Basing Non-Linear Displays on Vector Map Formats

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One approach to increasing the area coverage of small-screen map displays is to exploit the 'elasticity' of the electronic display through use of non-linear scaling. Although resolution is necessarily lost in areas of smaller scale, bitmap images lose important information when re-scaled. This can render features unrecognisable and text unreadable. Vector maps are more tolerant to non-linear scaling because critical position information found in vertices of lines is distorted without being lost. Examples of non-linear scaling are presented to demonstrate the effect on bitmap and vector images. Ongoing research examining the user performance benefits of non-linear displays is also described.

KEY WORDS

1. Maps/Charts. 2. Display. 3. Design.

1. INTRODUCTION. Due to the physical space limitations in aircraft and other vehicle applications, electronic display size is necessarily restricted to fit within the confines of the given workspace. Coupled with the low pixel density of electronic displays, the display of large areas is not possible without sacrificing resolution and detail. This hinders the operator's ability to view larger areas of space without switching between map scales or viewing orientation. Unfortunately, switching views does not lend itself well to the maintenance of a clear mental image of the surrounding area or entities existing within it (Henry and Hudson, 1991; Tolsby, 1993). It is logical to assume this also adds to the physical and cognitive workload required of the operator.

Since display space is limited (as is the cognitive capacity of the operator), it seems wise to exploit the 'elasticity' of the electronic display itself. That is, we should not always force ourselves into using the electronic display to mimic a paper map product directly; rather, we should take advantage of its inherent ability to be magnified, de-magnified, stretched, or otherwise distorted through software. This can allow a single display to represent one or more areas of interest at some specified level of detail (i.e. scale), while simultaneously displaying 'less important' areas in lesser detail. Referred to here as non-linear scaling, this technique is sometimes called 'non-linear magnification', 'distortion-oriented display' or 'detail plus context display'.

The following sections of this paper will describe non-linear scaling in more detail (along with a summary of some historical applications), discuss the merits of using

