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FUNCTIONAL CHARACTERISTICS OF TACTICAL DISPLAYS

A.P. GABB

COMBAT SYSTEMS INTEGRATION GROUP
WEAPONS SYSTEMS RESEARCH LABORATORY

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TECHNICAL REPORT
WSRL-TR-7/88

FUNCTIONAL CHARACTERISTICS OF TACTICAL DISPLAYS

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SUMMARY (U)

Computer generated tactical displays are now commonly used in presenting information to aid decision making in military command and control systems. Similar displays are used in non-military applications, particularly air traffic control. This paper examines the functional characteristics of such displays with the aims of establishing a baseline from which decisions of equipment selection and more importantly functional design or specification may be made.

Author's address:
Combat Systems Integration Group
Weapons Systems Research Laboratory
PO Box 1700, Salisbury
South Australia

Requests to: Head, Combat Systems Integration Group

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GLOSSARY OF ABBREVIATIONS

GOP	Global Operations Plot
HTDS	Helicopter Tactical Data System
LLSA	Limiting Lines of Subsurface Approach
LOP	Local Operations Plot
LPD	Labelled Plan Display
MHWS	Minehunting Weapon System
NCDS	Naval Combat Data System
PED	Position Entry Device
PDI	Positional Data Item
RAN	Royal Australian Navy
XOR	Exclusive Or

1. INTRODUCTION

1.1 General

Computer generated tactical displays are now commonly used in presenting information to aid decision making in military command and control systems. Similar displays are used in non-military applications, particularly air traffic control. Typically, these displays are analogous to dynamic maps, with the positions of objects designated by symbols in a plan layout. Usually the identity of the objects and other useful information such as speed and course can also be derived from the symbology.

This paper examines the functional characteristics of such displays with the aim of establishing a baseline from which decisions of equipment selection and more importantly functional design or specification may be made.

In designing user interface systems, it is unlikely that any design will be optimal for all users and all modes of operation(ref.8). Necessarily, the final system will be based on trade-offs among user preferences, equipment flexibility, processing power and other factors. This paper provides some guidance in the selection of various alternatives.

1.2 Purpose of this document

One of the primary functions of Combat Systems Division (CSD) is to provide scientific and technical advice to the ADF on design aspects of new combat system proposals. An important element of these is the display subsystem, the effectiveness and suitability of which is dependent on a complex relationship between a number of factors. The principles governing the relationship are not widely understood, or described in the open literature. The purpose of this document is to record the knowledge and experience gained at CSD from a number of completed tasks, and to provide a reference for use by CSD and other staff in future tasks.

1.3 References

While there are numerous publications relating to interactive display systems, very few address tactical displays or even interactive graphics displays in any detail. Reference 10, "Design Guidelines for User-System Interface Software", prepared for the United States Air Force is perhaps typical of documentation in this field. A large document (over 400 pages), it contains comprehensive guidelines for alphanumeric data entry and display, but almost no guidelines for interactive graphics, even though (empty) sections are assigned to the subject. The fact that the relevant Military Standard MIL-STD-1472C(ref.14) suffers from the same problems also indicates the unwillingness of authors to generalize in this field.

Those references which do address the subject directly tend to be either application-specific(ref.5,11,13,15,19,20) or text books for display engineers(ref.22).

This paper does not directly address the format and use of alphanumeric displays. Authoritative guidelines may be found in references 9,10,18 and 21.

1.4 Spaces, windows and viewports

The nomenclature used for display systems tends to vary widely and depends to some extent on the application. This section describes some of the nomenclature used in this paper, which conforms with that used in much of the literature.

A tactical display primarily consists of a two dimensional (plan) representation on a visual display unit screen of elements such as ships and aeroplanes in the physical world. The symbols used to represent these elements are labelled to assist identification and hence the display is referred to as a Labelled Plan Display (LPD). The LPD area does not necessarily occupy the entire screen area - other (secondary) data, mainly text, is often displayed outside the LPD area.

Display of an item requires conversion of the item's position in the physical world - world coordinates in the world space - to a position on the screen - screen coordinates in screen space. The world coordinates may be geographical (specified in latitude or longitude) or grid coordinates (perhaps in nautical miles) or some other internal computer representation. The world space is large enough to encompass all the positions needed in the use of the tactical system.

The screen coordinate space, by comparison, is extremely limited and dependent on the display system used. It is typically limited to the screen area.

The region in world space displayed at any one time is referred to as a <u>window</u>, which corresponds to a <u>viewport</u> in screen coordinates (figure 1). In most systems the LPD area and viewport are coincident on the screen, with the LPD consisting of primary viewport data as well as optional secondary data.

The viewport is a fixed area on the screen. Variations in display are effected by changing the position and size of the window in world space. A small scale (global) display is provided by a large window - a small window results in a large scale (local) display. Much of the processing required in tactical display systems is in deciding which items or parts thereof are within the window (clipping) and in then converting the world coordinates to screen coordinates for display.

A third space is used in some systems, referred to as "terminal space" by Tektronix. This is a large coordinate space, often large enough to accommodate all items of interest, which is internal to the display system. After a window (terminal space) and viewport (screen space) are defined the display system can then automatically create the display from the stored display information.

2. TACTICAL DISPLAYS - AN OVERVIEW

This section describes the general characteristics of tactical displays. Although such displays are used for widely differing applications, the display requirements and the design problems faced tend to be remarkably similar. For example references 1 through 5 define the requirements for tactical displays for specific minehunter, helicopter, army command and control, and air traffic control applications. The displayed objects range from mines to sonobuoys and from artillery positions to ships. Such systems have many requirements in common, including:

- the need for different range scales and centres
- display of symbols and text
- cursor control to indicate positions and designate objects
- supporting text fields
- modification of displayed objects

2.1 Physical characteristics of displays

While the functional requirements of displays may be almost identical for different applications, the required physical characteristics may be different to the extent of being mutually exclusive.

A display in the cockpit of a helicopter for example, to be used in full sunlight conditions or with night vision goggles, is likely to have different requirements from those for a display used in the command centre of a submarine. Other applications call for large screen displays or single displays used by two or more operators.

Because the physical characteristics (such as size, weight, persistence, luminance, stability, linearity, readability, precision) are so dependent on the application, they are not considered in any detail in this report. However, the type of display, particularly whether it is vector scan or raster scan technology, will affect the flexibility of the potential functional characteristics and a comparison of these two types is presented in Section 3.

2.2 Summary of functional characteristics

2.2.1 Display items

The primary display items on a tactical display typically consist of positional items and spatial items.

The positional items generally depict physical units in a plan view. Examples of such items are ships, aircraft, sonobuoys, artillery units and landmarks. Spatial items represent lines or areas and may include rivers, borders, bearing lines, flightpaths and areas of probability. Symbology and annotation are used to distinguish between different items.

Primary display items are discussed in Section 4.

For example, the Minehunter Weapon System (MHWS) in reference 1 includes as positional items the following:

- underwater contacts of various types distinguished by symbol, colour, and unique numeric labels
- the current position of the minehunter itself: a unique symbol including a heading line
- navigation reference points: a common symbol with identifying labels
- general purpose markers: a common symbol with identifying labels
- radio location beacons: a common symbol with identifying labels

The spatial items include the following:

- a safety circle around the ship
- the borders of the current minehunting sonar sector extending from the ship to the safety circle
- laptracks to be traversed by the minehunter, identified by number
- boundary lines, usually used for coastline or potential hazard areas
- a rectangular box, indicating the limits of the current (hardcopy) plot.

2.2.2 The database/display interaction

The display presented at any time is a function of various display parameters such as display centre and range scale and the working database of items which may be displayed. The representation of these items is important to maintain an efficient interface between the database and display. The MHWS, for instance, represents positions in latitude and longitude which must be converted to cartesian coordinates for display.

