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Human-Machine Interface Considerations for Inclusion of an Electronic Map in a Mission System

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HUMAN-MACHINE INTERFACE CONSIDERATIONS FOR INCLUSION OF AN ELECTRONIC MAP IN A MISSION SYSTEM

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Summary

A key component of any future integrated mission system will be an electronic map or chart. It provides the user with a context in which to assess sensor and tactical information. The usefulness of the information provided by the map will depend on its visibility and interpretability. Poor information display will increase workload and processing time or lead to inaccurate interpretation. Over the past few years, we have been investigating some of the factors that can affect the processing of information on electronic charts. The factors that we have looked at include the selection of colours and symbols and more recently the integration of radar with an electronic chart. The results of our research have led us to an improved understanding of the factors that must be considered in the design of displays incorporating an electronic map or chart. However, considerably more research is required if we are to provide system developers with detailed guidelines for designing suitable interfaces for mission management systems incorporating electronic maps.

Introduction

Maps have always been an important component of a military command and control system. They provide the commander with vital information about the nature and spatial layout of the environment. They have also been used to integrate other sources of information and for planning. The paper map with its overlays was the centre of the mission management system of the past. The commander still wants to be presented with an integrated picture of the information available. Thus, an electronically generated map with electronically generated overlays will most likely be the primary interface between the commander and the mission management system of the future.

Future mission management systems will 'integrate many different sources of information. These sources will vary in the timeliness and reliability of their information as well as in the form that the information takes Computer systems, not operators, will filter and integrate this information and present it on one or more electronic displays With paper maps, dynamic information is added manually. This is time consuming, but it gives the commander and/or his aids ultimate control over what is included. It also limits what can be added or removed in a timely manner. With the computer, sets of data can be added or removed with the click of a button. However, it can be more difficult to precisely tailor the information presented. This makes it very easy to present too much information or not enough. Since what is critical changes from moment to moment, critical data will always be accompanied by less critical data. Moreover, the system will be constantly updating the display as the environment and the tactical picture changes. For these reasons, the design of the interface becomes very important. The display must present an integrated picture of the current situation while insuring that potentially critical events are clearly visible.

Ultimately, the success of a given interface depends on a good understanding of the requirements of the user and the skill of the designer. Underlying both of these is a good understanding of the factors that affect the visibility and interpretability of information in complex displays Considerable research has been carried out on the perceptual factors affecting the processing of visual information. This research has been and continues to be incorporated into guidelines for the design of visual interfaces for electronic displays (e.g. Boff & Lincoln, 1988; Mullet & Sano, 1995). However, most of the research is based on the use of relatively simple stimulus situations. Additional research using more complex display configurations is required to improve our understanding of the factors affecting the visibility and interpretability of information under a wide range of tasks. Over the past few years, we have been examining ways of improving the display of information on electronic charts through the appropriate use of colour and symbols. More recently we have begun to examine the usefulness of integrating sensor data such as radar returns with an electronic chart. Our research has employed relatively simple as

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well as more complex display configurations The results of these studies have led us to an improved understanding of the factors that must be considered in the design of displays incorporating an electronic map or chart. However, as will be outlined below, considerable research is still required In the interim, the available information provides useful guidance

Symbolic overlays

Symbols are used to present well-defined information in a succinct form. Depending on the requirements, they may vary from relatively simple geometric shapes to complex drawings. In some cases, symbols are stylised versions of familiar objects. Thus on charts, wrecks are symbolized as a sinking ship, anchorage areas by an anchor, and a tall chimney as a chimney stack with smoke coming out of it The primary aim in developing these types of symbols is to convey information to the user as directly as possible and to reduce the amount of memorization required. In other cases, the complex symbols are composed of multiple components with each component providing a piece of information about the object being symbolised. The problem with many of these symbols is that they were designed for use with paper maps that are large, have high resolution, and are often not used in real time.

Today, maps are presented on electronic displays that are relatively small and have relatively low resolution Thus, it can be difficult to accurately reproduce these complex symbols without making them overly large. Moreover, the increase in available information means that the number of symbols is increasing to deal with new categories of information. Finally, the information is usually processed by a user who is also carrying out other tasks simultaneously. This makes it important that critical information, such as the location of hostile air targets, can be processed quickly. These differences between paper and electronic maps leads to a requirement for simpler symbols that are as conspicuous as possible while still conveying the necessary information.

