generated Fresnel Zone Plate

The Fresnel zone plate presented in figure 3 can be displayed on the LCTV directly from the computer. This result is focusing of light as shown in figure 4, which is captured in real-time and with no computer enhancement. It should be noted that the bright circular line on the edges of the picture is not related to the zone plate in any way. This pattern is due to the fact that the polarizers (circular) are smaller than the LCTV screen. Therefore, when the unpolarized light diffracts around the polarizers, the circular line appears. Still, this is the best possible output that can be obtained by this system since the computer generated zone plate has the best contrast. This is a very important step in the calibration of the system because it sets a reference between worse and best case scenario. It is also important because we use this computer generated zone plate to calibrate the LCTV for it's maximum contrast.

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3.0 EXPERIMENTAL RESULTS- FRESNEL ZONE PLATE

The target recognition feature of this system relies completely on the quality of the SLM used. As mentioned before, a modified Radio Shack LCTV was used. Since these devices are not manufactured for optical processing purposes, they have limited dynamic range and add significant noise to the information carrier, thus reducing the signal-to-noise ratio in the results. However, even with this noise, the system still worked properly. In other words, this system is noise tolerant. Figure 5 shows the three different faces to be inspected under standard room illumination and structured illumination.

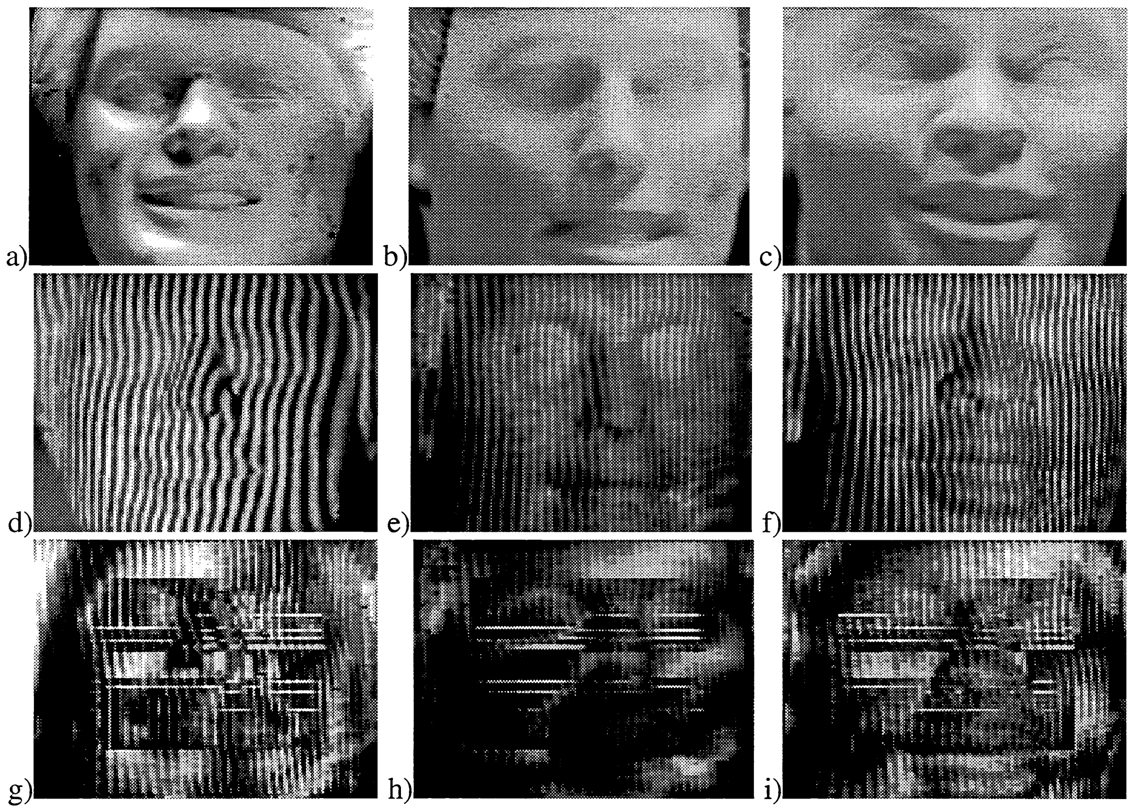

Figure 5 - a, b & c show the 3 targets under standard illumination; d, e & f correspond to the 3 targets under structured illumination; g, h & i are the outputs (live video mix) moire patterns corresponding to the three faces.