In addition the capacity of the display may not meet (or be required to meet) the full capacity of the database.

These issues are discussed in Section 5.

2.2.3 Secondary display data

In addition to the plan display, most systems include on the display screen other data which are relevant to the operation in progress. These items are usually presented in text or symbolic form at the boundaries of the plan display.

The minehunter secondary data includes text fields indicating time of day, ship course and speed and cursor position, as well as analogue indications of heading and drift on the compass rose surrounding the plan display.

In many cases (including the minehunter), the display of the bulk of secondary data occurs on a separate display unit adjacent to the tactical display, catering predominantly for text data. This paper however is restricted to display of secondary data on the plan display, and its interaction with prime (plan) data.

Other examples of secondary data include data amplifying the function of a selected item, the use of display fields for control purposes (selected by cursor) and messages alerting the operator to conditions of immediate interest.

Secondary data display interaction is examined in Section 6.

2.2.4 Changes in display

The ability of the operator to adjust his display to meet the requirements of the moment is very important to the efficiency of the display. This includes control over the position of the display window in world space (usually by controlling the coordinates of the display centre), the range scale in use, and the manual and automatic decluttering of the display to ensure that the volume of displayed data does not degrade the operator's performance.

Certain systems also require control over the orientation of the display, or movement of the displayed area consistent with motion of the host platform.

Changes in display, various options and how they may be effected, are discussed is Section 7.

2.2.5 Display response to database changes

A tactical display is usually dynamic, representing a changing scenario. This means that the display must cope with changes in the position of an item as well as creation and deletion of items in a rapid and ergonomic fashion. Changes to symbology caused by the change in status of items must also be catered for. This is discussed in Section 8.

2.2.6 Highlighting and the use of colour

Section 9 describes some methods used for emphasizing displayed items to distinguish them from others, including blinking, pulsing, and the use of brightness and colour. These methods of discrimination are often necessary to highlight important items requiring urgent action. Colour and brightness are also used to aid in the general discrimination between items on the display.

2.2.7 Cursor control and hooking

The prime means of interaction between the operator and the display is normally the cursor (or balltab). Efficient use of the display can therefore depend on the operator's ability to position the cursor quickly and accurately, and then use it to designate items and geographical positions (hooking).

Facilities for cursor control and hooking are discussed in Section 10.

2.2.8 Response times and update rates

The speed with which the display responds to changes in the data base and display parameters such as range scale and centre can severely affect the efficiency of the system. Section 11 recommends minimum response times for various actions and discusses design features affecting response times. Also addressed are the update rates for cursor data and moving items.

2.2.9 Graphical tools

Different applications may require the use of graphical tools for the solution of operational problems. These tools are usually extensions of the simplest graphical tool, the cursor, and are discussed in Section 12.

3. VECTOR OR RASTER DISPLAYS

Although this paper generally avoids discussion of the physical characteristics of the display system, an exception is made in the comparison of vector scan and raster scan displays. This is necessary because the type of display method used can be critical to the design of the system, particularly in software, and hence to its performance(ref.5).

Several years ago the decision as to which display to use was simple: only vector displays provided the performance required. Currently, however, raster displays can match vector displays in performance for many applications and show advantages in cost, size and some aspects of picture quality.

3.1 Vector scan displays

Vector scan displays (also referred to as calligraphic or strokewriter displays), construct a picture by direct control of the electron beam striking the phosphor of the screen(ref.6). To draw a line, for example, the beam is directed from one point on the screen to another, rather in the manner of an X-Y plotter.

The relative intensity of individual elements can be controlled by the speed of the beam movement on the screen - the slower the speed, the brighter the display. Colour is often provided by the penetration method where different voltages are used for the electron beam to energise different phosphors in the screen. This limits the number and quality of colours.

The display is generated from a "refresh file" in computer memory, under software control. Each refresh cycle (say 20 ms) the refresh file is executed to derive the beam movement on the screen. Commands in the refresh file are used to direct the beam as well as to change display-relevant parameters such as colour, intensity and line style. More sophisticated systems allow some logic in the command language to provide conditional branching within the refresh file, and the calling of display subroutines. Alphanumeric and other symbols are usually developed using special commands which activate a preset sequence of beam movements.

The display capacity is limited by the time required to move the beam through the sequence of the refresh file, as well as other time delays such as that required to change colours. If the required time exceeds the refresh period (20 ms above) then the display will be refreshed at a lower rate resulting in a decrease in intensity or flickering, or both.

Some design considerations which are specific to vector scan displays are as follows:

(a) Colour switching. The time to change colours during the refresh cycle is usually significant. One common solution is to group the display of items of each colour together to minimize switching.

(b) Display update. The problem of changing the refresh file while it is being interpreted by the beam controller is analogous to changing a computer program asynchronously while it is being executed. There is a finite risk that an undesired interim version of the refresh file will be interpreted, causing at best momentary errors on the display and at worst a fatal display system error. This is usually avoided by modifying a copy of the refresh file, or more often a segment thereof, and switching the flow of the beam controller through the new version when it is complete.

(c) Display item displacement. Some systems allow various modes of beam position addressing including absolute screen coordinates, coordinates relative to the last position, and coordinates relative to a reference screen position which can be set in the refresh file. These last two options allow development of a complex display item relative to a movable point, so that by moving the reference point the item may be simply moved to any point on the screen.

Most systems provide high level software packages to simplify use of the displays. While such a package may significantly reduce development time, the user will have very little control over the efficiency of the package, which is likely to be developed for more general use. In addition, the tuning of performance may be much more difficult.

3.2 Raster scan displays

Raster scan displays use a system similar to television to display the contents of pixel memory(ref.7). Each picture element (pixel) on the screen corresponds to a bit in one or more bit planes in pixel memory. Where different colours or intensities are required, the number of bit planes required increases. For example, to display 8 colours or 8 intensity levels, 3 planes are required.

The pixel memory is generated by microprocessor controlled hardware from a user supplied "display list" which is very similar to the refresh file discussed for vector displays. Here a command to draw a line, for example, is translated into pixels in pixel memory for display. It is this translation step (which is not required for vector displays) which has in the past made raster displays relatively slow in responding to display updates(ref.5). Because a change in the display list could theoretically affect any point on the screen, the entire pixel memory may need to be regenerated.

This may be overcome in some applications by using an "exclusive or" (XOR) display technique, which is a feature of most display systems. Each colour - a different intensity of the same colour is treated as a different colour - is assigned a code. (For example, a 4 bit-plane display would have colours with codes 0 to 15, noting that one of the codes, usually 0, must be reserved for the background colour.) When a pixel is written, the value stored is the previous value XORed with the new value. A display item may be deleted by individually rewriting the item's pixels, again using the XOR technique. To move an item it is deleted as above then rewritten. This offers considerable savings in time over regenerating a complex display.

The disadvantage of this technique is that the intersection of display items, ie the pixels that they share, will be the colour of the XOR of the different colours of the items. In particular, where two items of the same colour overlap the intersections will be the same colour as the background, effectively invisible. If the symbols are identical and coincident, neither symbol will be visible.

3.3 Comparison

A comparison between the features of vector and raster displays, for tactical displays in general, can be subject to misinterpretation when a particular application or specific display equipment is considered. The comments below, then, are offered as broad comparison guidelines.

3.3.1 Cost

Generally, raster displays are now less expensive than comparable vector displays. One factor leading to this situation is the fact that raster displays are much more common in other similar applications such as computer aided design, and hence have the advantages of economy of scale.

