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IMAGE REMAPPING STRATEGIES APPLIED AS PROTHESES FOR THE VISUALLY IMPAIRED

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Prepared by: Curtis D. Johnson, Ph.D.

Academic Rank: Professor

University & Department: University of Houston
College of Technology
Houston, TX 77204-4083

NASA/JSC

Directorate: Engineering

Division: Tracking and Communications

Branch: Tracking Techniques

JSC Colleague: Richard Juday, Ph.D.

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ABSTRACT

Maculopathy and retinitis pigmentosa (rp) are two vision defects which render the afflicted person with impaired ability to read and recognize visual patterns. For some time there has been interest and work on the use of image remapping techniques to provide a visual aid for individuals with these impairments. The basic concept is to remap an image according to some mathematical transformation such that the image is warped around a maculopathic defect (scotoma) or within the rp foveal region of retinal sensitivity. NASA/JSC has been pursuing this research using angle invariant transformations with testing of the resulting remapping using subjects and facilities of the University of Houston, College of Optometry. Testing is facilitated by use of a hardware device, the Programmable Remapper, to provide the remapping of video images.

This report presents the results of studies of alternative remapping transformations with the objective of improving subject reading rates and pattern recognition. In particular a form of conformal transformation was developed which provides for a smooth warping of an image around a scotoma. In such a case it is shown that distortion of characters and lines of characters is minimized which should lead to enhanced character recognition. In addition studies were made of alternative transformations which, although not conformal, provide for similar low character distortion remapping.

A second, non-conformal transformation was studied for remapping of images to aid rp impairments. In this case a transformation was investigated which allows remapping of a vision field into a circular area representing the foveal retina region. The size and spatial representation of the image are selectable. It is shown that parametric adjustments allow for a wide variation of how a visual field is presented to the sensitive retina.

This study also presents some preliminary considerations of how a prosthetic device could be implemented in a practical sense, vis-a-vis, size, weight and portability.

INTRODUCTION

Maculopathy and retinitis pigmentosa (rp) are two forms of human vision defects which are characterized by partial loss of ocular function. In the case of maculopathy the dysfunction is in the foveal region of the retina and thus the area of greatest resolving power. The resulting scotoma or "blind spot" leaves individuals so afflicted with an impaired ability to read and to recognize patterns since both functions involve high resolution visual imagery. They learn to partially compensate by fixating on a spot removed from the focus of attention such that the image falls on the most optimum peripheral retina. Figure 1 illustrates how a sample of written material might appear to a maculopathic individual where the eye is "focused" upon the region directly under the scotoma blocked text. If fixation is made on the center of the circular area the difficulty of character recognition using images falling on peripheral retina can be noted.

It was a dark and stormy night. The rain
It was a dark and y night. The rain
It was a dark anc , night. The rain
It was a dark anc , night. The rain
It was a dark and .y night. The rain
It was a dark and stormy night. The rain
It was a dark and stormy night. The rain

Figure 1. Text viewed with a scotoma

The case of retinitis pigmentosa is the inverse of maculopathy in that it is the peripheral regions of the retina that lose sensitivity while the foveal region remains functional. Individuals afflicted with this "tunnel vision" condition have difficulty in navigation and dexterous activity since loss of peripheral vision disturbs the awareness of local surroundings. Sensitivity to motion detection is also impaired. Afflicted individuals learn to compensate by swinging the head during ambulation to sweep the field of view through the sensitive retinal region.

As part of space activity related research NASA Johnson Space Center has developed considerable expertise in the theory and techniques of visual image warping. The Programmable Remapper[1] (PR) is a hardware device developed by NASA/JSC which is capable of providing specified warping of an input TV image to an output monitor display at better than 30 frames per second. Considerable research has been conducted on how image warping may be applied as a prosthesis for individuals afflicted with maculopathy or rp. The basic concept is to warp the image such that a portion of the lost data is redistributed to remaining sensitive regions of the retina[2-4]. Research thus far has involved remapping of textual material in such a way as to warp the image partially or totally exterior to an assumed scotoma. The warping transformation employed in these initial investigations is an angle invarient shift of the image along radial lines from the center of the scotoma. Figure 2 illustrates the appearance of warped text for which approximately 80% of the image has been remapped outside of an assumed scotoma. Experimental testing was accomplished by using the PR in conjunction with an eye tracker to provide a warped image for subjects with simulated maculopathy. The results suggest some improvement in reading capacity[5].