Much basic research has been carried out on the factors affecting the discriminability of symbols during visual search (Quinlan & Humphrey, 1987; Treisman & Gelade, 1980, Treisman and Gormican, 1988; Wolfe 1994). Most of these studies find that symbols that differ substantively along certain dimensions are easily discriminated. In these studies, two (or more) symbols are considered to be easily discriminated if the time to detect one of the symbols (the target) does not change substantially as the number of instances of the remaining symbols (the distractors) increases. Under distractors which differ from the target symbol in pre-defined ways such as colour, orientation, or size However, the results do provide information about what kinds of dimensions humans use in discriminating amongst different objects and some of the factors that are likely to affect conspicuity. For example, the more features that a target symbol has in common with the distractor symbols in the field, the longer it will take to detect it (Quinlan & Humphrey, 1987). Discriminability is also reduced as the target and symbol become more similar along a given dimension such as colour or size (Wolfe, Cave & Franzel, 1989).

The influence of these studies can be seen in the development of symbol sets for electronic displays. For example, the International Hydrographic Office (IHO) standard for colours and symbols (International Hydrographic Office, 1995) includes a set of simplified symbols for critical objects such as buoys and beacons These symbols are simple colour coded geometric shapes that are more easily recognised and discriminated from each other on an electronic display than the traditional symbols used on paper charts A field study comparing the simplified and traditional symbols indicated that the mariners found the simplified symbols more visible than the traditional symbols (Kaufmann & Eaton, 1994). Observation of operational systems tends to confirm this finding (McFadden, 1998) Although the simplified symbols may give somewhat less information and require relearning, they allow a busy mariner to quickly grasp the location of critical objects in a complex display

Another example is the symbology in NATO STANAG 4420 (1990). In that symbol set, the overall shape indicates whether the target is surface, subsurface, or air; its colour indicates whether it is friendly, unknown, or hostile, and details within the symbol provide additional information about the type of target. The aim is to make the critical differences among this large set of symbols clearly differentiable as well as providing more detailed information on closer examination. Moreover, this type of coding should allow the user to more easily group together similar types of targets or information and distinguish different types of targets or information For example, a quick glance at the display should allow the user to pick out the hostile targets from friendly targets. However, if additional information about the platform is required, it will be necessary to examine the symbol in more detail

An extensive evaluation of the NATO STANAG 4420 symbol set found that the symbols were superior to the Naval Tactical Data System (NTDS) symbol set which does not make use of colour coding or filled geometric symbol set indicated some problems. Recognition of the icons that provided more detailed information about the underlying object (e.g. carrier versus destroyer) varied across the symbol set. Not surprisingly, icons that the operators were familiar with or "looked like" the real object tended to be recognised more consistently (Kirkpatrick et al, 1992) These results demonstrate the difficulty of developing a successful symbol set as the amount of information that needs to be encoded increases.

The success of these symbol sets indicates the relevance of basic research to more complex displays. However, the basic research does not provide all the answers As stated above, how different a target is from its distractors along a given dimension is an important determinant of conspicuity or visibility (Wolfe, Cave & Franzel, 1989). However, it is less clear what the critical separation is for any particular dimension. Most of the basic research has concentrated on threshold differences. The primary exception is in the area of colour. Based on the work to date, colours should be easily discriminable under most conditions if they are separated by more than 20 ΔE* units[1] (Carter, 1989). The discriminability of colours closer than that will depend on factors such as symbol size, spatial and temporal separation of the colour coded objects, and colours being compared (Kaufmann and McFadden, 1989).

Recent experiments in colour discrimination suggest that even this recommendation may not be sufficient. For example, Bauer, Jolicoeur, and Cowan (1996) showed that a target colour that is clearly discriminable (as defined above) from a second colour, can become less discriminable if a third colour, equidistant from the target colour as the first, is presented at the same time. Under these conditions, it was found that the discriminability of the target colour depended on whether it was linearly separable from the two distractor colours. A target colour is linearly separable from the remaining colours in a set if a straight line can be drawn between the target colour and all the other colours when they are plotted in an arbitrary colour space such as the Commission Internationale de L'Éclairage (CIE) 1976 Uniform Colour Space (UCS) Figure 1 shows a set of six colours plotted in the CIE 1976 UCS chromaticity diagram, that are at least 30 ΔE* units apart from each other. In a display containing all six colours, the ones indicated by the asterisks would be easily discriminated because they are linearly separable (as indicated by the dashed lines) from the remaining five colours. The colours indicated by the triangles would be less easily discriminated. Fortunately, linear separability is only likely to be a concern if the number of colours being used is relatively large or the range of available colours is limited. Currently, this phenomenon has been most carefully studied for colour However, the results of one unpublished study (Bose, 1991) suggest that a similar situation may exist with other dimensions. In that study, detection of a square in a field composed of three different sizes of squares was more difficult when the target square was the middle sized square than when it was the largest or smallest square.