3.3.2 Brightness

Raster displays usually provide better brightness control, particularly for colour display, and may be more suited to applications where high ambient illumination is required.

3.3.3 Picture quality

In general, high precision raster displays provide a better quality picture, particularly for symbols and text, and have less tendency to flicker. On the other hand, vector displays can provide cleaner fine lines, and smoother curves. This latter deficiency in raster displays, caused by the need to draw curves using pixels, is reduced in some more sophisticated displays by the use of "anti-aliasing" which provides an illusion of smoothness.

3.3.4 Colour

Colour vector displays usually provide up to four colours, from a palette fixed by the screen phosphor. Raster displays can usually provide a much larger number of colours selectable from a huge range of hues and intensities.

3.3.5 Speed of response

Vector displays inherently provide a better response to display changes because they do not need to translate the new picture into pixels. Fast raster displays are now available, however, which provide competitive response times for some applications, particularly when the "exclusive or" update method discussed earlier is used.

3.3.6 Capacity

Because vector displays need to execute the refresh file for each display refresh cycle, their display capacity can be limited for complex pictures. This limitation does not apply to raster displays, although the initial picture translation time may be quite high.

3.3.7 Block fill

One feature which is restricted to raster displays is the ability to fill an area of the screen with colour, or a colour pattern. Although this may occur with some time penalty, it can be very useful for highlighting and the display of windows.

4. DISPLAY ITEMS

The primary elements of tactical displays are the display items which correspond to objects and features of the physical world. Although these objects and features may be quite different in different applications, their representation on a display is usually implemented in a similar fashion, which is described in general terms in this section.

4.1 Item classes

4.1.1 Positional data items

A Positional Data Item (PDI) is a display item related to a position in the physical world. It may, for instance, represent a ship, city, target point, lighthouse or an unresolved radar contact. It need not correspond to any particular object in the physical world, as in the case of a data link reference point which is a geographical position which is used as a basis for relative coordinates. The representation of a PDI on the display typically consists of a symbol indicating the type of item (see symbology below), a label adjacent to the symbol uniquely identifying the particular item, and amplifying data relevant to the item. Examples of simple PDIs are shown in figure 2.

4.1.2 Tracks

A track is a Positional Data Item which generally represents an object capable of physical movement in the physical world. It is sufficiently different from simple PDIs in its display requirements that it is treated here as a different class of display item. Examples of tracks are shown in figure 3 and may include ships, aircraft and bodies of troops.

Not only are tracks more dynamic than other PDIs but they generally have more information of interest associated with them, being the fundamental participants in any activity. Thus the amplifying data for a track is usually more complex than for a simple PDI.

Similarly, the display of the direction of movement of a track, and its past movement, will often be required, usually as a course marker and a series of history points. The history points, although associated with a track's symbology, are in fact fixed positions in the world space and could be regarded as PDIs themselves. It is usually more convenient, however, to regard them as part of the track display item.

4.1.3 Spatial data items

This set of data items covers items which do not represent a single point and includes lines, ellipses, and combinations of lines and ellipses. Examples are zones, maps, error estimates, bearing lines and search patterns.

Unlike PDIs, spatial items are not inherently associated with a unique point on the screen. To position, move or copy such an item, therefore, may require the definition of a unique reference point associated with the item which can be designated by the operator. The reference point may be marked by a special symbol which is only displayed when required for designation or identification (see comments on annotation below).

In some applications there may be lines displayed which have an undefined length in the world space. These lines usually represent contacts from a directional sensor which has detected acoustic or electronic emanations on a particular bearing. In most cases, the length of the bearing line may be physically limited by the range of the sensor, but could extend beyond the limits of the database coordinates.

The existence of infinite bearing lines can complicate the display design, and the normal solution is to treat them as lines of large fixed length. The length is chosen to be sufficiently large to ensure that the line extends beyond the accepted area of operations.

4.2 Display accuracy and representation

In most applications the display accuracy (the accuracy of mapping the world space onto the screen space) is not of critical importance because the screen is only used to represent the relationship between items and to assist in controlling those items or their world equivalents. This does not mean that a high precision display is not required. The precision of the display affects the readability of symbols, their possible complexity and the achievable complexity of the picture as a whole. This is discussed further in Section 5.

4.3 Symbology

4.3.1 Factors in symbology selection

The decision on which symbols to use to represent different items can be very difficult. It will depend on standards already existing in the user's organization (if any), the particular application, user preferences and ergonomic considerations, often, unfortunately, in that order.

As an example, the symbology for the Minehunter Weapon System was drawn from the RAN's Naval Combat Data System (NCDS) and standards used at the time in manual plotting (see figure 4). Other symbols, such as those for the radiolocation beacons, were designed for the application. Although it was suggested that the symbology conform strictly to NCDS, this would have resulted in an inferior system, because NCDS does not address mines and minehunting in any detail. It would not have been possible to indicate the type and status of underwater contacts, for instance, using NCDS symbols. On the other hand, care was taken to avoid the use of standard NCDS symbols for minehunting-specific items, where possible.

The problems at this time in defining symbology for new applications is that the existing standards are often based on the limited display technology available when they were defined, and also that the standards were not intended to encompass more diverse applications. This can lead to the symbology for a new system being far from optimal. In such cases the requirement for "commonality" overrides the requirements for an ergonomic and efficient system, often on dubious grounds.

4.3.2 Composite symbology

Most systems use composite symbology for some data items to convey effectively as much information as possible about the item's status. Figure 5 shows a subset of NCDS track symbology where the identity (unknown, hostile, friendly), the category (air, surface, subsurface), the classification (eg missile), and the status (eg assigned, engaged) may be seen at a glance.

Colour and various forms of highlighting as discussed in Section 9 may also be used to enhance the meaning of a symbol, or its label.

In the design of composite symbology there are two main considerations. Firstly the effect of an attribute should be in proportion to its importance. For example, in the NCDS symbology for a track, the shape has the most effect, followed by the orientation, followed by the status flags. Secondly, if too many attributes are indicated, the symbol becomes too complex and the operator error rate will increase.

It is important that the actual position of a complex PDI be easily discernable, to aid in designation by cursor. Where the symbol is symmetrical the centre of the symbol may suffice, or a dot may be used to indicate the true position as in figure 5.

4.3.3 Track motion

A special case of composite symbology is the indication of motion for a track. This may include an indication of course and speed as well as past movement (history).

Course and/or speed is usually indicated by a "leader" (or possibly a "trailer") line from the centre of the track symbol in the direction of predicted movement (in the reverse direction for a trailer). The length of the line may also be used as an indication of speed. Because of the variation in speeds between different types of tracks, and to keep the leader to a reasonable length - observable but not too long - the ratio of speed to length may vary with different track types. The HTDS uses leaders with the following lengths:

Ship/Submarine	33.8 kn/inch
Helicopter	200 kn/inch
Aircraft	1080 kn/inch

Conversely, a display may occasionally be required with genuine proportional leaders, even if momentarily.

History is usually displayed as a series of points in the wake of the track. The number of history points is limited (say 10) with the oldest being deleted when a new point is generated. Points may be generated at fixed time intervals - possibly depending on the track type - as in NCDS, or at fixed distances (MHWS).

Because of the total number of points required for several displayed tracks (100 or more for 10 tracks), history points will often be a significant part of the processing load in generating a new picture, because of the number of coordinate conversions required.

4.3.4 Annotation

The annotation of data items - labels and amplifying data - is used to distinguish one item from another and to provide further information about the item. In some systems highlighting is used in the annotation of a symbol to provide additional information without increasing the number of characters. Thus the label of a sonobuoy may be displayed with inverse video to show that it is currently in contact with a target.

Although annotation is typically directly to the right of the symbol, different systems may have several rows of annotation or annotations, at different orientations to the symbol.