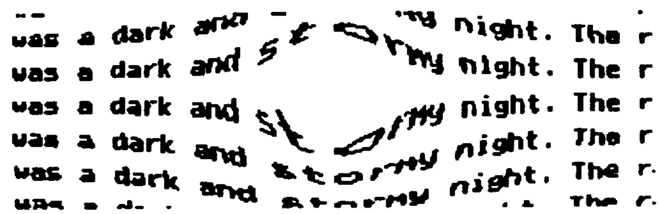

Figure 2. Radial warping of text.

The particular radial transformation employed in the testing and shown in Figure 2 results in considerable distortion of the text characters. This may adversely effect the results of reading rate measurement since, although the image has been warped to a sensitive region of the retina, character distortion hinders recognition.

This paper presents results of two aspects of continued work on the application of warping strategies toward development of a prosthesis for those with maculopathic or rp afflictions. The first aspect involves a study of alternative warping transformations and the second focuses on issues related to the practical and feasible implementation of a prosthesis.

Transformation Formulation

In general a visual image to be remapped consists of a rectangular array of pixels, where each pixel is represented by a two dimensional coordinate and has a "value" which describes the attributes of the pixel. Attributes include such features as intensity and color. The transformation process specifies how a pixel located in the image input plane at (x,y) will be re-mapped to the image output plane at location (u,v). This transformation is specified by equations relating (x,y) to (u,v),

$$u = f(x,y) \quad (1)$$
$$v = g(x,y) \quad (2)$$

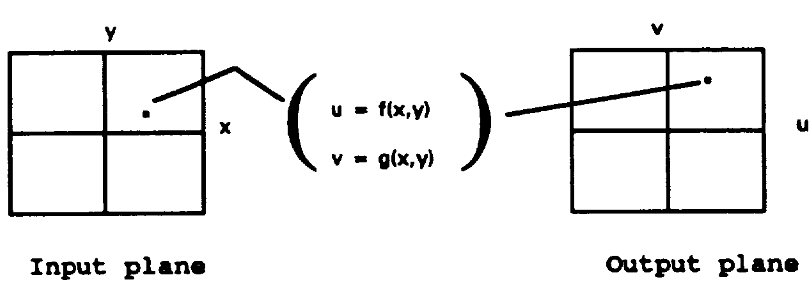

Figure 3. The transformation process

Whereas the process of Equations (1) and (2) is analytically complete it fails to consider the discrete nature of the pixellated image. If the Jacobian of the transformation is greater than unity in some region then a single pixel in the input plane may transform into several output plane pixels. Of course if the Jacobian is less than unity the converse may occur wherein several input plane pixels transform into a single output plane pixel. In these cases interpolation processes must be used to relate un-mapped input and output pixels and the attributes of the input and output plane pixels must be modified to retain image features such as color and contrast.

The Programmable Remapper described earlier includes pixel interpolation and attribute adjustments so that only the analytical features of the transformation need to be developed.

In order to statically test the transformations studied in this work the test text of Figure 1 was employed. The transformation equations were used to recast this image so that the effect of the warping could be examined. Since the objective was to study the effect of transformations on character shape and orientation, only very elementary interpolation and fill-in routines were employed. Therefore the appearance of the test text after warping as shown in this report is is only partially filled and is not to be interpreted as the final representation for actual patient testing.

MACULOPATHIC TRANSFORMATIONS

Study of alternative transformations for maculopathy compensation was confined to those which appeared to be most suitable for enhanced reading skills as opposed to facial recognition. It is not at all clear that the optimum transformation for the first would also be optimum for the second. This choice was made since experimental studies are presently concentrated on measurement of reading enhancement via image warping.

It is assumed that an optimum text warping transformation would be one which:

(1) displaces the text image blocked by the scotoma to sensitive retina just outside the scotoma,

(2) minimizes distortion of the shape of the text characters, and

(3) maximizes preservation of the textual flow of characters as lines are warped around the scotoma.