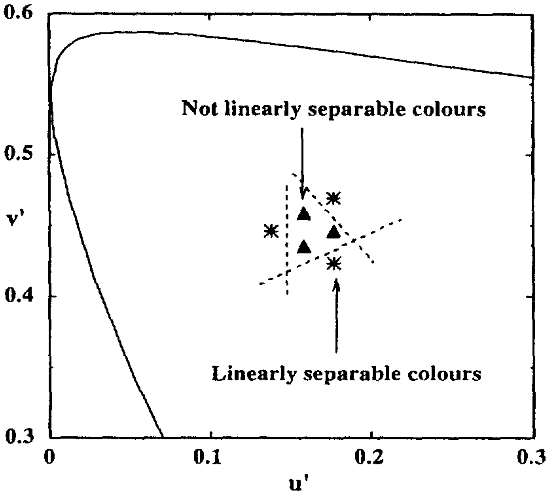

Figure 1: An example of a set of colours in which some members of the set would be linearly separable and the others would not (taken from Bauer and McFadden, 1997).

Visibility is not the only factor that needs to be considered in designing symbols. Simplified symbols while potentially more visible have no inherent meaning Thus, the user must learn to associate a meaning with each symbol in order to "recognise" it. With a small number of symbols this is not a problem. In large-scale military systems, the number of potential symbols is likely to be very large. The use of "meaningful" symbols reduces memory load, but it does not necessarily ensure good discrimination. Thus, it would be useful to determine the dimensions that are used to discriminate symbols that do not vary along predefined dimensions. This information could then be used to design symbols that are both meaningful and discriminable.

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[1] The unit ΔE* is a measure of the discriminability of two objects on the basis of the differences in their hue, saturation, and brightness relative to a specified white source. A description of ΔE* and the formula for calculating it can be found in Wyszecki and Stiles (1982).

A few studies have looked at the dimensions used by people in discriminating amongst sets of arbitrary symbols. One of the most relevant was by Geiselman, Landee & Christen (1982). Using data collected in a similarity-rating task, they concluded that people used overall shape in discriminating amongst a set of military symbols. In our own lab, we have investigated the underlying dimensions used to differentiate amongst symbols in different types of tasks. In the initial study (McFadden, Bauer & McManus, 1997), it was found that the dimensions used varied as a function of the task that the participants were doing. Participants were asked to rank the similarity of each pair of symbols in the set. Next, they carried out a visual search task in which they counted the number of instances of a target symbol in a background composed of multiple instances of a second symbol in the set The tasks were carried out for each pair of symbols Separate multidimensional analyses were carried out on the similarity rankings and the response times from the visual search task. A one-dimensional solution was sufficient to describe the similarity ratings. Participants differentiated the symbols on the basis of their overall or dominant geometric shape In the visual search task, a two and possibly three-dimensional solution accounted for the data better. The dimensions tended to correspond to vertical extent, diagonal extent, and height to width ratio. Thus, a large and a small square were rated as relatively similar, but were highly discriminable in the search task. These results suggest that people are using the same dimensions with more complex symbols that they used with simpler symbols, at least for search tasks. It also suggests that the dimensions that determine the visibility of a set of symbols may differ from what the designer intended

Overall, the use of existing perceptual data and guidelines can result in the design of symbols that can be clearly discriminated or will group together. However, our current knowledge is inadequate if it is necessary to encode many different categories of objects that vary along multiple dimensions To develop guidelines for these situations, we need a better understanding of the impact of context on the visibility of symbols and patterns.

The special problem of colour

Of all of the coding dimensions that can be used on an electronic display, the one that has been studied the most thoroughly is colour. There are multiple guidelines and even books on the use and specification of colour (for example Davidoff, 1987; Durrett, 1992; Kaufmann & McFadden, 1989; Widdel & Post, 1992) coding information, but no well defined rules about how to use it. Beyond using red for danger, colours have no intuitive meanings that are agreed upon by every one Thus, there have been a large number of studies looking at the detection, discrimination, identification, and use of colour on electronic displays. However, even with all this information, additional issues present themselves when dealing with the use of colours on electronic maps.