Design of the annotation for spatial items poses more of a problem. Fortunately, many spatial items such as boundary lines do not require annotation. When it is necessary to refer to these items, for example to modify them, they can be designated by cursor. While it is relatively simple for a user to determine that the annotation directly to the right of a symbol refers to that symbol, similar approaches for lines and circles are not as effective, particularly on a crowded display. This problem is compounded by the fact that, unlike PDIs, spatial items may overlap the LPD boundary and be partially displayed.

The annotation of laptracks in the MHWS is designed to show both the lap number and the directivity of the lap. As shown in figure 6 the lap number is displayed at the start of the lap at a fixed screen distance from the start point, and at a fixed angle offset from the track direction. If the start of the lap is off-screen, the number is shown as if the intersection with the boundary is the start point. This has the advantage of showing the numbers of all laptracks displayed, while perhaps giving the impression that the start points of some lines are on screen when they are not.

Where the annotation of spatial items is only required occasionally, and with low priority (such as the radius of a circle), it is often better to provide the data only on request by hooking the item (see Section 10). This avoids cluttering and reduces the possibility of misinterpretation.

4.4 Slaving

It is sometimes useful to be able to "slave" data items to a track or other PDI, so that the slaved item moves at a fixed relative position to the PDI. In some instances the course of the PDI is irrelevant to the orientation of the slaved item, as in the case of a minehunter's safety circle. In other cases the slaved item is aligned with the position and course of a PDI, such as the limiting lines of subsurface approach (LLSA), indicating the zone in which a submarine needs to be positioned to threaten a surface force.

The slaving of data items adds to the complexity of display management in that the slaved item must be updated with any change in the position or course of the master PDI. In addition, the effects of deletion of the master PDI must be considered.

4.5 Scaling

The scaling of data items when displayed at different range scales (Section 7) is important in the design of their display implementation. Normally, the symbol, leader and annotation of a track must remain unscaled while the item's position relative to other items and history points must be scaled.

Relatively modern display systems, such as the Tektronix 4125, introduce new problems. Although they may provide scaling automatically, the ability to avoid scaling particular display subsets is often not provided, and these need to be rescaled independently.

In some systems the display content will also change with different range scales. Such systems recognise that the use of the display is different at different range scales, and that fine detail is not required (or indeed is not usable) on a small scale display. In these cases symbols may be automatically suppressed below a prescribed range scale, or groups of items may be replaced by a composite item (several ship symbols being replaced by a convoy symbol, for example).

5. DATABASE CONSIDERATIONS AND COORDINATE CONVERSION

The design of the database in which items to be displayed are stored can have a serious impact on display performance. One of the more critical decisions is the representation of an item's world coordinates from which the viewport and screen coordinates are derived.

5.1 Coordinate conversion

The efficiency of coordinate conversion depends not only on the world coordinate representation but also the system's ability to handle more complex mathematics efficiently. Obviously conversion from latitude and longitude will, for example, depend on the system's speed in executing trigonometric functions.

It is not essential that the internal representation of coordinates correspond with numeric coordinates used by the operator. Calculations can be extremely difficult (and inefficient) when geographic coordinates are involved. Where the area of operations is relatively small, the errors involved in representing geographic coordinates by cartesian coordinates internally may be insignificant. Conversion between cartesian and geographic coordinates would then only be necessary for numeric display and data entry.

Where items are represented internally by cartesian coordinates, further efficiency can be gained by choosing a representation that facilitates simple conversion to screen coordinates. For example, where different range scales vary by factors of 2, a representation could be chosen where the conversion can be achieved by logical shifting rather than multiplication and division.

As was discussed above, the fine accuracy of conversion to screen coordinates is usually not critical to performance. It is important, however, that the conversion is consistent (eg that two items with the same world coordinates are seen to be coincident on the display) and reversible, so that positions in the world space may be specified using the display(ref.14).

Special care must be taken with spatial items when converting from geographical coordinates. It should be noted that the errors inherent in the conversion depend on the sophistication of the conversion algorithm and the proximity of the geographic poles. The method chosen must therefore also consider the regions in which the system is to be used.

In the MHWS for example, in some modes the distance of the Minehunter from a laptrack line is displayed numerically. If the line is very long, and the item is close to it, the distance displayed graphically on a large scale can be visibly inconsistent with the numeric value. This anomaly is caused by an approximation during coordinate conversion when the cartesian coordinates of the line's endpoints are calculated. It could be corrected by a slower, more accurate conversion, or by choosing points on the line closer to the window boundaries rather than the endpoints. In fact, the anomaly noticed in the MHWS is only evident for unrealistically long laptracks and hence is not a serious problem.

A similar problem can occur when using Great Circle navigation. In general, Great Circle routes are not straight lines on the projections used for LPD displays but a segment of the route can be approximated as such with little loss of accuracy. Care must be taken in calculating the intersection of the Great Circle line with the window boundaries, however.

5.2 Database capacity

In many systems it is unlikely and unreasonable to expect that the full database should need to be displayed in full detail on the screen at one time. A ship-based helicopter, for example, may require in its database a set of tracks that it is updating, perhaps by radar, as well as numerous other data passed by data-link. Its general requirement is to view the local area and to occasionally view other areas, or perhaps a small scale plot with less detail. Consequently it is unnecessary to require a display capacity commensurate with the total database capacity, or to severely restrict the database because of display limitations.

It is, however, important to determine:

(a) the minimum requirements for a full detail, undegraded display, with regard to the numbers of different items displayed;

(b) the display performance with content increasing past this minimum; and

(c) automatic decluttering of congested displays.

The minimum plot should accommodate all the operations required by the system except those at a small scale (global picture). All display variations, including the various types of displayed items and their different display options must be considered. The HTDS includes in its minimum plot and database the following items (among others):

Item	Minimum plot	Database
Tracks (with history, labels etc)	16	64
Markers (other PDIs)	8	40
Circles	8	16
Lines	8	32

The performance of the display will also change with the size of lines and circles and the types of symbols and annotation. These aspects should also be considered when defining the minimum plot.

The performance of the display system when displaying the minimum plot should then meet the required display quality and response times (see Section 11). A vector display's quality may degrade when the plot complexity becomes too great and either diminish in brightness or flicker, or both. A raster display is more likely to have difficulty in meeting the response times for display changes for plots of excessive complexity.

Because the minimum plot requirements are likely to be exceeded occasionally, it is necessary to ensure that the performance degradation, if any, does not seriously endanger the effectiveness of the system. One method by which the performance may be improved is by a reduction of the amount of data displayed, either by manual selection, or perhaps automatically. At small scales, for instance, the usefulness of history points may be low (they may be visually inseparable from the track symbol) and their suppression could significantly improve performance (see Section 7.3).

6. SECONDARY DISPLAY DATA INTERACTION

Secondary data refers to items which are not a natural part of the LPD display. Examples include:

(a) Amplifying text on a primary data item which is either momentarily displayed in the LPD area, or displayed outside the actual LPD area;

(b) General text such as time, own track speed and position;

(c) Control data such as menus and icon selection areas; and

(d) Messages and alerts.

The use and design of secondary data for tactical display, particularly text, does not differ significantly from that for purely alphanumeric displays (such as inquiry systems) and is treated in detail in many of the references. Accordingly, only the aspects in which secondary displays interact with the LPD are addressed in this report.

6.1 Symbology

It is sometimes useful to be able to include the symbology used on the LPD in secondary data, to denote display items. Figure 7 shows a comparison of a list of underwater contacts with and without LPD symbology. Not only can this technique reduce the size of such lists without decreasing the information content (for a trained operator), but it can also assist in visually correlating items on the primary and secondary displays.