Of course the true test of a transformation is in its efficacy in improvement of maculopathic reading rate.

A Conformal Transformation - $\sin^{-1}(z)$

A conformal transformation is one which preserves angles between line segments through the transformation. This means that the basic orientational features of characters and lines consisting of characters would be preserved. This is consistent with the optimum transformation objectives. The conformal transformation employed was a two step, complex arcsin/complex sin process.

The first step is to perform a transformation of the form,

$$z' = \sin^{-1}(z) \qquad (3)$$

where $z' = x' + jy'$ is in an intermediate image plane
and $z = x + jy$ is formed from the input image plane
An offset is now added to y',

$$y'' = y' + c \tag{4}$$

so that $z'' = x' + jy''$.

The reverse transformation is used to construct the output image plane,

$$w = \sin(z'') = u + jv \tag{5}$$

It is easy to show that this transformation creates an elliptical void about the origin of the (u,v) plane with dimensions shown in Figure 4. Essentially the transformation expands the line from (0,-1) to (0,+1) in the input image plane into the indicated ellipsoidal shape. Thus images in the input plane will be warped into the output image plane such that all input image pixels are remapped into the space surrounding the elliptical void.

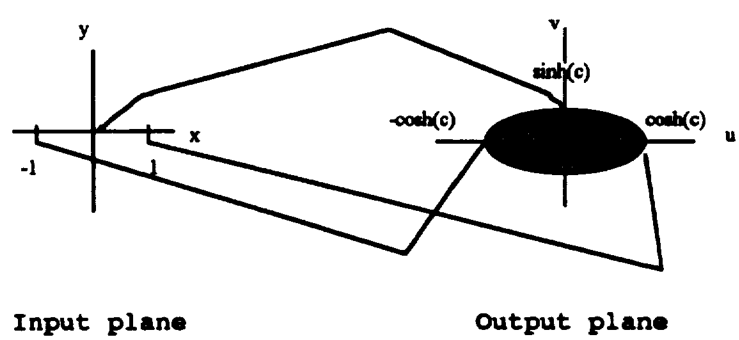

Figure 4. Conformal remapping by arcsin/sin

Since unity points play an important role in this remapping, proper normalization of the input image must be included. To test this transformation for maculopathy a circular scotoma of radius r_s is assumed, as shown in Figure 1. The input image is then normalized to some radius, r_n, about the scotoma site, to define the unity points. If the entire scotomal area is to be remapped then the origin in the input image plane must map to the edge of the scotoma on the output image plane. In general one may wish to remap some fraction, α, of the scotoma blocked region of the input image to unblocked regions of the output image. This defines the value of the transformation displacement, c, through the relation,

$$\sinh(c) = \alpha(r_s/r_n) \tag{6}$$

Thus two parameters determine the features of the remapping. The fraction of image recovery, α, and the normalization radius, r_n.

The transformation was tested using $\alpha = 0.8$. Figure 5 shows the result for the case $r_s/r_n = 0.5$, which means that the unity points lie outside of the scotoma.

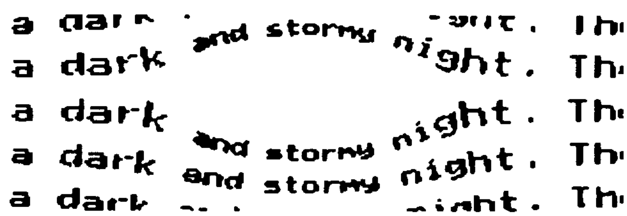

Figure 5. Conformal transformation, 80% and $r_s/r_n = 0.5$

Notice the way the characters flow around the scotomal area while retaining their effective shape and orientation. Also the process of displacement in the transformed domain results in a magnification. Figure 6 shows the remapping which results from a remapping with $r_s/r_n = 1.0$ and Figure 7 for $r_s/r_n = 1.5$. Note the increased magnification in each case.