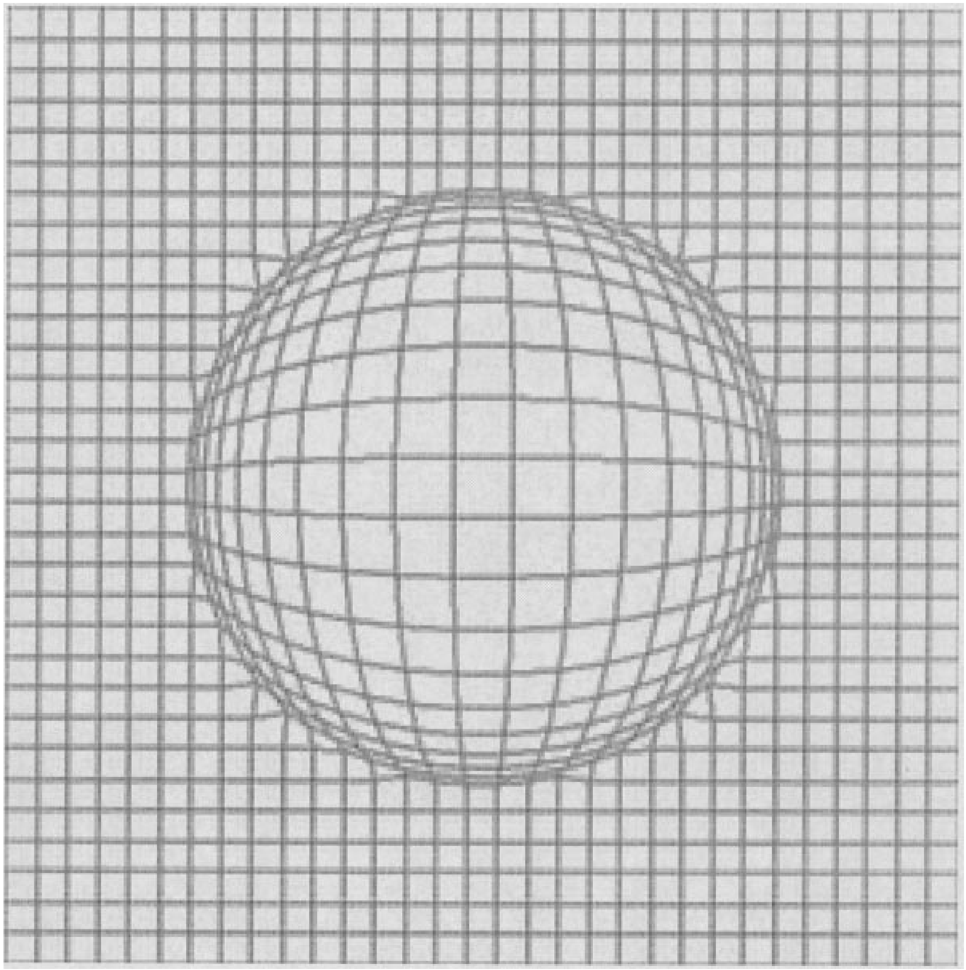

Figure 1. A rectangular grid transformed using a fisheye distortion. (Source: Keahey, 1998).

vector-based image formats, and provide a brief description of human factors research presently underway to examine possible performance benefits of non-linear displays.

2. NON-LINEAR SCALING.

Non-linear scaling is a software-driven process that transforms a standard map image into one containing more than one scale or magnification level. Designated areas within the map can be maintained at a desired level of scale, while other areas are de-magnified. By doing so, exact spatial relationships between the inside and outside of the area of interest may be sacrificed, but a high degree of context is preserved. The importance of this is, although information in surrounding areas may not be of immediate concern, it can aid the operator in more fully understanding the current situation, and possibly lead to better prediction of future events.

Several types of non-linear transforms are possible. Leung and Apperley (1994) provide a comprehensive guide to classifying various non-linear scaling techniques

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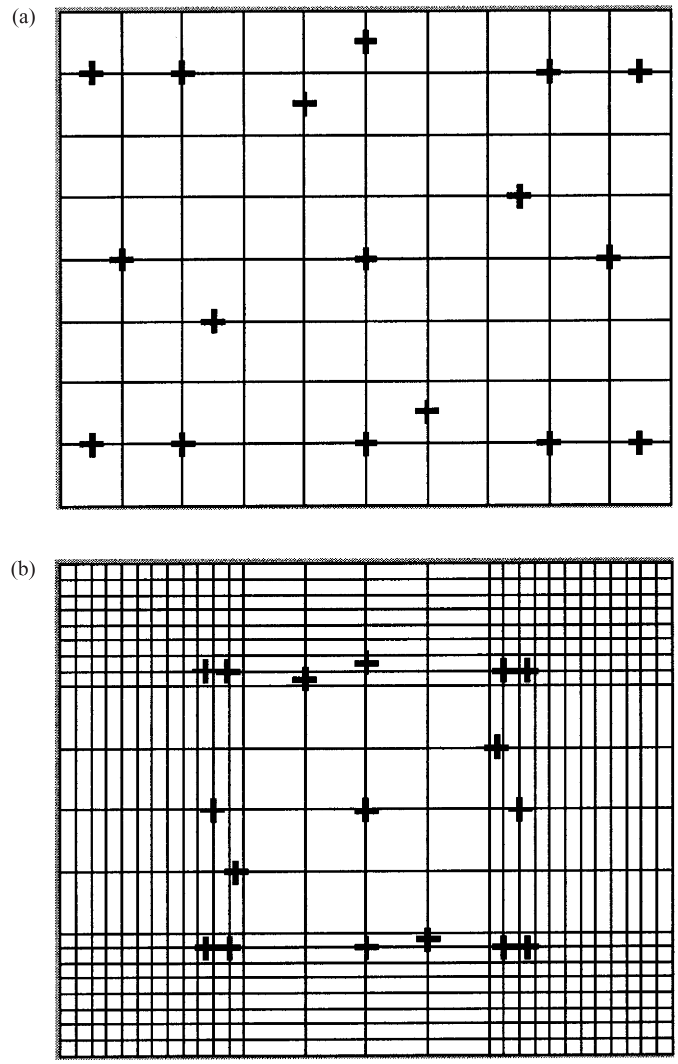

Figure 2. (a) Standard linear grid. (b) Example bifocal grid (at 0.25 × demagnification outside the area of responsibility). The crosshairs are located in the same relative positions as in (a).

along with example functions used to generate them. Depending on the intended application, one type of distortion (or scaling) may be better suited than another. Two major types of transformation functions exist: continuous and non-continuous.

