An Application Programme for Examination of Differential Linear and Nonlinear Magnification Methods and Magnification Interface Factors

Fion C. H. Lee and Alan H. S. Chan

Abstract—**The variable visual acuity nature of human vision across fovea and periphery prompted the need to study the differential magnification method as compared with the traditional linear magnification. With differential magnification, outer-area objects were magnified at a level higher than the inner-area objects. An application software was specially developed by the authors previously for the examination of differential linear and traditional linear magnification methods. This paper presents the enhancement of the application software and the addition of other magnification interface factors which worth further investigating. The newly designed differential nonlinear magnification method was featured and comparisons were made with the differential linear and the traditionally linear magnification methods.**

Index Terms—**Industrial inspection, magnification, software, visual search.**

I. Introduction

In order to study the magnification interfaces on visual inspection performance, an application programme specifically designed for producing the desired magnification effects and the visual inspection tasks were developed [1]. The magnification interface was a virtual magnifier, which was navigated with the use of a computer mouse, on a simulated visual inspection task generated by the programme. The magnifier acted like a simple bi-convex lens of an ordinary magnifying device, so that the objects and inter-objects spacing on the stimulus image were scaled proportionally. The magnification of objects was done on a pixel-by-pixel basis with equal scaling levels in the horizontal and vertical directions. Subjects moved the magnifier around the stimulus image with a mouse cursor so as to enhance visualization of some areas of focus of the stimulus image.

Two kinds of differential magnification methods namely differential linear magnification and differential nonlinear magnification were studied and compared with the traditional linear magnification. In the proposed differential magnification methods, the domain on the lens was divided into two cores of scenes described as the inner circle and the peripheral ring (Fig. 1). All the objects falling within the inner circle were scaled at a magnification level smaller than those falling within the peripheral ring. Particular attention was paid to ensure that images remained smooth and clear even at high magnification or high movement speed. The software was prepared using the latest version of C++ language and contained functional modules with which researchers were able to quickly prepare a customized program for a specific test. Besides the main effect of magnification method, this programme flexibly supported a range of variations in other magnification interface factors such as size, shape, and power of the magnifier, the target character and density of non-targets of the visual inspection task, and the visual and auditory cue provided to subjects. This application programme was used for generating stimuli, capturing subjects' responses, and exporting data to other statistical software for determination of search performance and evaluation of user interface factors.

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II. Supporting Hardware

A personal computer with a 2.8 GHz Pentium 4 processor and a 17" LCD monitor were used for stimulus presentation and response capture. A quality display adapter (NVIDIA GeForce FX 5700LE) was used for smooth performance of image magnification. Microsoft Visual C++ and Win32 API (Application Programming Interface) were used to develop the virtual magnifying lens and the simulated visual inspection task. Subjects had to use a computer mouse for controlling stimuli, navigating, and inputting responses of target position.

III. Stimulus Image

Fig. 2 shows the flow chart of the application programme. Each inspection trial started with the display of a pivot, which was a grey cross '' in the centre of the screen, for attracting subjects' attention to the upcoming stimuli. The grey cross comprised four (three grey and one black) bars extending from the centre to 0, 90, 180, and 270 deg orientations and the black bar moved in a clockwise direction. Subjects pressed the left button of the mouse when the bar appeared at the 90 deg orientation. A stimulus image and a magnifying lens then appeared, with the centre of the lens at

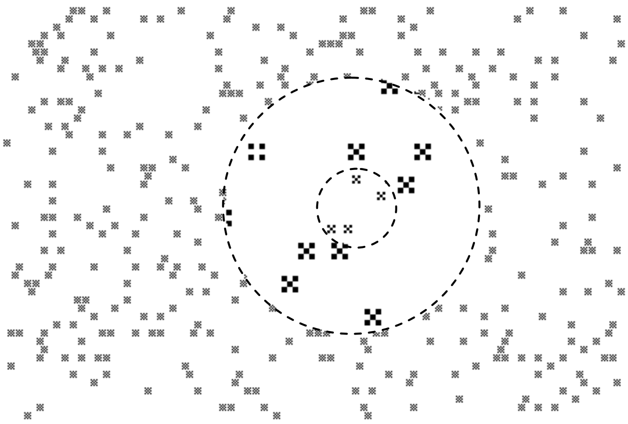


Fig. 1 An illustration of lens domain using a differential linear magnification method. The dotted lines were added to indicate the two cores of scenes.