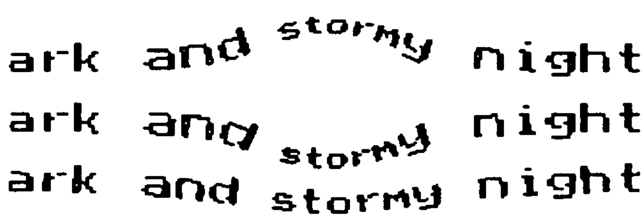

Figure 6. Conformal transformation, 80% and $r_s/r_n = 1.0$

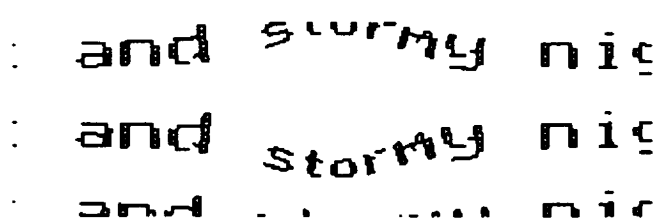

Figure 7. Conformal transformation, 80% and $r_s/r_n = 1.5$

The above examples assume that the fixation point of the observer is between lines of text. The effect of scanning the fixation point down across the lines of characters can be seen in Figure 8.

Figure 8. Effect of changing fixation point on warping (80%, $r_s/r_n = 0.5$)

Experimental study of the efficacy of this conformal transformation on reading enhancement is presently underway at the University of Houston, College of Optometry.

Hyperbolic Secant Transformation

Another transformation studied which has many of the desired features for the optimum transformation is defined by the following equations:

$$u = x \tag{7}$$

$$v = y + a(\text{sech}(bx)) \tag{8}$$

The effect of this transformation is such that the y space of the input plane is warped such that an approximately ellipsoidal void, similar to the conformal, is produced. Figure 9 shows how the test text is warped by this transformation.

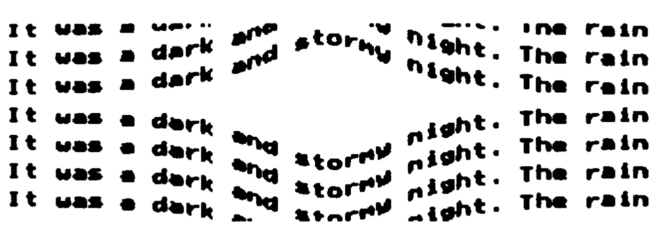

Figure 9. Secant transformation

The x space is unchanged. Thus the transformation pushes characters up but does not totally preserve the shape of letters. Unlike the confromal transformation there is no magnification associated with the warping, although this can be added. Variation of parameters allows for changing the roll-off of character lines and the vertical extent of the warping. Experimental studies of this transformation will be conducted at the College of Optometry of the University of Houston.

RETINITIS PIGMENTOSA TRANSFORMATIONS

Transformations for retinitis pigmentosa (rp) are required to remap the input plane into a smaller field of view centered on the fovea. This kind of transformation leads one to consider transformations which map a Cartesian system into the unit circle as suggested in Figure 10.

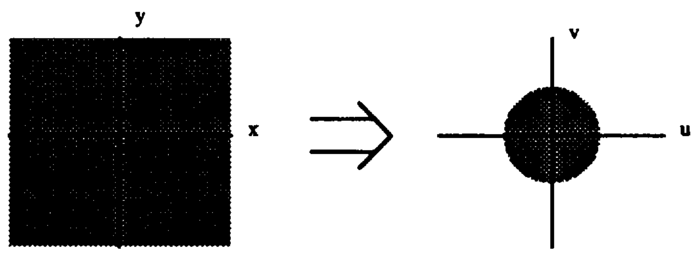

Figure 10. RP Transformation

During this project a radial transformation was studied which maps the entire world view into a circular region of variable radius. By variation of transform parameters it is possible to vary not only the radius of the output plane image but also the region of the input plane which appears relatively undistorted in the output plane. The transformation equations are given by:

$$r = [x^2 + y^2]^{1/2}$$

$$u = [1 - e^{-gr}]x/r \qquad (10)$$

$$v = [1 - e^{-gr}]y/r \qquad (11)$$

Figures 11, 12 and 13 show three samples of how the test text would appear following transformations given by Equations (10) and (11). Note that the entire field of Figure 1, without the scotoma overlay of course, is included in these image views. The original image has been compressed toward the edges in a circularly symmetric way.

