Visual Characteristics of Tanaka`s Relief Representation Method Through Observation of Eye Movement

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Abstract

Tanaka`s relief representation method is one of the most widely used hill shading techniques. The effectiveness of this method for representing concave and convex forms is verified through the use of an eye movement tracking technique. The results show that an observer was able to clearly distinguish between convex and concave forms.

Key words

Tanaka's method, relief representation, shaded contours, eye movements, concave, convex

1. Introduction

It is well known that the perception of concave-convex objects in relief shading representations changes with lighting direction (Imhof, 1982). This author has already examined eye movement patterns over shading relief models (Morita, 1999). In this study, the effectiveness of Tanaka's relief representation method is verified by detailed observations of eye movement.

2. Analysis

2-1 Eye movements measurement

Eye movement usually follows sequential fixation points on objects (Noton and Stark, 1970). Digital techniques have been developed to capture the location these points and the length time spent by the observer at each point. In one such technique, the subject wears glasses that incorporate a near-infrared spot projector. The projector places a point-of-interest (POI) on the surface of the eye. The location of this POI corresponds to the location of the fixation point on the object. When the observer moves to the next fixation point, the line-of-sight vector changes and the location of the POI moves to the corresponding position on the surface of the eye. These sequential movements are captured in a series of images by a sensor and hence, the location of each spot can be obtained through image processing. After calibration for each subject, it is possible to obtain a series of x-y data corresponding to the location of the fixation points. This technique allows us to determine how people observe maps and other images.

2-2 Tanaka's relief shading method

Tanaka proposed two relief representation methods, the orthographical relief method (Tanaka, 1932) and the relief contour method (Tanaka, 1939 in Japanese and 1950 in English). The second method was used for this experiment. Tanaka suggested that the object of cartographic relief representation is not to produce a photo-realistic representation but a simplified model. The principal of Tanaka`s method is shown in Figure 1. Namely, contour lines (2) are drawn on a medium gray color plate (1), (5). The contour lines are represented as white bands (6) when the light source is incident on the surface (3) and black bands (7) when the light source is obscured by the object. The thickness of the band depends on the angle between the light source vector (3) and the slope (4). Figure 2 shows an example of Tanaka`s principle for the representation of a bathymetric chart.

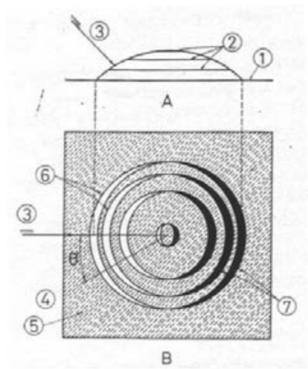

Fig.-1 Principle of Tanaka's Relief Contour Method (Tanaka, 1974)

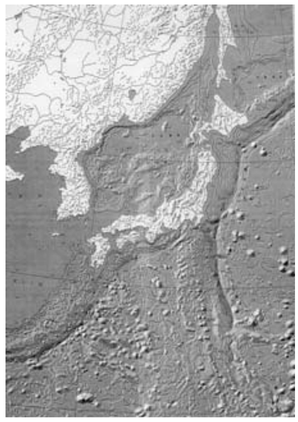

Fig.-2 Bathymetric Chart (generated according to Tanaka`s method), (Hydraugraphic Department, 1971)

2-3 Experiment

The objective of this experiment was to observe the reading and perception of shaded relief models generated according to Tanaka's relief representation method by analysis of eye movements and hence, evaluate its effectiveness for minimizing the occurrence of the concave-convex illusion. The concave-convex illusion is when convex features are interpreted as concave features and vice versa, e.g. a relief model of a mountain lit from a particular direction might be interpreted as a deep basin. This phenomenon may not be observable in all situations, particularly if the relief is well known to the observer.

2-3-1 Data Collection

The experiment was executed using a Konide shaped terrain model first generated by Tanaka (Tanaka, 1939)(Fig.-3). The test subject observed a series of images of the model displayed on a computer screen through an EMR data detector (NAC Co., Ltd., Tokyo). X-Y looking point data was captured every 1/30 second.