The fisheye display (Figure 1) is an example of a continuous transformation function where a selected display area is magnified, but none of it is completely in focus. Non-continuous functions, however, generate at least one distinct area of focus. Outlying areas (depending on the characteristics of the transformation function) are de-magnified, and can either be in or out of focus.

In addition, transformations can be performed using either Cartesian or polar coordinates. A variety of non-linear transformations can be applied to maps that distort the point-to-point distances to reduce map size, but retain the spatial gestalt

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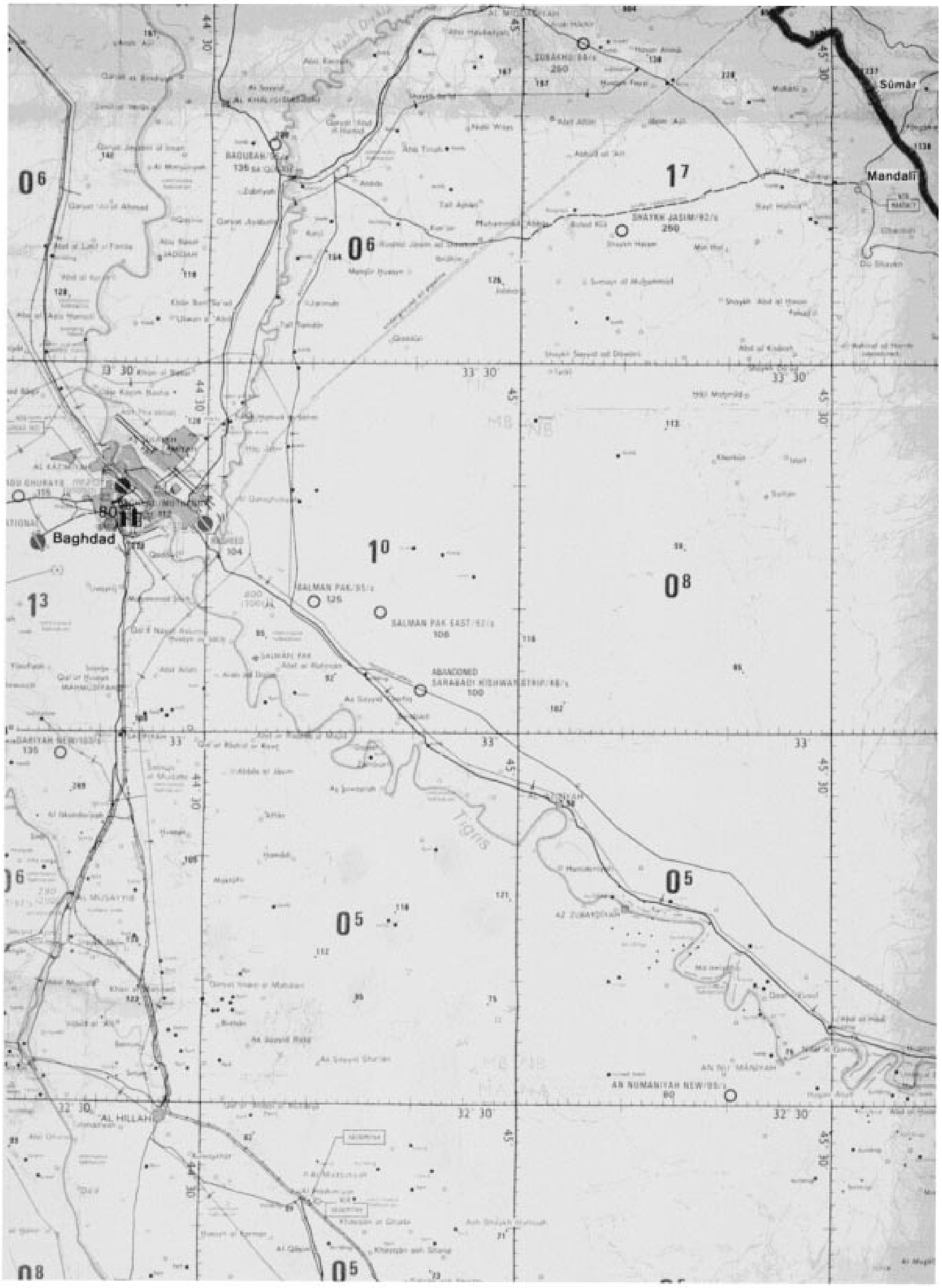

Figure 3(a). An original 1:67K scale map of Baghdad, Iraq area.

of the situation. An example Cartesian transformation is the bifocal display (Spence and Apperley, 1982), which differentially magnifies the map centre and surround. For illustration purposes, a linear grid (Figure 2a) is distorted using the bifocal approach as shown in Figure 2b.