This feature may influence the selection of a separate secondary display unit - sometimes called a "tote" - if one is required. Many alphanumeric displays do not have the flexibility of LPD displays, and are limited in the size and variety of symbols they can display.

Similarly, again for ergonomic reasons, it is preferable that the character fonts and colours used on both displays do not differ significantly.

6.2 Control data

Another use of secondary data is in menus as part of the control process for the system. These may be in the form of text as shown for the minehunter in figure 8, or symbolic, using "icons", as shown for the helicopter in figure 9. The method of selection of items from menus will depend on the input devices available.

6.2.1 Keyboard selection menus

The use of alphanumeric menus for control is described in detail in references 9, 10 and 18. The menu shown in figure 8 is controlled initially by pressing a number on a numeric keypad, resulting in a change of colour in the appropriate line of the display, followed by keyboard data entry if appropriate, and finally pressing a "select key" to activate the function.

6.2.2 Direct selection menus

The use of symbolic menus is discussed here in more detail, partly because they are less well documented, but also because they tend to be an integral part of the tactical display when they are used. One of the advantages of this form of control is that it can use a single positional entry device (PED - eg mouse, forcestick, trackball) and a single viewpoint for the operator - the tactical display screen. Hence it would be unusual for the symbolic menus to be presented on a display separate from the LPD.

The primary icon menu shown in figure 9 is only displayed during control operations. Subsidiary "pull-down" menus are also used at the top of the screen to qualify primary menu actions. The use of pop-up and pull-down menus reduces the permanent obscuration of useful data on the screen. Note that the primary menu in the example provides a function to position the menu on the other side of the display.

It is possible to use symbols, rather than text, in these menus because of the method of direct selection using a positioning device and associated buttons, rather than a keyboard. In some applications, the use of text in conjunction with, or instead of, symbols is preferable, either where the menu tree is large, or where meaningful symbols cannot be easily defined.

Because the same PED is usually used for LPD and menu control a single button is often used to switch between the two modes. Alternatively, the cursor may be slewed from the LPD to the menu area with the boundary between the two areas delineating the PED control mode. This latter method is often unsatisfactory because it is common for many tactical display commands to be used in conjunction with LPD cursor position, for example when recentering the display on the cursor.

The effect of moving the cursor in the menu area should typically be different from that in the LPD area. The LPD cursor, described in Section 10, is used for precise indication on a large display grid. By contrast the menu cursor is used to select from a limited number of options (perhaps 10). This requires that the cursor response - the distance moved on the screen for a given PED input - be different in the menu area, and designed to provide rapid but positive selection of menu items. Similarly, it is unnecessary and perhaps confusing to use the same cursor symbol for menu selection. More commonly, the cursor position in the menu is shown by highlighting the currently indicated menu item by some form of highlighting such as colour, brightness, inversion or background colour.

This form of selection is very positive and leaves no uncertainty as to which item is currently indicated. It does, however, require greater effort in design of the display software, to ensure that the response speed in terms of display change for PED movement can be accommodated.

6.3 Amplification data

Although careful selection of symbols and labels can provide a great deal of information about a data item, it is common to provide facilities to examine an item in more detail by a display of amplification data. Often this text display is provided adjacent to the LPD display, but on the same screen. Where the data display is required momentarily, which is typical, and the display system supports such a feature, the amplification data may be displayed in a "box", adjacent to the item, on the LPD display. The amplification box is a rectangular area of screen which only contains the amplification data - the display of LPD data within the area of the box is suppressed.

Although this method obscures other data on the display, it has the advantage of providing the information in the direct area of interest of the operator. If the methods of activation and removal of the box are simple, and the display change response is sufficiently fast, it provides an effective tool.

One difficulty in the design of this feature is the location of the box on the display with respect to the item, particularly when screen boundaries are considered. It is obvious that a simple rule such as "the box is centred immediately above the item" cannot be obeyed when the item is near the top, left and right hand sides of the display. One solution is shown in figure 10 where a tag is used in the box to indicate the item it amplifies.

In cases where the operator may require an amplification box to be displayed for a longer period, a facility to define the position of the box display with respect to the item is useful, so that the obscuration of immediately useful data is minimized.

6.4 Display obscuration

The problem of display obscuration by secondary data, whether pop-up or pull-down menus, or amplifying data, is not generally serious when the obscuring data is only present for a second or two, and in any case is the operator's main object of attention. A difficulty may arise, however, when an alert occurs to draw the operator's attention to a data item which is temporarily obscured. If such alerts depend on the highlighting of display items as a cue, the system must detect that the item is obscured and indicate this in another way, perhaps in the same manner as for off-screen alerts - items which are not in the current window.

An alternative method is to superimpose the highlighted item on top of the obscuring data, at the expense perhaps of a more complex display software structure.

6.5 Alert messages

One further example of secondary data is the display of messages from the system to the operator. These may be the result of incorrect operating procedures, warnings of potential future problems, software or equipment failures, or critical messages requiring immediate action(ref.20).

This aspect of displays is often underestimated and hence requires frequent redesign. The relevant items for consideration will usually be:

(a) What types of alerts can be anticipated?

(b) What is their priority?

(c) How will the different types be discriminated?

(d) How will the display system handle several concurrent alert messages?

(e) Can specific alerts be suppressed from display?

As the name suggests, alert messages must attract the attention of the operator, and although often used in conjunction with audio alert tones, this is not always the case, particularly when the operator needs to listen to other sources. Highlighting, as discussed in Section 9, is used to distinguish alert messages from other secondary data. High priority occasional alerts may also be overlaid on the LPD area when immediate action is required, but the consequences of obscuring the operator's main work area must be considered.

Many existing systems are deficient in their handling of alert and error messages. The most common fault is persistent reporting of known small faults which in themselves do not seriously affect system performance. If the alert requires acknowledgement, the operator's workload will be increased. More importantly, frequent occurrence of alerts may accustom him to ignore them, at the cost of missing a serious alert. Alternatively, where alerts are displayed in the same area of the screen, the non-acknowledgement of the repeating alert may suppress the display of others.

The solution to this problem is not really in the tactical display area, but lies in the careful design of fault and alert handling, and by providing controls to the operator to suppress the reporting of specific alert conditions.

7. COMPREHENSIVE DISPLAY CHANGES

This section discusses general changes to the tactical display which in some cases require a complete regeneration of the picture. These changes usually result from an operator action to change the display, rather than changes to individual items in the database.

7.1 The display boundaries - clipping

The display boundaries in world coordinates (defining the primary window) are determined by the coordinates of the display reference point (usually the LPD screen centre), the range scale and the screen LPD boundaries (the viewport). As discussed above, the viewport need not encompass the full screen if other areas are required for secondary data.

The viewport shape is typically circular or rectangular, the choice depending on the application and to some extent the display system characteristics. Traditionally, displays which consisted of a centred radar display overlaid with symbolic data have been circular, to match the characteristics of the sensor. Such displays are now less common, and many current tactical displays are rectangular.

Without any other overriding criteria, the choice of the display shape may be dictated by the requirements for "clipping". Clipping is a term used for determining which data items are inside and which outside the window (or displayed viewpoint), and therefore which will be displayed. The flexibility and efficiency of clipping depends very much on the features provided by the display system.

Display systems vary considerably in the facilities provided for clipping, and hence the effort required in user developed software. The following categories encompass many of the display systems currently available.

7.1.1 Hardware clipping

This feature is provided in the Sanders Graphic 7 system(ref.6) where the screen addressing space is larger than the screen itself, and the display is automatically clipped at the screen boundaries. The screen addressing space, however, is much too small for most tactical display applications and hence software clipping is also necessary. Another disadvantage of this type of system is that it only supports full-screen viewports without resorting to software clipping.