the position of the computer mouse cursor, which disappeared as soon as the lens was shown. In the simulated visual inspection trial, a stimulus image with a horizontal and vertical dimension of 150 mm and 100 mm, respectively was placed centrally on the screen. Assuming a viewing distance of 500 mm, it subtended 17°4' and 11°25' to subjects' eyes in horizontal and vertical dimension respectively. The target (‘∷’, ‘▜’, ‘◘’, ‘✣’, or ‘▚’) and non-target (‘⁙’) were of 1 mm width, subtending 7' of arc in both horizontal and vertical dimensions, and their separation was again 7' of arc. The display was set in positive polarity with dark characters on a white background. The white background luminance was 150 cd/m^2 whereas the luminance of the visual objects was 5 cd/m^2. Each stimulus image contained at most one target which was positioned randomly on the image. This type of simulated stimulus image was found sensitive to subjects' performance in many previous laboratory studies [2], [3]. During an experiment, subjects had to move the magnifier with a mouse to locate the target whenever necessary, and click on the target position once it was found. The objects outside the magnifying lens were blurred so that subjects' attention was paid on the lens only. The blurred image provided subjects the information of object density and contextual information of objects around. Previous experience showed that for this type of search task, subjects were able to give correct responses and the search time formed a useful basic performance measure for comparison [4], [5]. In addition to the search time, the stopping time provided useful information on stopping policy that subjects adopted in the search [6], [7].