We selected the individual in figures 5 a) to be our "correct face", therefore, the filter grating (shown in figure 6) was generated to only identify this face. The other two faces (figures 5 b) and c)) were selected to be the "incorrect faces". The filter grating is obtained by subtracting a scaled version of the desired output from the phase information and then taking the cosine of this result. This filter grating or mask is shown in Figure 6. The live mix from the three faces is shown in figures 5 g), h), and i).

Again, this calculated filter grating produces the desired moiré pattern when mixed with the structurally illuminated target. The system then uses the live chroma key operation to mix the filter and the live target. The resultant image will have background noise due to the feedback induced by the chroma key circuit. However, even with this noise levels present in the image, a well defined zone plate arises from the live mix, producing a line focus at the CCD. It is very obvious that the line focus produced by the live mix will not be as bright as the one produced by the computer generated zone plate. This can be easily identified by observing figures 4 and 7.

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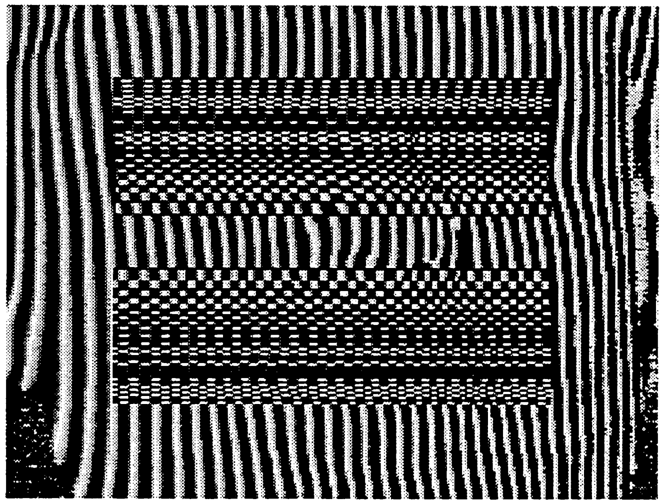

Figure 6: Filter grating obtained by combining the phase information and the desired output

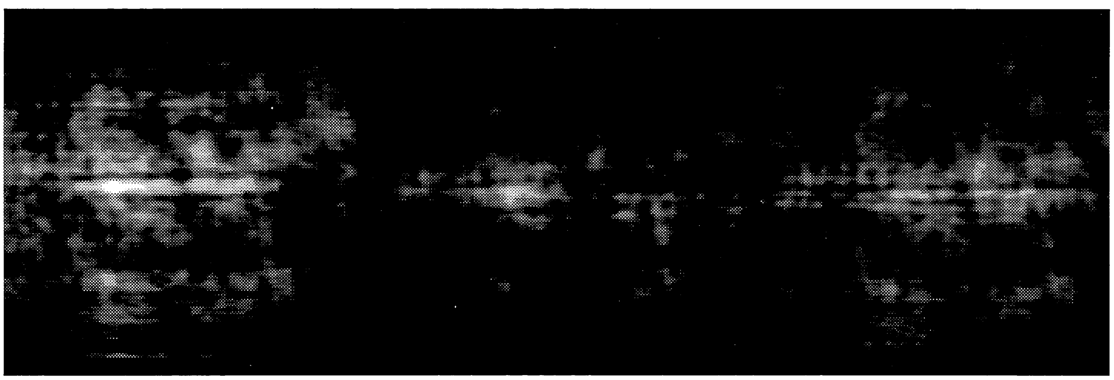

Figure 7 - Outputs obained with images 5g, 5h and 5i respectively

Figure 7 shows Fresnel zone plate focused outputs obtained at the CCD when the live mix (figures 5g, 5h and 5i) are displayed on the LCTV. The left side of figure 7 was obtained with the correct face and the filter grating. As mentioned before, this line focus is not as bright and defined as the one presented in figure 4, however, the system is calibrated to identify this as the maximum expected output. The resultant outputs of the incorrect target mix are shown in figure 7 center and left. These live mixes were obtained with different but very similar faces. As it can be seen, neither the center not the left output shows a distinct focus line. This proves that the system is sensitive to slight differences between objects. The difference between the three output images in figure 7 might not be very apparent to the human eye. Consequently, a surface plot is presented in figure 8. The system's detector can be calibrated to differentiate these three distinct but similar outputs. As long as the expected zone plate foci are aligned along the pixel readout direction, a simple analog integrator or adder followed by a comparator could be used for recognition. This approach, though, might prevent the system from performing in true real-time.