7.1.2 Automatic clipping

Display systems such as the Tektronix 4125(ref.7) offer the capability to specify rectangular viewports on the screen corresponding to windows in "Terminal Space", which is large enough to represent most tactical display applications. This allows viewports of any size, with clipping automatically handled by the display system.

Automatic clipping usually results in the LPD display being cleanly terminated at the boundary of the viewport, so that symbols near the boundary, for instance, may only be partly displayed. Depending on the method used for clipping, the time overheads for generation of a complex picture may be quite high, and should be considered in display design.

7.1.3 Software clipping

Where the tactical display developer is obliged to provide his own clipping, it is important that it be done efficiently to optimize response times. Reference 22 provides a good discussion of clipping for rectangular viewports, particularly for lines. Curiously, clipping algorithms for circular viewports can be much simpler than those for rectangular viewports, but unless the processor provides high speed trigonometric functions, the processing of rectangular clipping will normally be faster.

Unlike automatic clipping, software clipping cannot efficiently provide a clean boundary to the viewport, except in simple cases such as lines and circles. In most cases a symbol is displayed if its position is in the window, resulting in some symbols overlapping the boundaries of the viewport slightly. Where a large, complex symbol is used, it may be necessary to consider clipping the symbol itself, or restricting the size of the effective viewport for these symbols.

7.2 Range scale and centre changes

When the operator requests a change in range scale or a change to the centre of the displayed window, complete regeneration of the tactical display LPD area is usually required. With a less sophisticated display system, this can involve the following steps for each item in the database.

(a) Determine whether the item will be displayed (even partly).

(b) Determine the cutting points with the window boundary for items partly displayed eg lines.

(c) Determine the screen or viewport coordinates for the item.

(d) Insert the item's display commands in the command list.

Although the display needs complete regeneration, efficiencies may be gained by changing only part of the command list each time. With many applications and display systems a change in range scale or centre may require command list changes only in the coordinates of displayed items and in the visibility of an item's individual definition. Other characteristics, such as annotation, colour and symbology remain unchanged.

In these cases, it may be possible to design a fixed format command list encompassing the entire data base, with off-screen or suppressed items bypassed during picture generation.

Where there are no special display requirements the centre of the display is usually selectable anywhere in world space and factors of 2 are used between adjacent range scales, giving the operator a reasonable flexibility in defining his working picture. The maximum and minimum range scales will depend on the application but because the provision of additional scales often requires little extra effort, it is advisable to provide too many scales rather than too few.

7.3 Decluttering

Many applications require so much displayed information, particularly at smaller range scales, that the display becomes difficult to use. Similarly an item's display features which are essential in one mode of operation may be unnecessary in another (eg track history). Decluttering is the process of systematically reducing the amount of displayed information to a usable level, or rearranging the display items to improve the operator's performance.

7.3.1 Reducing the display content

Figure 11 shows the declutter menu for the MHWS, where the operator may choose the features (or display items) he wishes to suppress or enable on the screen. The requirements for decluttering will vary considerably with the application, as this example shows, but the principle will normally be similar - classes or categories of displays items or features are suppressed or enabled on the screen.

The implementation of decluttering depends on the display system used. Some systems allow decision logic in the displav list so that the visibility of any number of display elements can be controlled by a single flag. The Tektronix 4125 provides "matching classes" by which categories of elements may be addressed as a group, and made visible or invisible.

A simple method in some less capable systems is to use a display list subroutine as a switch. Each element of a particular category calls a controlling subroutine which can switch the current colour to the background colour. In this case the elements are "displayed" but are invisible.

7.3.2 Rearrangement of display items

An alternative method of decluttering is for the display software to detect where overlap of symbols is likely to reduce the effectiveness of the display, and to rearrange the symbols so that overlap does not occur. Where the indication of an exact physical position is important, the actual position can be indicated by a vector drawn from the symbol to the point.

Because the position of the symbol may not directly correspond with the position of its object in world space, and the addition of a new symbol may result in the movement of several others, this method is usually restricted to applications where the objects are fixed or move relatively slowly, such as an army command and control system(ref.4).

7.4 Dynamic centre and orientation

Most modern tactical displays use a selectable geographically fixed centre (earth stabilized) and a North-up orientation. Older displays tended to feature platform-centred and heading-up displays, primarily to coordinate with the simultaneous display of raw sensor data, particularly radar and sonar. The requirement for such displays is now less common, and is often included as a display option, rather than a prime display mode.

Implementation of platform oriented displays can be difficult, because of the need to continually adjust the total picture as the platform moves. If the update rate is high (say 1 Hz or faster) the processing load is likely to require a dedicated display processor for simple display systems. Some features of particular display systems may reduce this load significantly such as being able to slew the entire display by the use of screen addressing relative to a movable datum. Other displays allow relative polar coordinates providing for simple rotation of the picture. The clipping algorithm, however, will still need to be executed frequently to ensure that the viewport's contents are consistent with the moving window.

Because the window of a display with a dynamic centre moves at a limited rate (or the display would be unusable), it is possible to design clipping algorithms which use the information of previous passes to reduce the number of items which must be considered for display. Hence fixed items distant from the window need not be considered for clipping until the window has moved a certain distance, or the range scale changes. Similar logic can be applied to items which themselves move at limited speeds.

7.5 Set windows

It is sometimes useful to provide two or more "set windows" to enable the operator to select different LPD windows efficiently. Typically the windows may have different centres, scales, decluttering parameters and other attributes which may be set or changed by the operator.

In the HTDS the operator has the facilities to define two set windows: the General Operations Plot (GOP) and the Local Operations Plot (LOP). Each window has its own centre, scale and decluttering parameters, and the operator alternates between the two with a single keystroke, rather than changing the relevant parameters individually.

The requirement for two or more set windows does not impact the display design significantly - it is merely a method of achieving the same display with less control actions. It differs, however, from the incremental approach in that the generation of a new picture may involve the changing of several display parameters simultaneously, and the regeneration software should cater for this event efficiently.

7.6 Transition - the visual effect

The foregoing discusses the before and after effects of a display change, but not the visual effect during a change. A range scale or centre change is a major picture change with most items changing their positions on the screen. It is not satisfactory, therefore, to display each new item as it is processed, mixing old and new data on the screen until the entire picture is changed, because of the confusion in the interim display. This type of update may be adequate, however, for changes which do not affect items' positions, such as the suppression and re-display of groups of items.

The most effective method to process a major change is to replace the old picture with the new picture instantaneously, after the whole picture is generated. Alternatively, the LPD display can be erased and the new picture created one item at a time. Where the time taken to generate the display is relatively short (perhaps less than one second) the former method is preferable because it gives the impression of a shorter response time, and is less distracting to the operator. For larger delays the latter method may be advisable to provide confidence to the operator that his request is being processed.

With vector displays, the instantaneous change merely involves switching the display control from one refresh file to another. Raster displays require two groups of pixel memory planes to support this feature - one to display the old picture while the new picture is being generated in the other. The display is then switched to the new group of display planes.

The practice of instantaneous change should also extend to the movement of data items, where possible. If a complex data item moves to a new position on the screen it is preferable that it is seen to move instantaneously and as a whole, rather than be built up in one position as it is visibly dismantled in another.

7.7 Cyclic display update

Where the tactical picture changes continually, either as a result of a display with dynamic centre or orientation, or because the data items themselves are moving, a cyclic display update can be useful. Using this method the display is repeatedly rebuilt from the database and current display parameters as a background processing task. The update may take place at a fixed rate (say 1 Hz) or as a continuous task where the rate is dependent on the complexity of the database and picture, and higher priority processing.