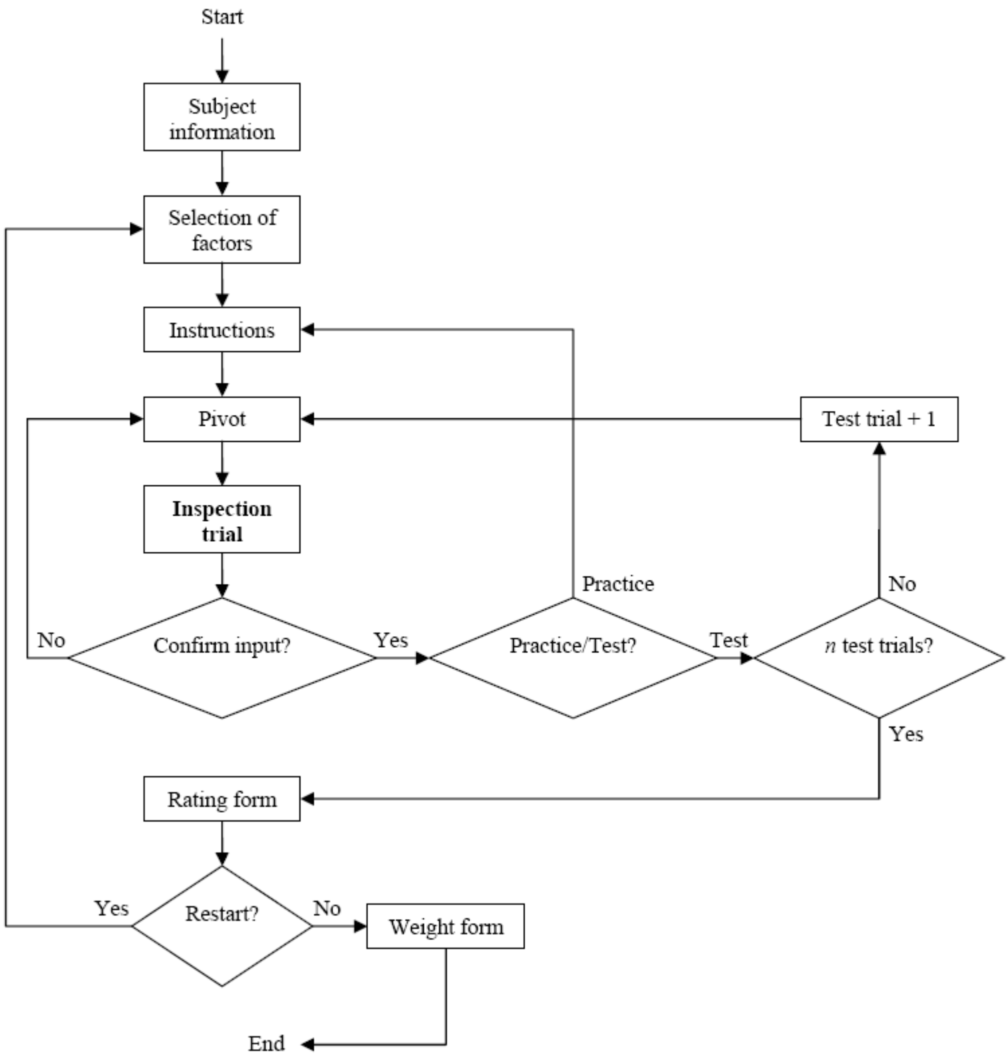


Fig. 2 Flow chart of application programme.

IV. Experimental Inputs

The application programme supported high level of flexibility for changes of different factors for accommodating various experimental design requirements.

A. Magnification Method

The options of linear, differential linear, and differential nonlinear magnification methods were provided. For the linear one, objects under the magnifying lens were scaled at a preset magnification power and the image on the lens was updated as the magnifier (or the computer mouse) moved. Fig. 3a shows the transformation function [8] for the linear magnification method which defined how an original stimulus image was mapped to a magnified image. The origin of the chart refers to the centre of the stimulus image under magnification along the x-axis. It also refers to the centre of the magnified image along the y-axis in the transformation function. A magnification function [8], which was the derivative of a transformation function, provided a profile of the magnification associated with the domain of stimulus image under consideration (Fig. 3b).

For the differential linear magnification, objects under the lens were not scaled at the same level of magnification power. For instance, if the inner area of the lens was set to be 1X (unmagnified) and the outer area was 2X, the magnifying window was analogous to a 2X hand-held magnifier with a hole drilled in the centre. The magnified images on the inner and outer area of the lens were refracted from the centre point of the stimulus domain under consideration. Fig. 3d and 3e show the transformation and magnification functions for the differential linear magnification and illustrate how the objects on the stimulus image were transformed to its magnified view and the magnification profile of the stimulus image. Objects on the stimulus image within point p_1 and p_4 were projected on the inner area of the magnifying lens (i.e. between point r_1 and r_2) at the magnification power of m_1 while objects beyond point p_2 and p_3 were projected on the outer area at the magnification power of m_2. As long as the magnification power at the inner area of the lens was smaller than that at the outer, the magnifying lens would contain all the objects from the domain under the lens. The advantage of this differential magnification method was that images appearing on the inner and outer areas of the magnifying lens were not distorted. However, continuation of image was sacrificed since duplication of stimulus image was found for objects within point p_1 and p_2, and within point p_3 and p_4.

The third magnification method was differential nonlinear. It also aimed to produce magnified image with outer-area objects magnified at a level higher than those inner-area objects. Compared the transformation function for the differential linear magnification (Fig. 3d) with that for the differential nonlinear magnification (Fig. 3g), the solid line representing a higher magnification (with slope = m_2) was shifted outward and connects to the solid line representing a lower magnification (with slope = m_1). The connecting point of the two lines was smoothened, such that stimulus objects between point p_2 and p_1, and between point p_3 and p_4 were magnified progressively from m_1 to m_2 (Fig. 3h). The corresponding magnified images were projected within point r_3 and r_4, and within point r_2 and r_1 of the magnifying lens. Such horizontal shift with progressive magnification at the connection eliminated the problems of image duplication and image discontinuation. However, image distortion was inevitable at the connecting area. With this unique method of differential nonlinear magnification, better space utilization was and more peripheral objects were presented under the magnifying lens, which then increased the effective size of the visual field and lead to an expected shortening of fault search time in inspection. The stimulus images and magnifying lenses with different magnification methods are shown in Fig. 3c, 3f, and 3i. It was worth noting that the numbers of stimulus objects enclosed within a linear and differential linear lens were the same while a differential nonlinear lens encompassed more stimulus objects. It was anticipated that for the differential nonlinear magnification a reduction of number of fixations would be resulted for completion of a search on the same stimulus area, and hence the search speed would be improved.