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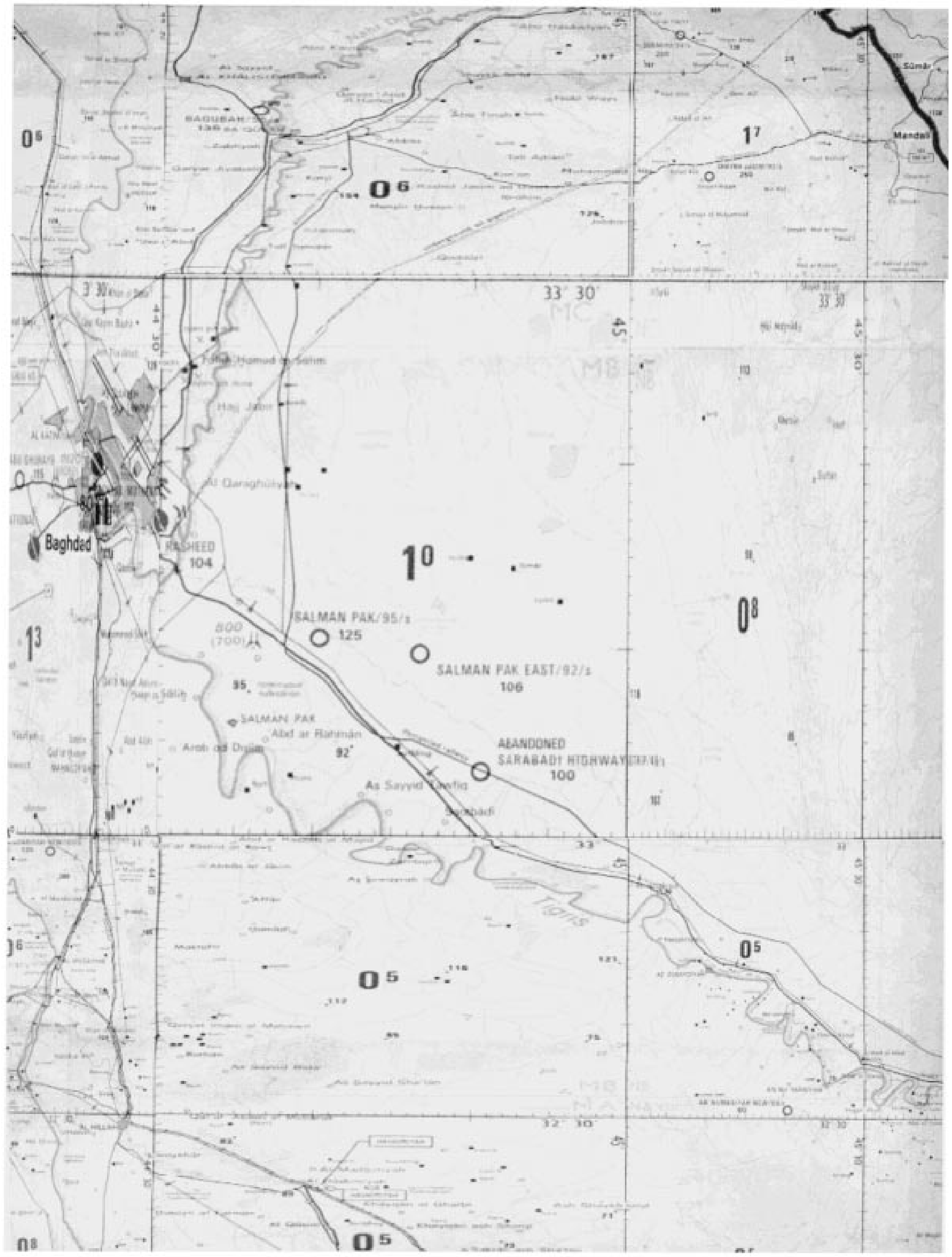

Figure 3(b). Mockup of the map from (a) after undergoing a Cartesian demagnification (0.5 ×) in areas outside of grid location 1°.