Nearly all of the available guidelines deal with the use of colour against a uniform background. Such guidelines are potentially inadequate for designing displays that present multiple sources of information. In paper maps, colour is used primarily to code large areas in order to separate out different types of land mass and different depths of water. On tactical and other type of graphical displays, colour is used to code different types of information such as friendly versus enemy forces or different types of data. If the two are combined, it becomes necessary to ensure that the colours within each set are discriminable from each other and from members of the other set. Insuring discriminability can be difficult because the appearance of a small area such as a symbol or a track is affected by the colour of the background against which it is presented (Wyszecki, 1986). If a symbol is always presented against the same background, its appearance will be unchanged. However, in a dynamic display with a multicoloured background, the appearance of identically colour coded objects may differ depending on the background against which they are presented.

This phenomenon is known as chromatic induction Typically, the effect is for the colour of the foreground area to move away from the colour of the background area where the defined colours of the objects are their location in the CIE colour space. Thus, a yellow object presented against a red background appears greener and the same object presented against a green background appears redder than when it is presented against a grey background. More generally, a saturated colour presented against a desaturated background appears more saturated and a desaturated colour presented against a saturated background appears more desaturated (Ware and Cowan, 1982) There is a similar generalisation, known as simultaneous contrast, about the effect of a luminance difference between the foreground and background. A brighter background makes a foreground colour appear darker and a darker background makes it appear lighter relative to its appearance against a background of similar luminance (Wyszecki, 1986). These results lead to the recommendation that the background colours on a display should always be less saturated than the should be relatively similar in saturation and brightness (McFadden, 1992)

Ambient illumination also affects colour appearance. If the number of colours is small and the background uniform, the use of a small number of highly saturated, easily discriminated colours will mitigate the effects of ambient illumination (Laycock, 1984). Even with complex displays, the effect is not substantial unless the illumination is highly coloured such as in the use of red lighting or it is very high such as in a cockpit or on the bridge of a ship. In the first case, the red ambient illumination will reduce the discriminability of red and orange or red and pink objects (Kaufmann, 1990). Thus, if it is possible that the display will be used in red lighting, colour coding should be adjusted commensurately. In high ambient illumination, the brightness of both the background and foreground colours on the display is increased. Since perceived contrast is a function of the ratio of the foreground to the background, perceived contrast is reduced. Also, the addition of the white light to the coloured area results in desaturation. Colours become washed out. This can be compensated for by making use of chromatic induction and simultaneous contrast If the foreground objects are presented against a relatively bright, desaturated background, the apparent contrast is increased. Thus, under high ambient illumination it is preferable to use a relatively light background (Cowan, 1993).

As stated at the beginning, displays for mission management systems are constantly evolving as the tactical picture and the environmental conditions change. The designer cannot predict exactly what the display will look like at any given moment in time or the environmental conditions under which it will be used Thus, it is important that the potential range of variation in the display be taken into consideration and compensated for so that the appearance of colours and symbols remains stable. With colour coding we have a relatively good understanding of the factors affecting colour appearance and can compensate for them. Similar factors may be operating with other coding dimensions. As stated in the previous section, we need to study the impact of context on visibility.

Beyond graphical overlays – incorporating sensor data

For some tasks, it is useful for an operator to have access to both the processed and/or historical information such as would be found on an electronic map or chart and the underlying data collected by one or more sensor systems. It is now possible to combine the output of these different types of data on a single display. However, even with good interface design there will be a limit to the amount of information that can be presented on a single display. Thus, an important design consideration is when and under what conditions is it more effective and efficient to use multiple displays or multiple windows. We have recently begun to address this question in our research program by looking at the usefulness of integrating radar with an electronic chart rather than presenting the two on separate displays.

The potential advantages of combining sensor data with an electronic chart with a symbolic overlay are reduced processing time and increased confidence in the validity of the symbolic information derived from the sensor data and that the sensor data corresponds to known features. On the other hand, the addition of radar data to an already complex display has the potential of increasing processing time, masking or reducing the visibility of some of the symbolic data, and distorting or masking critical aspects of the radar data or the underlying map. Beyond these issues is the question of how to display the data. Possibilities include simplifying either the map or the sensor data or attempting to maintain the same level of detail available on the separate displays.