It is clear that the only area being inspected by the system so far is the area covered by the zone plate. This problem can be addressed by choosing our desired output to be a set of gratings (tilted at a specific angle) that would cover a complete screen and leave less room for unaccounted target variations. This requires small modifications to our system. A focusing lens is needed in front of the LCTV and a camera with a microscope objective is needed in order to observe the elements in the Fourier plane.

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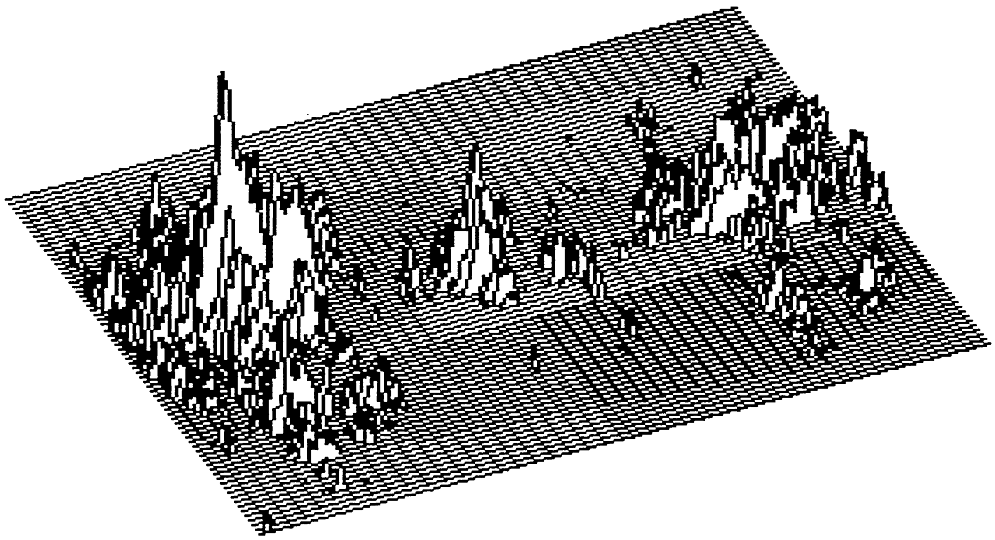

Figure 8 - Surface plots of the three focus lines

4.0 SIMULATION AND EXPERIMENTAL RESULTS- DIFFRACTION GRATING

It is possible to identify the zero and first order elements generated after a Fourier transform is performed on a set of gratings[9]. According to Fourier transform and diffraction theory, several dots (representing the mathematical orders) should appear along the 45° axis of the output plane. It is known that for different spatial frequencies the dot's position varies with respect to the origin. For high frequency gratings, the dots appear further away form the origin, and the opposite happens for lower frequencies. Furthermore, as the tilt angle of the gratings changes, the position of the dots also changes.

Figure 9 shows the results of the experiment performed with the new desired output. Due to the excessive noise induced by the chroma key circuit, the live video mix of the structurally illuminated face and the filter grating was simulated by NIH image's XOR function. This simulated output was still displayed on the LCTV for recognition. It can be seen that the output corresponding to the computer generated gratings is much more apparent than the output obtained with the simulated desired output. This has to do, for the most part, with the poor resolution and contrast of the LCTV. The fact that the XOR function is not an exact replica of the chroma key function also plays a role in the lower definition of figure 9 d compared to figure 9b. For much better results, a higher frequency grating can be used. This places the off axis components further away from the origin, which makes them easier to locate. However, due to the high frequency, the XOR function did not yield a well defined set of gratings. A better quality chroma key circuit combined with a high definition LCTV would yield remarkable results.

5.0 TARGET ANGLE AND TARGET SHIFT RECOGNITION TOLERANCES

An experimental target angle and shift tolerance analysis was performed on the system. The results of this analysis are shown in figure 10. Within these values, the system is still capable of recognizing the target.