This method has the advantage of simplicity in some applications in that database changes are separated from display changes. The developer can be confident that any changes to the database will eventually be reflected in the display without taking immediate action to implement them.

The disadvantages can be as follows:

- Where multi-tasking is used to provide cyclic update, care must be taken to ensure that the database is consistent, ie that a partially updated item is not displayed.
- The cyclic update rate will not normally be sufficient to meet the faster response times required, and independent updates will be necessary in these cases.
- This method can result in significant variations in the response times to operator actions, which is detrimental to operator performance(ref.16,18).

8. DISPLAY RESPONSE TO DATABASE CHANGES

This section addresses the changing of the displayed picture in response to changes in the position or characteristics of individual displayed items. Such changes fall into two categories:

(a) incremental changes, where the position of an item changes, usually as a function of time; and

(b) discrete changes, often as a result of operator actions.

8.1 Incremental changes

Incremental changes usually occur without direct operator action and involve (typically slight) display changes over a period of time. Examples are moving tracks and dynamic graphic solutions (see Section 12).

These changes can result in a processing load which is quite high if there are many moving items and the update rate is high, because of the necessity to perform the clipping algorithm each time. This load may be reduced by updating only the items that have moved since the last update, or reducing the frequency of update (see Section 11).

The visual effect of a number of display items continually changing position on the screen is controlled by the method by which the update is processed. There are three more obvious alternatives:

(a) updating each item when the data base changes - depending on other processing, this could result in a semi-random effect;

(b) updating all moving items in sequence, resulting in a ripple effect on the screen; or

(c) updating all incremental changes at fixed intervals (perhaps each second) - the picture would then change instantaneously, as discussed for major display changes in the previous section.

In my opinion the first solution above provides the least disruption to an operator's concentration and may avoid the pulsing or flashing effects of the other two.

8.2 Discrete changes

These changes usually result from operator action in the addition, deletion or modification of database items, and consequently require a rapid visible response. It is therefore often not satisfactory to wait for a cyclic scan of the database to make the appropriate changes.

Where these changes are made in conjunction with cyclic generation (Section 7) it is important that changes made to the visible picture are also made to the picture currently being generated to avoid the display of momentary errors.

9. HIGHLIGHTING AND THE USE OF COLOUR

9.1 General

Highlighting and colour are used in tactical displays for two reasons:

- to draw the operator's attention to specific display items
- to discriminate between items of different types, particularly on a densely populated display

The choice of a highlighting method (or methods) can be difficult considering the varying priorities of data on the screen in typical displays. In addition, the selection of highlighting in the LPD area must also take into consideration the methods used for highlighting secondary data such as alert messages, discussed in Section 6.5.

Typical uses of highlighting are as follows:

- to indicate items requiring immediate attention, such as incoming missiles
- to show items designated for use in a current operation eg hooked items
- to indicate items which have been created externally to the display system, without the operator's knowledge or participation eg radar contacts and tracks provided from other systems by data link
- to indicate items of particular sensitivity, which may require more attention from the operator than other items
- to draw attention to alert messages.

Since all of these may be required in a single application, the design of highlighting and the use of colour must take into consideration the priorities of the different requirements, and in some cases different priorities in particular categories eg alert messages.

Excessive use of some highlighting techniques can be annoying or tiring for the operator, and may reduce the effectiveness intended(ref.13,18).

9.2 Highlighting techniques

This section discusses techniques which may be used for highlighting with the exception of texture and colour, which are considered separately.

The methods are addressed in approximate order of effectiveness for directing attention, although this will depend strongly on the implementation and application. A small pulsing symbol on a dense display, for example, will not be as effective as full-screen crosshairs.

Advantages may be gained by combining methods, for instance by using high intensity or blinking markers. Also the same techniques may be used for various degrees of highlighting, by different blink rates or levels of brightness for example.

References 9,13,14 and 18 address highlighting in some detail.

9.2.1 Blinking and pulsing

Blinking an item (turning its display off and on) at a fixed rate demands a high level of attention. The blink rate should be about 2 to 3 Hz so that the character is readable with a quick scan, but the effect is not overly tiring.

Pulsing is a variation of blinking where the item is always visible and the intensity is varied. Although less effective, it is also less annoying.

Blinking and pulsing should use a mark/space ratio of between 1 and 4, with the larger ratio preferred. No more than two blink rates should be used.

The readability of longer lines of blinking text is dependent on the blink rate and mark/space ratio. Pulsing or indication by a blinking marker is recommended in this case, rather than blinking the entire line.

Because of the effectiveness, and annoyance, of this type of highlighting it should not be overused, and designed to occur for short intervals only. It should normally be terminated automatically or after appropriate operator action.

9.2.2 Blocking and inverse video

This form of highlighting only applies to raster type displays and involves the display of a block of consistent brightness around the item. This is common in text displays in the form of inverse video, where all the pixels in the block are "reversed" and symbol appears as black on a green background rather than green on black, for example. It is also used frequently in the LPD area on tactical displays but usually only for text data such as labels.

Note that blocking does not necessarily require the use of full inverse video. With adequate shadowing techniques - dark lines around the symbology - the original symbol's colour or brightness does not need to be changed.

Where it is not used for other purposes (such as display of item status) the use of blocking can be nearly as effective as blinking, and much less annoying.

9.2.3 Intensity

The effectiveness of highlighting by displaying selected items at higher levels of brightness than others is dependent on many factors including the display used and its settings, and the intensity and variability of ambient lighting. An incorrectly set up display or one used in a well lit environment may provide insufficient observed contrast between items of different intensity.

Under controlled conditions no more than two levels of intensity are recommended.

9.2.4 Markers

The variability, and the effectiveness, of special markers to provide highlighting is almost boundless. With this technique the displayed item is unchanged but a separate marker, blinking or with greater intensity if required, is used to highlight the item. Some different forms of markers are as follows:

- pointers such as arrow or pointing finger symbols
- associated symbols such as the asterisk (primarily for text)
- encircling symbols such as a circle or box around the item
- full-screen markers such as crosshairs extending to the limits of the viewport
- underlining (primarily for text)

When used as the sole form of highlighting, markers which are not themselves highlighted may not be very effective on a crowded display.

9.3 Colour and texture

This section deals primarily with techniques used to discriminate between different classes of display items rather than the attention seeking highlighting methods of the previous section. Colour is, in fact, an effective highlighting technique, but because of the many contending priorities of display functions, is more often used as a discriminator, because of its decluttering effect.

9.3.1 Colour

The use of colour in displays is widely covered in the relevant literature with references 5,8,9,11,12,13,14,15,18 and 19 addressing the subject. The selection of specific colours, the relative contrast between colours and the allocation of colours to item types is covered in detail in most of the references and is not considered further in this paper.

Because of its effectiveness as a discriminator, and hence as an aid in decluttering, different colours should be used only where discrimination is important. The use of different colours for secondary text data fields outside the LPD area for example, where the association of the fields is evident from position, labelling or context, will detract from the effectiveness of different colours on the LPD display. Overuse of colours results in the "Christmas tree" effect with little advantage to the user.

Other guidelines applicable to colour displays are as follows:

- use no more than 6 colours
- use colours which are standard to other displays in the application, and to panel lighting (eg switches)
- use colour only as an <u>additional</u> discriminator where operators with deficient colour perception may use the system, ie the items should be further discriminated by shape or annotation.

9.3.2 Line texture

The use of line texture can be useful in discriminating between spatial data items. The variability in texture will depend on the facilities provided with the display system and may include dotted and dashed lines as well as control of line thickness.

Where a display contains many spatial items of different types, such as on a map display which shows roads, rivers and railways for example, it is important to be able to distinguish between the different types of lines. Line texture can be a useful way of achieving this, perhaps in combination with colour coding.