B. Magnifier Dimensions

The dimensional inputs of outer and inner areas were used to control the sizes of the magnifying lens and the inner area for the differential lens. If the linear magnification method was tested, only the dimension of outer area would be decided. The determination of size of outer area incorporated the consideration of subjects' visual lobe area so that objects falling within the lens were seen at a single glimpse. If the differential magnification methods of differential linear and differential nonlinear were selected, in addition to the determination of outer dimension, the inner dimension would also be imputed and ideally equivalent to the area of subjects' foveal vision, which constituted 1 to 2 degrees of their visual field.

C. Magnifier Shape

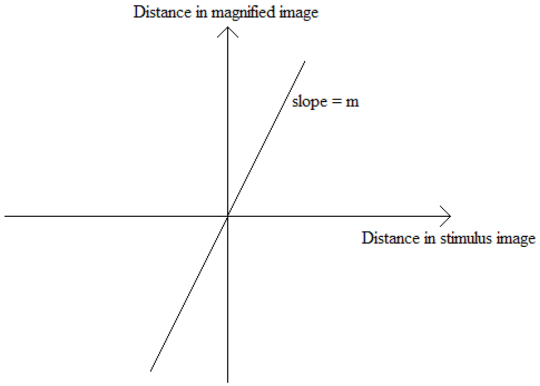
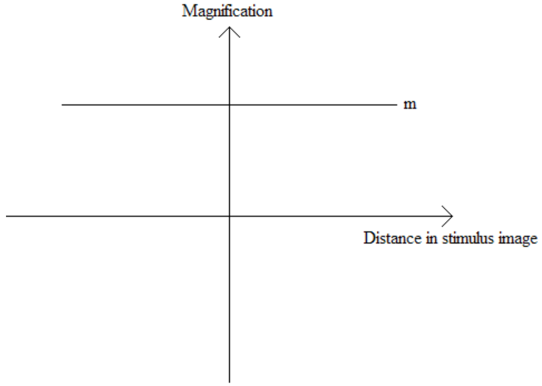
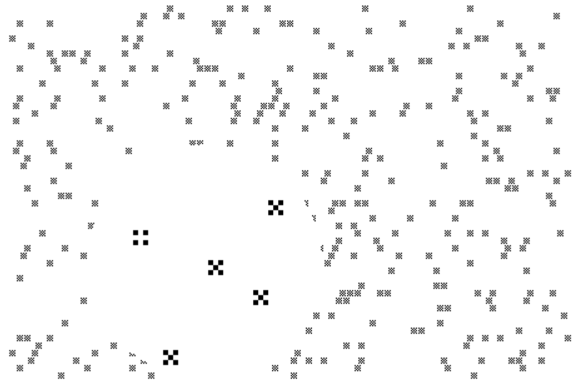
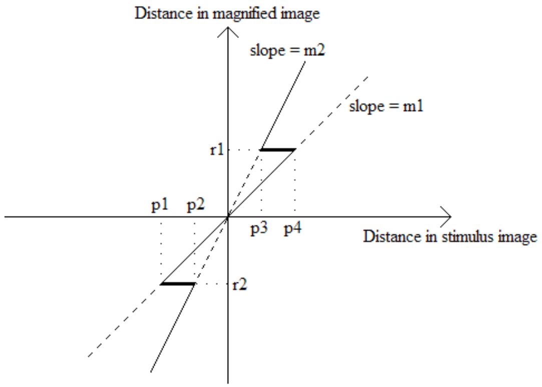
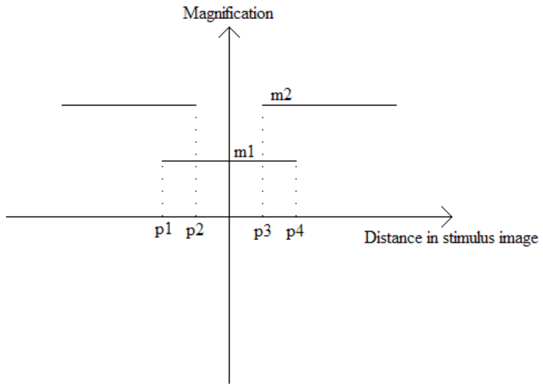
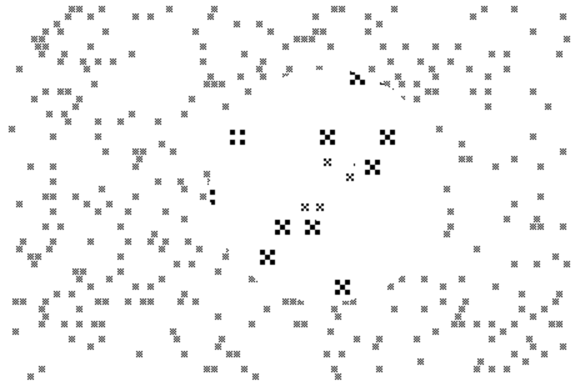
The shape of the lens was set by inputting the ratio of the horizontal axis to vertical axis of an ellipse, and the actual lengths of each major axis were calculated with the inputs of areas in the dimensions block. If the ratio of 1:1 was set, a circular magnifier would appear. For meaningful comparison of effectiveness of circular and elliptical magnifiers, the areas of the magnified windows were kept the same.