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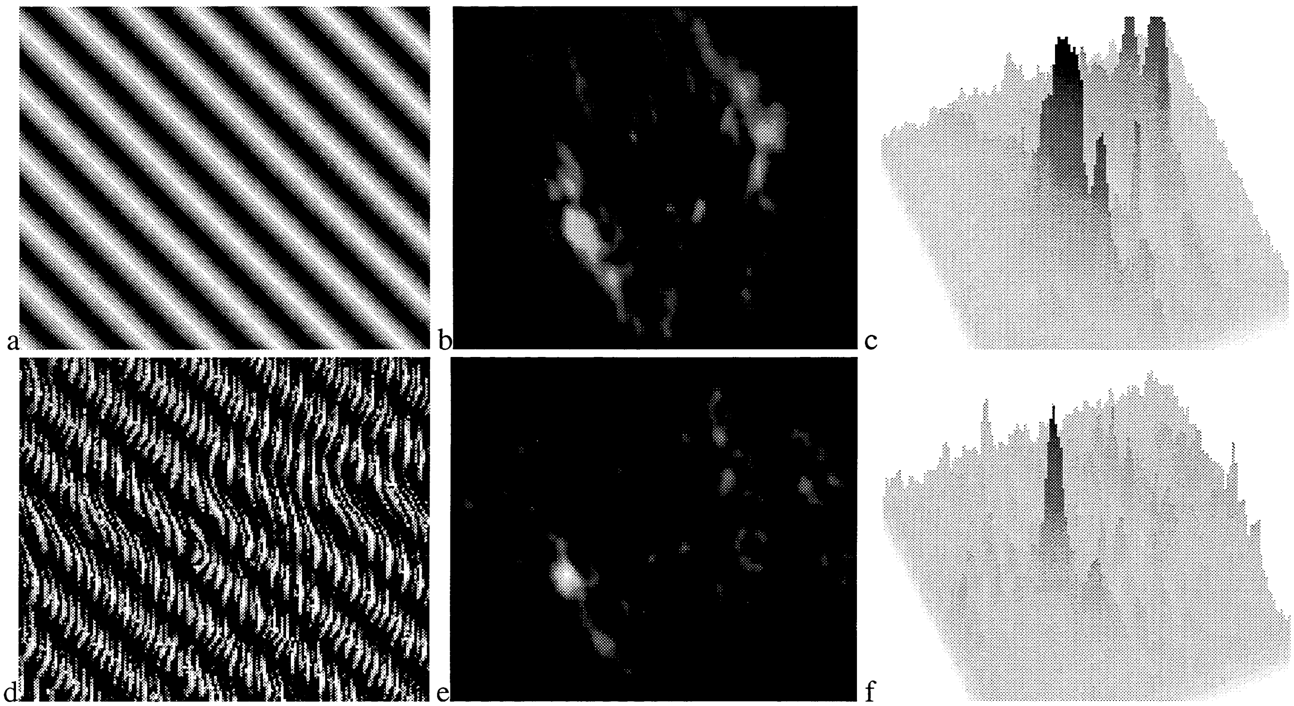

Figure 9 - a) Computer generated desired output, b) off axis components produced due to figure a, c) 3D plot of b, d) simulated desired output using XOR function, e) off axis component due to d, f) 3D plot of e.

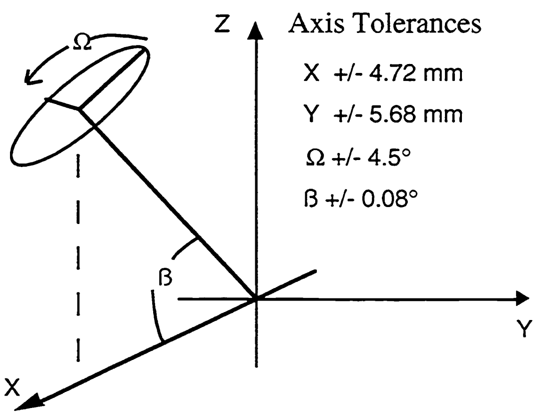

Figure 10 - Recognition Tolerances

6.0 CONCLUSIONS

A real-time system that utilizes optical rather than computer processing techniques for target recognition has been presented in this document. It has been proven that it is possible to construct custom reference gratings that form a desired moiré pattern when mixed with images of structurally illuminated test objects. By selecting the moiré pattern to be a Fresnel zone plate we were able, through basic diffraction, to optically process information without major computer intervention. Finally, the restrictions on the shape of the output moiré contours were removed producing a real-time automated inspection system based on optical processing of arbitrary moiré contours. It was proved that when illuminating the zone

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plate with parallel coherent light, focusing occurs at the focal plane. The use of an alternative diffractive mask was simulated, indicating the possibility of recognition over the entire visible 3-D surface of a target. The possibility of real time recognition of different targets was discussed. Furthermore, by selecting a high quality SLM, a compact portable system is feasible. The result is a system that could be used for real-time recognition of multiple objects and for multiple applications.

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