Another mock-up of the bifocal distortion was applied to a 1:67 K map (Figure 3a) with the resulting transformed map shown in Figure 3b. Notice that the transformed map is quite a bit smaller in size, but retains the spatial relationships in a distorted form.

An alternative compression algorithm similar to the fisheye concept uses polar coordinates to modify the map based on location relative to the map centre (Figure 4). This map has a linear centre and a surround collapsed about it. Although distances are distorted, the polar transform preserves directional relationships between the centre and surround (Mountjoy and Marshak, 1998). The authors refer to this as the 'modified fisheye' distortion.

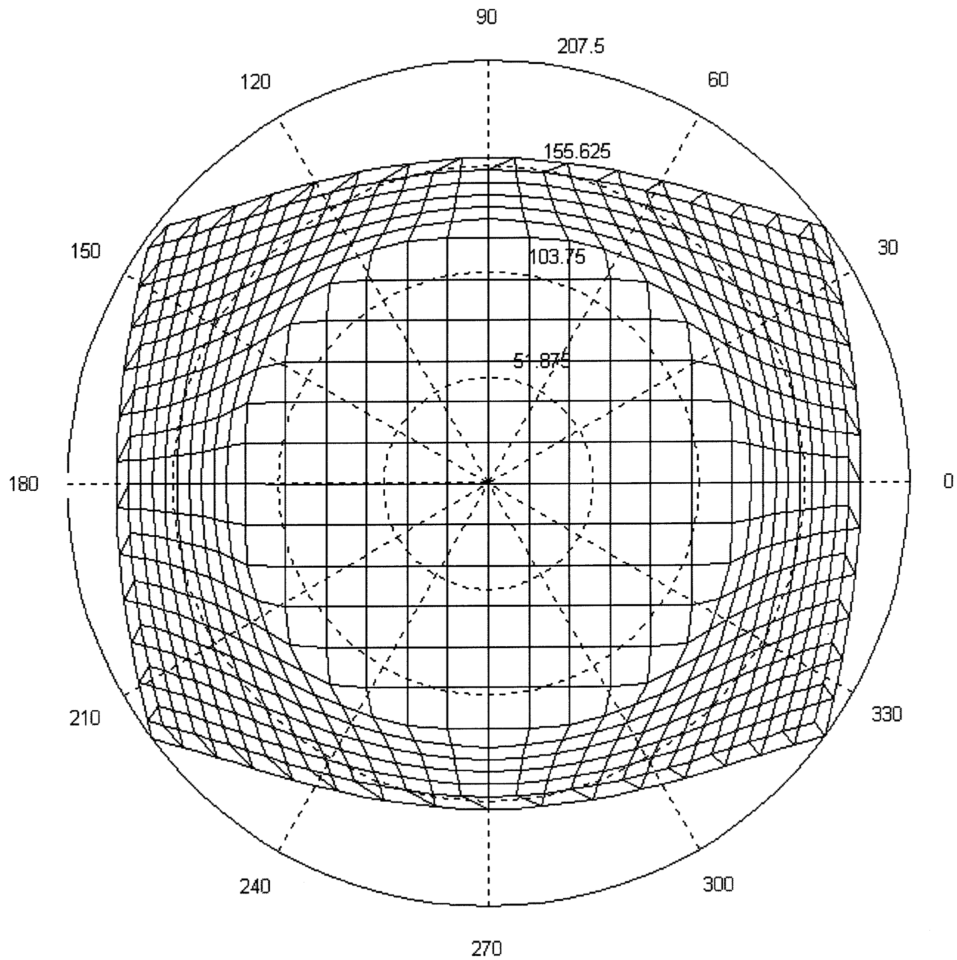

Figure 4. Example grid transformed into polar coordinates outside a designated linear area (also known as the modified fisheye distortion).