D. Magnification Power

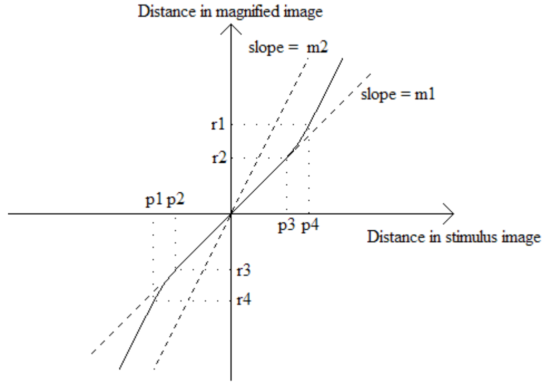
Intuitively, the number of objects presented decreased with increasing magnification within an area of view. For any industrial inspection tasks, there was a magnification level beyond which it became uneconomic to increase magnification further. Also, a too high magnification level was very difficult to manage practically and the problems of jagged edges of objects at a high magnification might occur. In this study, as the focus was on the understanding of the search process and not on the decision stage, relatively low magnification levels of 1X, 1.5X, 2X, 2.5X, 3X, 3.5X, and 4X were used.

E. Density of Background Objects

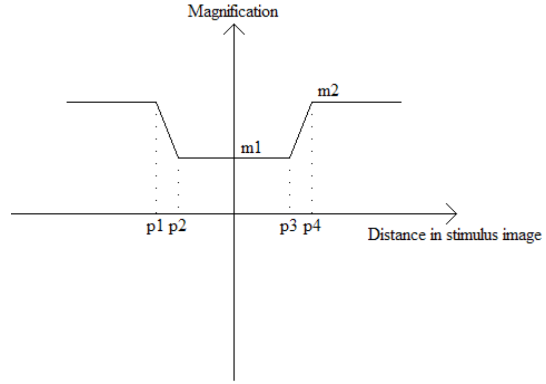
Visual search time was found to depend heavily on number of background characters [9] and object density [10]. For a constant area of search field, number of objects and object