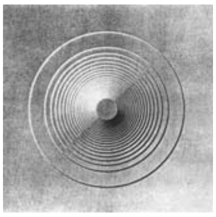

Fig.-3 Konide Shape Terrain Model generated by Tanaka

The images used were; (1) two images of single Konide shaped terrain models with shaded contours and external shape outlines, one lit from the upper left corner, the other from the lower right (2) small models composed of either concave or convex units displayed in a matrix, (3) a mixture of small concave and convex models displayed in a matrix.

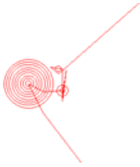

Fig.-4 Scan Paths (straight lines) and Duration Time (circles)

The observer was asked to determine the terrain forms (concave or convex) of the models. The observation time was 10 seconds per image.

2-3-2 Data analysis

2-3-2-1 Method

The x-y data for each image was plotted and the structure of the plot patterns compared. Sequential x-y point data were plotted as scan paths by connecting sequential data points and plotting circles, the diameter of which were proportional to the duration spent at each fixation point (Fig.-4). To avoid congestion of the plot diagrams, passage diagrams were plotted. Each passage diagram layer contained all fixation points observed within a certain radius from the point of interest. As soon as a point was observed outside of this radius, a new layer was initiated (Fig.-5). The radius is therefore a scan path length threshold. If the scan path length is less than the radius, the subject is deemed to be continually observing a particular fixation

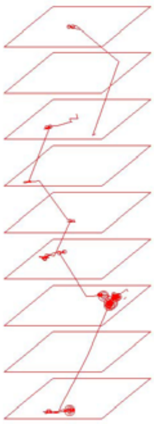

Fig.-5 Passage Diagram of Sequential Layers point or area. If it exceeds the radius, the subject is deemed to be observing a new fixation point. The radius was changed to discriminate between areas at the data analysis stage.

2-3-2-2 Results

Three subjects were used in the study. However, it was found that there was little variation between the subjects. For brevity therefore, the results for just one subject will be presented in this paper. Following data collection, it was found that all subjects were able to differentiate between the concave and convex forms generated according to Tanaka`s method.

(1) Single shaded relief models

For the single concave model, the subject first examined the diagonal edge between the light and dark regions, then observed the outline of the form, before examining details in the light and dark regions (Fig.-6 and Fig.-7). For the single convex model (Fig.-8 and Fig.-9), the subject examined the central circle, then examined the area alongside the diagonal edge between the light and dark regions, before observing the external outline and details in the dark region. In both cases, there was no trajectory repetition over the light and dark regions.

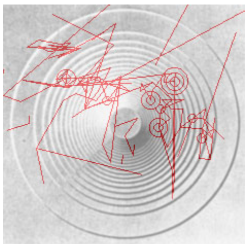

Fig.-6
Concave Model

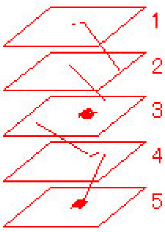

Fig.-7
Passage Diagram
(Concave)

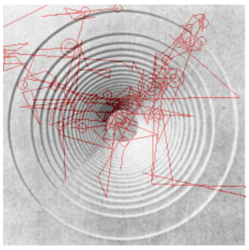

Fig.-8
Convex Model

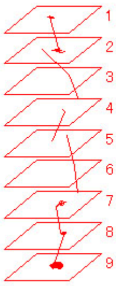

Fig.-9
Passage Diagram
(Convex)

(2) Concave and Convex Matrices

The subject searched a central circle and examined the external outline of the form before observing the next node in the concave matrix (Fig.-10 and Fig.-11). The direction of scan paths between nodes of the matrix was, at first, diagonal and then horizontal. The form located in the central grid was observed closely. Only half of the nodes in this image were examined. When the matrix was composed of convex forms,