2.1. *Historical Research.* The non-linear display concept has been discussed since at least the mid-1980s when George Furnas (1986) presented a fisheye view approach to displaying large volumes of text in computer programs and databases. According to Furnas, the fundamental motivation was to provide a balance between local detail and global context (e.g. understanding a single line of code versus understanding its purpose in the function in which it resides). Results of his experiments were indeed successful, for when tested on a code navigation-related task, subjects performed better (i.e. provided more correct responses) when using fisheye views than the standard 'flat' view.

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Sarkar and Brown (1994) took Furnas' fisheye concept in another direction, applying it to graphical structures. This work focused primarily on the development of efficient algorithms for generating and displaying fisheye views, and no results of their own performance testing were presented. However, other researchers have carried out performance tests in this area. For example, Schaffer *et al*. (1996) found favourable results when using a fisheye display to navigate hierarchically clustered networks such as a telephone network. Subjects were asked to find breaks in lines, and to 'repair' the network by re-routing lines to other nodes in the network. The fisheye display was tested against a full zoom approach where subjects could alternately zoom-in and zoom-out to locate problems. Subjects took less time to perform the task and required less navigation (zooming-in and zooming-out) when using the fisheye display. Schaffer et al. suggest that better performance was due to the greater context provided in the fisheye views.

2.2. *Small-Screen Map Display Application*. Over recent years, non-linear scaling has been explored in a variety of domains including Geographical Information Systems (GIS), workspace awareness, large graph viewing, and hierarchical network navigation (Anderson, Smith and Zhang, 1996; Gutwin, Greenberg and Roseman, 1996; Sarkar and Brown, 1992; Schaffer *et al*., 1996). Until now, the possible benefits of the technique when applied in a mapping domain have not been formally tested. The authors feel that non-linear scaling can enhance user performance on map-based monitoring tasks, especially when targeted towards small-screen applications where display space is at a premium. There are at least two major challenges in determining the potential success of a non-linear map display: image generation, and perceptual compatibility. Each of these issues is individually addressed in the following two sections.

2.3. *Bitmap Versus Vector Image Formats*. One of the challenges in creating non-linear displays is to limit the information loss that can occur at scale transition areas. Although the data contained in the transition areas and beyond are theoretically not of prime importance to the operator, it is desirable to maintain a clear image in these areas to make the transition as seamless as possible, and to maximise information transfer (i.e. to keep the information in these areas visually accessible if necessary). Present thinking is that vector graphics will be much more tolerant of the compression process and will generate more readable information in the periphery.

This supposition was tested with a series of simple abstract images of a line grid generated using the MATLAB mathematics program. A 640×480 grid (Figure 5) was drawn using a vector-based algorithm and served as the standard for judging the effects of bitmap-based non-linear transformations when compared with vector-based transformations.

This grid underwent two different modified fisheye non-linear transformations. The first (Figure 6a) is a result of treating Figure 5 as a bitmap and using a 'dumb' algorithm to collapse the periphery of the grid. Parameters for this collapse were a linear centre space of 0·4 the vertical dimension with the periphery compressed by a factor of 0·3. The resulting transformation subtends 284 h $\times$ 242 v pixels, which is only 22 percent of the original 640 h $\times$ 480 v pixel grid. The second transformation (Figure 6b) uses the same compression parameters as the first, but the compression was applied to the vertices of the grid and the vectors were redrawn with the