Integrating sensor and map data introduces a level of complexity that is well beyond the current guidelines for electronic display design. As indicated above, even small increases in complexity can have a major effect on the discrimination of colours and symbols. In order to develop design guidelines for such complex displays, it is necessary to investigate design parameters using stimulus configurations that more closely approximate the complexity of actual systems. Our initial study examined the participants' ability to extract useful navigation information from a single display in which radar data was superimposed on a chart as compared to two separate, side-by-side displays, one of which displayed the radar data and the other, the matching electronic chart. The radar return was mapped onto a single colour and luminance and appeared as a transparent overlay on the chart in the overlay condition and on the plain background in the separate display condition.

In the study, participants viewed static displays of either the overlay or the chart and the radar on separate displays Presentation of the images was preceded by statements about the displays that participants had to evaluate, as either "true" or "false", as rapidly and accurately as they could The participant read each statement, decided what information was needed to evaluate it, and then looked for that information on the display or displays One third of the questions could be answered using the radar image alone, one-third the chart alone and the remaining required both the chart and radar image. Participants included both university students and experienced mariners. Details of the method can be found in Donderi (1999).

Both the time spent viewing the display(s) and accuracy were measured. The results are shown in Table 1. Overall there was no significant difference in accuracy between the overlay and the separate displays for either group. The time spent viewing the images was significantly shorter on the overlay display for both types of participants. As well, a measure of efficiency, percent correct/image viewing time, was computed. It also favoured the overlay display over the separate displays. There were no significant differences between the two groups of participants in either viewing time or percent correct although there were minor differences in the results for specific conditions between the two groups. The students were slightly more accurate on the separate displays for chart questions but were more accurate for radar questions on the overlay display. The latter suggests that the context helped the interpretation of the radar information for naive participants.

Table 1. Percent correct and viewing time as a function of type of display, statement, and participant

Performance measure	Statement type	Group	Display type	
			Separate	Overlay
Percent Correct	Radar	Mariners	69.4	68.0
		Students	68.4	75.0
	Chart	Mariners	73.8	71.4
		Students	73.2	68.4
	R + C	Mariners	71.6	69.4
		Students	68.7	70.1
Viewing time (sec.)	Radar	Mariners	15.5	12.3
		Students	11.3	10.5
	Chart	Mariners	16.4	15.9
		Students	12.8	12.3
	R + C	Mariners	17.1	15.5
		Students	14.5	12.7

A second group of participants ranked the complexity of the chart, the radar images, and the overlay, and the similarity between each radar image and the corresponding chart. In general, the rated complexity of additive linear function of the rated the radar and chart information and that increased complexity does not always lead to degradation in performance. However, it should be remembered that this was an initial study using a limited number of images, static displays, and only one type of display concept. Participants were asked about the presence or absence of information on the display. The results may not apply to other conditions or tasks. Further research is required to explore performance under other tasks and on dynamic displays.

More generally, the results indicate that this sort of approach can yield useful information about the viability of display concepts. It is possible to develop complex display configurations with realistic tasks that can be carried out successfully by relatively naive participants. The mariners commented that they found the displays realistic and the questions posed reasonable. Moreover, using this type of tasks and display, predictions arising from more basic studies on shape and colour discrimination can be tested.

Conclusions

Over the past few years, designers have made an increasing effort to make use of data and models from perceptual research in interface design. Currently most of the data and models are based on relatively simple stimulus configurations. While the data adequately define basic perceptual processes, they do not necessarily account for perception of information in more complex displays. In order to provide designers with useful guidelines for designing mission management displays incorporating digital maps, it is necessary to understand the additional factors affecting performance in complex display configurations. As a result of our involvement in the development of standards for colours and symbols on electronic charts, we have been investigating different methods for improving the operator's ability to process information on complex displays. Based on our investigations, it appears clear that context affects the speed and accuracy with which an operator can detect information on a display. The research on the effects of chromatic induction and linear separability on colour discrimination indicates that the effects of context can be both positive and negative at the perceptual level. The results from the radar study suggest that it is not only important to provide the context, but also to facilitate the integration of different sources of information. Our next step will be to more broadly specify the effects of context on both perceptual and cognitive processing.

continuing support of our research through the provision of software and sample charts and radar images.

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