	Transformation function	Magnification function	Magnified image
Linear	 (a)	 (b)	 (c)
	Distance in stimulus image = x Distance in magnified image = $T(x) = mx$ Magnification = $T'(x) = m$ Note: m was the magnification power of the linear lens.		
Differential linear	 (d)	 (e)	 (f)
	Distance in stimulus image = x Distance in magnified image = $T(x)$ $= m_1 x$ when $p_1 \le x \le p_4$ $= m_2 x$ when $x < p_2$ or $x > p_3$ Note: $m_1 < m_2$, m_1 and m_2 were the respective magnification powers at the inner ($r_2 \le T(x) \le r_1$) and outer ($T(x) < r_2$ and $T(x) > r_1$) areas of the differential linear lens.	Magnification = $T'(x)$ $= m_1$ when $p_1 \le x \le p_4$ $= m_2$ when $x < p_2$ or $x > p_3$	

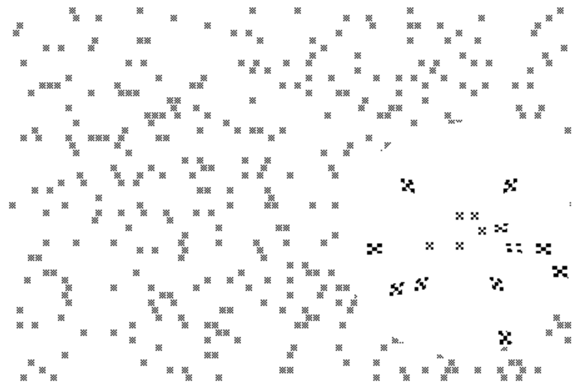
Differential nonlinear	



(g)



(h)



(i)

Distance in stimulus image = x

Distance in magnified image = $T(x) = m_1 x$ when $p_2 \le x \le p_3$

$$= m_1 x + \frac{m_2 - m_1}{p_1 - p_2}\left(\frac{x^2}{2} - p_2 x + \frac{p_2^{\,2}}{2}\right) \quad \text{when } p_1 \le x < p_2$$

$$= m_1 x + \frac{m_2 - m_1}{p_4 - p_3}\left(\frac{x^2}{2} - p_3 x + \frac{p_3^{\,2}}{2}\right) \quad \text{when } p_3 < x \le p_4$$

$$= m_2 x + \frac{(m_1 - m_2)(p_1 + p_2)}{2} \quad \text{when } x < p_1$$

$$= m_2 x + \frac{(m_1 - m_2)(p_3 + p_4)}{2} \quad \text{when } x > p_4$$

Magnification = $T'(x) = m_1$ when $p_2 \le x \le p_3$

$$= m_1 + \frac{m_2 - m_1}{p_1 - p_2}(x - p_2) \quad \text{when } p_1 \le x < p_2$$

$$= m_1 + \frac{m_2 - m_1}{p_4 - p_3}(x - p_3) \quad \text{when } p_3 < x \le p_4$$

$$= m_2 \quad \text{when } x < p_1 \text{ or } x > p_4$$

Note:

$m_1 < m_2$, m_1 and m_2 were the respective magnification powers at the inner ($r_3 \le T(x) \le r_2$) and outer ($T(x) < r_4$ and $T(x) > r_1$) areas of the differential nonlinear lens, while magnification power increased from m_1 to m_2 between the inner and outer areas ($r_2 < T(x) \le r_1$ and $r_3 > T(x) \ge r_4$).

Fig. 3 Transformation functions, magnification functions, and examples of magnified images for linear magnification method (a-c), differential linear magnification method (d-f), and differential nonlinear magnification method (g-i).

density were positively related in such a way that density decreased as number of objects decreased. In order to control the time and difficulty level of the simulated inspection task, the density of background non-targets on the stimulus image was varied by changing the number of non-targets appearing each time. Human vision inspection was found 80-90% effective in detecting the target [11], [12]. A pilot study was believed useful to determine the density of background objects so that subjects' response accuracies were within this range.