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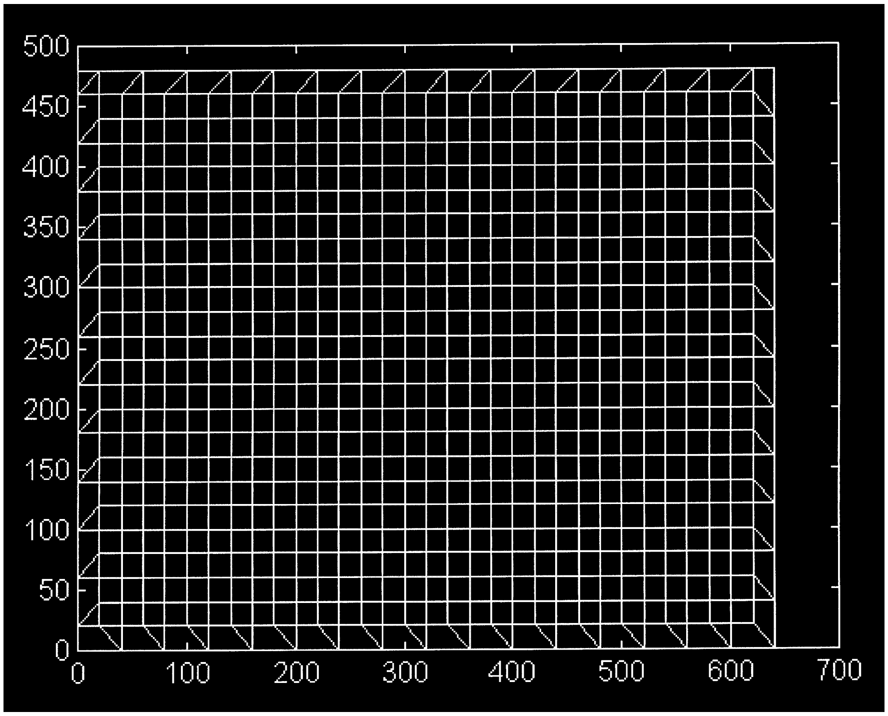

Figure 5. A full-sized vector-based grid used as a baseline for comparing the effects on non-linear transformations similar to the one used to generate Figure 4.

compressed vertices. The resulting vector-based transform subtends 252 h × 216 v pixels, which is slightly smaller than the first.

The bitmap-based transformation breaks up the lines, reflecting the information loss from pixels overwriting pixels. Each pixel is transformed in the bitmap, taking considerable computing to modify all 270 336 pixels outside the linear zone. Smarter transformations that try to maintain line integrity would further complicate the task. The vector-based transform has jagged lines (expected of those drawn at the lower resolution of the compressed periphery), but the lines are continuous and look much better than the bitmap compressed lines. Besides the better appearance, the vector-based transform required manipulating only the 700 or so vertices outside the linear centre area. This saving in computational burden is a 386:1 reduction in the floating point mathematics required for each point!

A further benefit of vector formats is the ability to choose which features are shown on the map at any one time, thereby providing the ability to de-clutter the display by removing non-essential information. This is a valuable capability, especially when viewing areas outside the non-linear focus area where the scale is potentially much smaller. Given the advantages of vector formats, this appears to be the logical choice for non-linear scaling applications.

2.4. *Perception and Performance Research.* Although past non-linear scaling research has been promising from the human performance standpoint, no research has focused on tactical mapping applications. Further, most non-linear scaling literature has reported on the efficiency of various computational algorithms, while

(a)

(b)