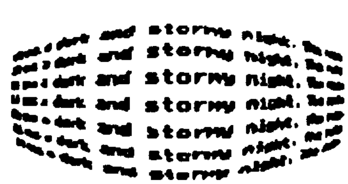

Figure 11. RP image for wide vision

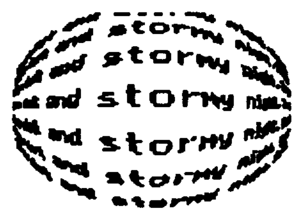

Figure 12. RP image for intermediate vision

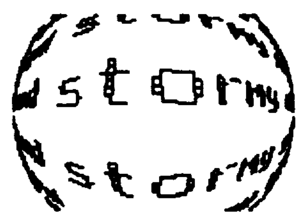

Figure 12. RP image for narrow vision

Although these show the effect of the remapping it should be noted that the real test of rp transformations lies in pattern recognition. The next phase of this work will be to implement transformations such as that presented here in a portable viewing system. This will study the efficacy of the system for enabling a person afflicted with rp to navigate, locate and retrieve objects. It will be necessary to be able to switch the rp correction system to provide various views such as for enhanced near-field vision or far-field vision.

IMPLEMENTATION CONSIDERATIONS

There were two issues explored during the project period with respect to implementation of a practical prosthesis using transformations. The motivation for study of this problem is the need for a portable, "heads up" system for practical use by a visually impaired individual. Although the Remapper is able to provide up to 30 frames per second, it consist of a large, heavy computer system with associated power supplies, monitors and so forth. The need is for a process by which a system could be head mounted, with associated video camera(s) and miniature display(s).

The first issue was to consider the construction of a sensor at the front end of the system which could perform part of the transformation in a hardware sense. The concept here is that variation of the size and physical geometry of the sensor pixel array could effect part of the required transformation[6]. Discussions were held with industrial representatives from Texas Instruments regarding the feasibility of building such a sensor. It appears that there are significant obstacles to such a device although similar sensors have been fabricated. This is an area for further study.

The second study regarded the possibility of implementation of an effective sensor using optical, distorted fiber bundle technology. In this case consideration was given to the use of a fiber-optic bundle which has been tapered. Such a device is commonly employed to provide a magnified or reduced image. In the case of a low vision prosthesis for maculopathy the die forming the original bundle would have a central hollow core as shown in Figure 14. When heated and drawn the core would normally reduce in proportion to the fiber bundle major radius. It may be possible however to draw down the heated bundle such that the core radius reduces to zero as the whole bundle is drawn. This would result in a structure similar to that in Figure 14. It is clear that if an image is presented to the reduced area surface it will be projected onto the larger radius surface with a void in the central region, where the scotoma would be located. In this way the image is warped around the scotoma.

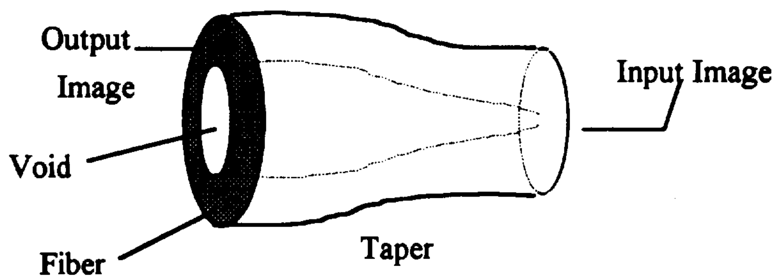

Figure 14. Taper glass fiber sensor

Whereas there is some technical reason to believe this process would work, the resulting remapping does not have good features with respect to providing a readable image. Further consideration will be given to this process and possible modifications to provide for useful transformations.

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3. Loshin, David S. and Richard D. Juday, "The Programmable Remapper: Clinical applications for patients with field defects," Optometry & Vision Science Vol. 66, No. 6, 389-395 (1989).
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