F. Targets and Nontargets

In visual search, task difficulty was found to increase with increased similarity of targets and non-targets [13]. Triesman [14] reported that early in the perceptual process, an object was analyzed into its features. Searching of target object from non-target objects was efficient when the target shared no common features with the non-targets. In contrast, when common features existed between the target and non-target objects, target detection became difficult and serial search to each object was required. The property of stimulus was found to influence visual selection, and the non-target saliency and target-nontarget similarity controlled the eye movements [15]. Therefore, a range of target types ('', '', '', '', and '') were available for selection for testing. The search display consisted of one target of a known type, which was embedded in a background of non-target ''s. Since the mean search time was found to decrease as the target surround density decreased [16], the target did not appear at the boundaries of the stimulus image in the simulated inspection task.

G. Cue

Two types of cue modality namely visual cue and auditory cue were provided for testing. The visual cue was a red '+' which appeared in the centre of the magnifying lens whereas the auditory cue was a pure tone of 22 KHz which was presented to both ears of the subject through a headphone. The cue was expected to direct subjects' attention to the visual inspection task and hence improving the search performance [17]. Nevertheless, the cue might interfere with the visual inspection task, though the level of interference was believed to be different when the types of cue modality were different. Other than the effect of cue modality on visual inspection, cue interval was another important factor needs to be studied. A more frequent cue occurrence might distract subjects' attention from the inspection task, whereas a less frequent one might show insignificant effect on orienting attention.

V. Experimental Outputs

Objective and subjective types of experimental data were collected and recorded in spreadsheets after each trial. Data was retained even the experiment was not completed or the application programme had run-time errors.

A. Objective Measures

Three kinds of objective measures were captured. They were response speed, response accuracy, and search scan-paths. The time elapsed from the onset of the stimulus to successful detection of response made by the subject was taken as the inspection time for that trial. The accuracy referred to the correctness of input location to the true target location. Regarding the search scan-paths, the movement of the magnifying lens was recorded as pairs of coordinates, with the coordinates of the bottom left corner of the stimulus image set to be (0,0) and that of the top right corner to be (150, 100). One unit in this coordinate system was equivalent to a distance of 1 mm (7' of arc) in the search field in both horizontal and vertical directions. The function "OnMouseMove" in Microsoft Visual C++ was employed for monitoring the position of the lens. Owing to the complexity of computation in the application programme, the sampling rate of recording the coordinate pairs was ten per second for linear and differential linear magnification and that was four per second for differential nonlinear magnification. The capture of movement and positions of magnifying lens in the inspection task enabled the examination of visual search scan-paths used by the subjects without the need for eye movement tracking equipment. Such information was valuable in understanding the eye-hand coordination when using a virtual magnifier.

B. Subjective Measures

In order to understand user perceptions about the effectiveness and user friendliness of the magnification methods and magnifier shapes, the NASA Task Load Index (TLX) [18] was used and programmed as a subjective means for mental workload evaluation. The TLX was calculated based on six factors, namely mental demands, physical demands, temporal demands, own performance, effort, and frustration. There were two parts in the evaluation of workload: weights and ratings. Subjects were asked to fill out the ratings form on screen after testing of each condition, to indicate the level of demand for each factor. At the end of the whole test, subjects were asked to fill out the weights form to evaluate the importance of each factor to the overall workload of a specific task (i.e. visual inspection). The TLX score was a weighted average of the six ratings. The score ranged from 0 to 100, with the least subjective workload at 0 and the highest subjective workload at 100. The TLX scores obtained under different conditions were useful for evaluation of subjective workload, in addition to the objective performance measures of inspection time and response accuracy.

VI. Conclusion

This application software featured a menu-driven interface for experimenters to set different experimental conditions. Throughout the experiment, subjects only needed to use a computer mouse to give responses about the location of the target and make subjective evaluation of task workload. The analyses of subjective evaluation together with the objective performance measures were useful to examine the main and interaction effects of different magnification interface factors, with an attempt to provide important information for the optimum design of video magnifier for industrial inspection task.

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