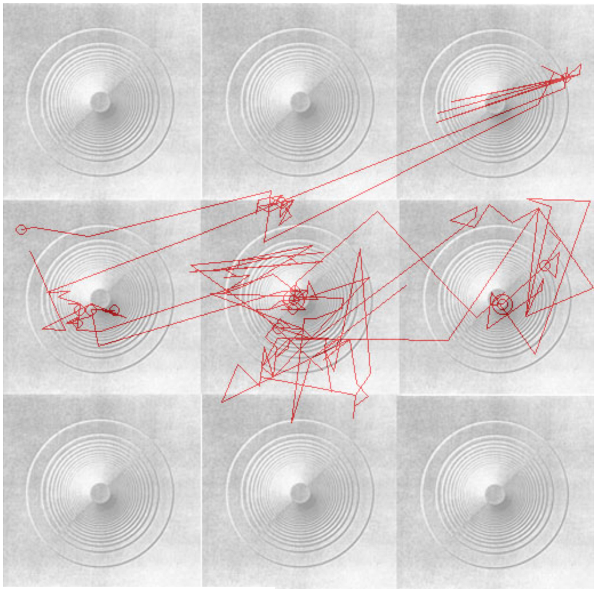

Fig.-10 Matrix Model
(Concave)

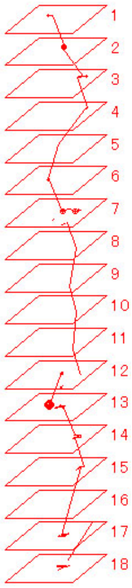

Fig.-11 Passage Diagram
(Matrix/Concave)

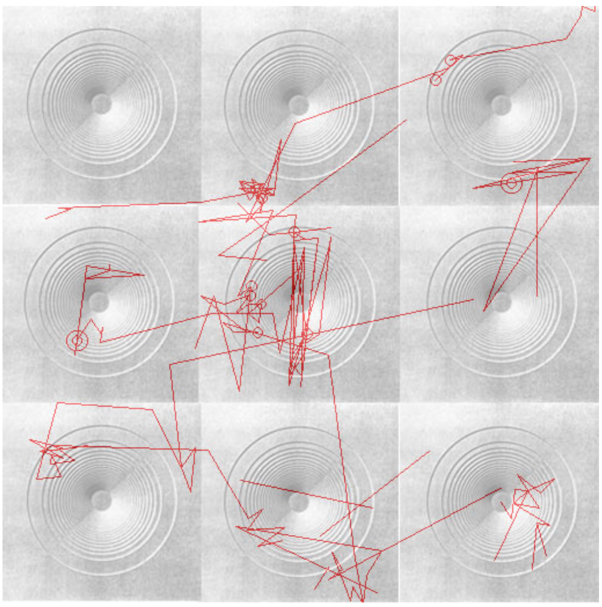

Fig.-12 Matrix Model
(Convex)

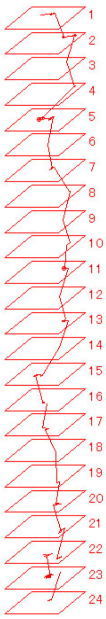

Fig.-13 Passage Diagram
(Matrix/Convex)

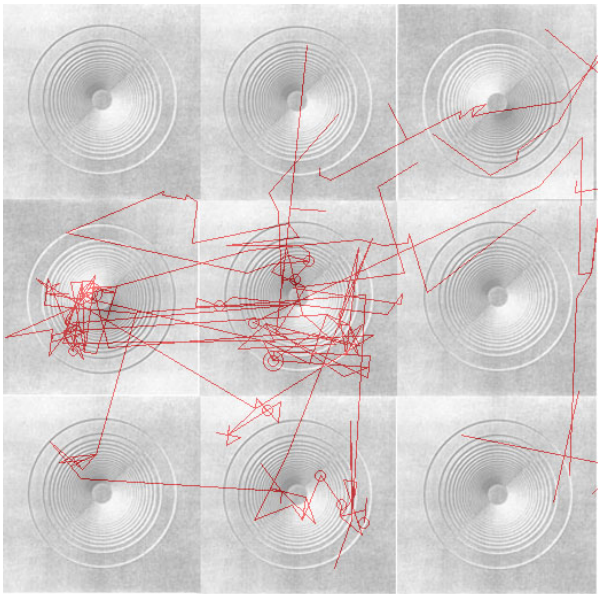

Fig.-18 Mixture Model
(Concave/Convex)