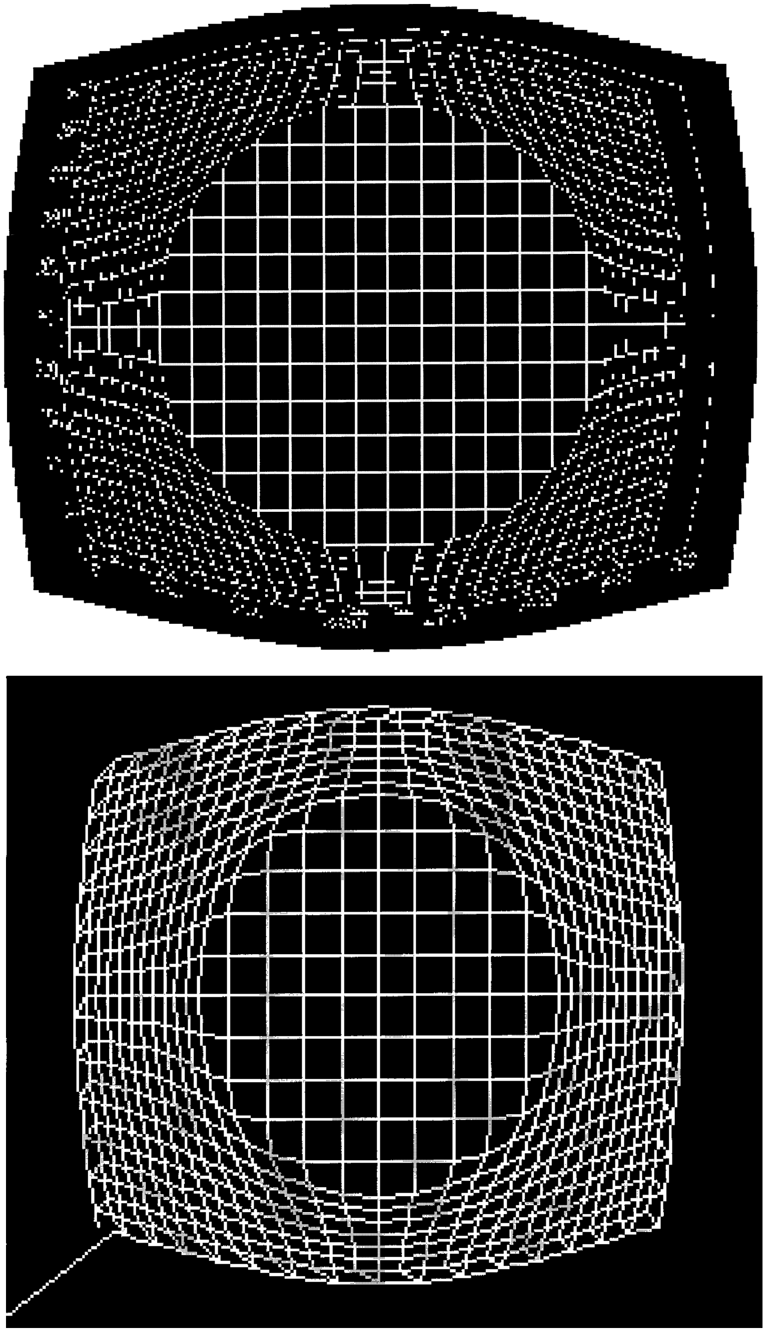

Figure 6. (a) Bitmap-based transformation of the grid in Figure 5, containing the same number of vertices. (b) Vector-based compression of the same grid.

user performance appears to be of secondary importance. Clearly, if this display technique is ever to be implemented in any tactical system, the human perception and performance costs/benefits should be well known. Three experiments are planned to examine these issues.

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The first perception experiment (nearing completion) is designed to determine the effects of non-linear scaling on mileage estimation (see Mountjoy and Marshak, 1999). Specifically, this first study is an attempt to understand the impact of non-linear scaling on mileage estimation accuracy, response time and perceived workload. Three different scale combinations (two bifocal, and one modified fisheye) are being tested versus standard (linear) display counterparts to examine the relationship between the magnitude of scale change and their associated errors. Also a perception study, the second experiment will examine the effects of non-linear scaling on mileage *and* heading estimation. For this experiment, the scale change will be fixed across conditions, but two distortion types (polar and Cartesian) will be tested (based upon the results from the first study) versus a standard display.

Results from the two perception studies will be used to specify the theoretical 'best' combination of non-linear map generation parameters. The resultant non-linear map will be incorporated in a tactical monitoring experiment, comparing its performance against a standard *pan and zoom* map display. Participants will be asked to monitor a simulated battle, and will be queried regarding unit positions and headings. In addition, participants will be required to monitor the 'battle' constantly and detect local force imbalances that would indicate either offensive opportunities or the necessity for defensive actions. It is expected that use of the non-linear display will result in faster detection of force imbalances, a decrease in perceived workload, and a decrease in the number of interface manipulations required.

3. SUMMARY. Along with the current efforts to digitise the battlefield comes the need to display a greater amount of information on relatively small electronic display surfaces. Current approaches in military command and control systems often require users to switch back and forth between various scale maps to see both detail and context. This methodology can fail to provide clear mental images of the battle-space, and important information may be missed if not within the current view. Non-linear scaling has the ability to transform a standard electronic display into a 'flexible' image space where selected areas are viewed in detail, and areas of secondary importance are simultaneously included, although in smaller scale, as context.

It is proposed that vector-mapping formats are appropriate for non-linear scaling transformations, since transition areas remain clearer, and should result in less information loss than bitmap images. With proper implementation (through a good understanding of human perception effects), the authors suggest that non-linear maps can be beneficial to small-screen monitoring tasks by enhancing the user's ability to view larger areas of real estate at any one time, decreasing perceived workload, and requiring less interface manipulation than traditional displays.

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