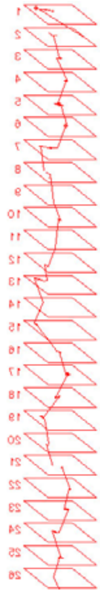

Fig.-19 Passage Diagram
(Mixture/Concave/Convex)

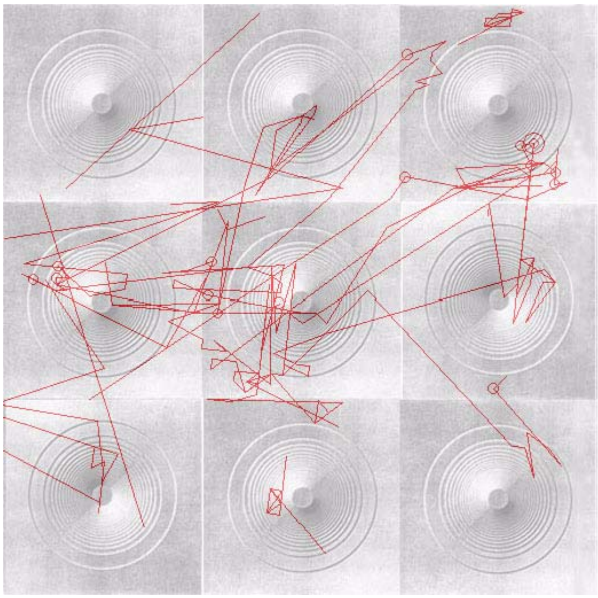

Fig.-20 Mixture Model
(Convex/Concave)

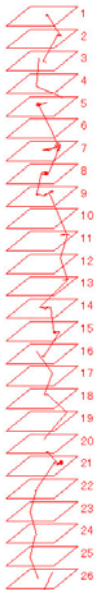

Fig.-21 Passage Diagram
(Mixture/Convex/Concave)

the subject observed a section of the brim before moving to the next node (Fig.-12 and Fig.-13). Almost all of the nodes in this image were examined. In both cases, the rectangle frames around some of the nodes were also observed.

(3) Mixed matrix

The first mixed matrix was composed of two concave and seven convex forms. The subject briefly examined the summits of the forms and then compared the concave and convex forms in the central area of the matrix (Fig.-14 and Fig.-15). The subject then examined the remainder of each node in a short period of time. The last matrix was composed of seven concave and two convex forms. The subject observed details of each node relatively closely (Fig.-16 and Fig.-17). There were many diagonal scan paths between nodes. The scan paths for this matrix represented the most dynamic and comprehensive set of observations.

3. General remarks

From these eye movement results, we can make the following general remarks:

(1) There were no large concentrations of eye movements in either the dark or light regions of the models. This may be because the utilization of a neutral gray as a background color reduces the contrast between the dark and light areas and hence there is no clear focus of attention. This is one of the characteristics of Tanaka’s method.

(2) The subject searched regions with the strongest contrast, representing the linear edges between dark and light regions. However, only a few fixation points were observed. This may be because the edges of the shapes were constructed using simple diagonal lines and the form of Konide is a simple circular shape, which does not need attentive observation with many fixation points.

(3) Determination between concave and convex shapes was a simple process. When the subject observed light regions above dark regions, the form was interpreted as a concave object and vice versa. As we have observed, it is not possible to observe an entire image at once. An understanding of the entire image is obtained from a set of individual visual units (eye movements).

(4) Searching of the matrices was a quick and smooth process, even though in some cases, sections of the matrix were not observed. This may be because once the characteristics of the forms had been identified, the shape-matching task was simplified and could be completed in a short period of time with the observer

drawing conclusions based only on initial observations.

4. Conclusion

These results have shown that Tanaka's contour shading method enables for a clear distinction between concave and convex objects in shaded relief models to be made. In this study, only simple shapes were studied. The process is made more difficult when a subject does not understand the overall form. In addition, the relationship between light and dark regions is subjective and dependent on how the observer first interprets the data. The relationship between visual units, entire images, form and scale, will form the subject of future research.

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