In the use of broken lines, however, the developer cannot usually control the spacing or layout of the texture of the displayed line. This can sometimes lead to distracting effects when the length of a line is changing with display updates at frequent intervals. These effects can also occur with lines of fixed length clipped by the LPD boundary, where the lines or the LPD centre are moving. Similarly, the display of short lines may produce an ambiguous effect.

In general, the use of broken lines should be approached with caution, and only used where it can be shown that adverse effects will not occur for all items of the type, and at all range scales.

9.3.3 Area discrimination

In some applications it is as important to show the discrimination between areas as it is to discriminate between individual display items. In these cases colour or texture (filling an area with a consistent pattern) can be used to identify the different zones.

The provision of area discrimination markedly increases the number of pixels displayed on the screen and can severely degrade the response time for display changes. Its use is therefore limited to applications which can tolerate the slower display update, or which can justify the higher cost of display systems with the appropriate performance.

10. CURSOR CONTROL AND HOOKING

In many systems the cursor (or balltab) controlled by a position entry device (PED - eg trackball, forcestick or mouse) is the most common method of interaction between the operator and the display. In these systems insufficient attention paid to the design of the cursor positioning and use can seriously affect the operator's efficiency in his task. It is important that the control of the cursor is both responsive and accurate, and its position after major display changes is appropriate for the application. References 10,13 and 18 address the use of cursors.

10.1 Use of the cursor

Fundamentally, the cursor is a pointing tool which may be moved by the operator. Its main functions may be one or more of the following depending on the application:

(a) indicating a position on the screen (and hence a position in world space);

(b) indicating a display item - this is called hooking, designating or picking;

(c) moving a designated display item (dragging) - the item moves with cursor movement; and

(d) indicating a control menu selection.

The use of the cursor in a single application can vary widely in different modes of operation. In these cases the cursor symbol itself may vary. For example, if the cursor is in a mode where the item indicated is deleted by a single PED button action, the mode could be indicated by a special cursor symbol.

10.2 Cursor response

The responsiveness of the cursor to the operator's PED movement is determined by the rate at which the PED is sampled, delays in processing and the cursor response law - the method by which PED movement is translated into screen movement. Experiments in this laboratory have shown that the relationship between these three factors is complex, and that the performance with a low sampling rate and significant delays can be compensated to some extent by response law changes.

In general, with small processing delays a sampling rate of 20 Hz provides a reasonable feedback to the operator to allow rapid and precise movement.

The cursor response law is determined by the digitization of PED movement and the display precision, as well as the requirements for large movements of the cursor. The table below shows a typical three stage response law:

PED movement per sample period:	1-5	6-20	21+
Pixel translation factor:	1	2	4

In this example, a slow PED movement of 3 units in a sample will result in a screen movement of the cursor of 3 pixels, whereas 6 units of PED movement will move the cursor 12 pixels. Effectively, the ratio of cursor speed to PED speed (or force) increases with faster PED movement. This allows fast coarse positioning of the cursor, without prejudicing precise movement at lower speeds.

With less favourable sampling rates and delays it is necessary to reduce the translation factor for slow movement to assist precise positioning.

The response law intentionally relates PED movement to screen movement rather than world space movement. This ensures that the cursor response, and the efficiency of its use, does not change with the range scale of the LPD.

10.3 Cursor position

10.3.1 Limits

The cursor position should normally be limited to the LPD area when used as an LPD cursor. It is advisable to avoid "wrap-around" (the cursor disappearing at one boundary and appearing at another) which can make positioning of the cursor near a boundary more difficult.

10.3.2 Position after display change

After a range scale or centre change, the cursor should be displayed at its previous world space position, if possible. This enables the operator to continue a cursor-related task immediately after a display change, without needing to reposition the cursor.

Where the change results in the cursor's position being outside the viewport, it is also sometimes useful to maintain the world space position, which conflicts with the limiting function described above. In the MHWS, a cursor which is forced off-screen is displayed blinking at the boundary. Any movement of the trackball immediately returns the cursor's world position to the current window and it stops blinking. Alternatively, a change of range scale before the cursor is moved from the boundary will result in the cursor being displayed at its previous position. This allows the operator to reduce the scale momentarily (usually to resolve overlapping symbols) without disrupting the cursor position.

10.3.3 Cursor coordinates

Like most items on the LPD, the cursor is defined in screen coordinates and world coordinates. When it is moved by the PED, the positions in screen coordinates can, if necessary, be converted to world coordinates according to the current LPD parameters. In some operations (eg hooking) the cursor may be automatically positioned at the exact world coordinates of a display item - and here the screen coordinates are calculated from the world coordinates.

Because the cursor is often used to provide coordinates for other processes, such as creation of data items, it is important that, unless it is moved by the PED, the cursor maintains its exact world coordinates through other display changes. Otherwise significant errors can be introduced when using the cursor to provide positions on small scale displays.

10.4 Hooking

Hooking is the series of actions whereby the operator selects a displayed data item using the cursor. This usually consists of moving the cursor to the item and pressing a button associated with the PED. Generally, the action of hooking designates an item for future operations, and the fact that the item is hooked is indicated by some form of highlighting, such as a large circle symbol on a hooked positional item. Usually, the cursor is moved automatically to the exact item position.

Often the hooking action may include some other implicit process depending on the current mode of operation, such as deletion or suppression (from display) of the item hooked, or a secondary amplifying display of data concerning the item hooked.

10.4.1 Hook capture area

The hook capture area is a region in screen coordinates around the cursor, in which a display item must be to effect the hook. The capture area must be large enough to allow rough (and hence rapid) positioning of the cursor, but small enough to minimize accidental or incorrect hooking. A diameter of about 8 mm is perhaps typical.

The shape of the capture area is not critical, provided that it is roughly symmetrical. Thus square and diamond-shaped regions are acceptable, although circular regions are ideal, providing the same hooking range at all angles.

Some display systems cater for hooking, providing a list of all display items with some part of their imagery within the hook region, which is usually square.

10.4.2 Selective hooking

When hooking a track, for example, the fact that some part of the track's display (eg history, label) may be in the hook capture area does not necessary qualify that track for hooking. The main criterion is that the position of a PDI - a single point in screen coordinates - be in the region.

Similarly, depending on the action or mode, the hook process may only apply to a limited subset of display items, and will never apply to items suppressed from display. In the MWHS, for example, the use of the CLASSIFY button can only result in the hooking of underwater contacts - all other data items are ignored.

10.4.3 Hook refinement

Understandably, the requirement is to hook the closest suitable item in the hook capture area. Many systems immediately hook this item, requiring the operator to position his cursor carefully, or use a larger range scale, when items are close together. Where the LPD is not congested this method is quite suitable, although alternative methods to discriminate between coincident items may be necessary.

In the HTDS, hooking requires two or more key actions. When the HOOK button is pressed, the cursor is moved to the closest item, which is pulsed. Successive use of the HOOK button cycles through the remaining items in the capture area with the final position being the original cursor position. The ACTION button may be used during the cycle to select the item (or position) required. Although this method requires more actions by the operator, it has the advantage of discriminating between adjacent and coincident items, as well as being able to indicate a position close to a hookable item.

10.4.4 Hooking spatial display items

It is not essential that the use of hooking be limited to PDIs. Lines and ellipses can also be designated using the cursor, when any part of the item is inside the hook capture area. In this way modification and deletion of spatial items can be effected graphically, perhaps eliminating the need for identifying annotation.

Highlighting a line or ellipse cannot be done effectively using a marker, and the use of blinking, pulsing or a change in colour or texture might be considered.

10.4.5 Implementation

Where the display system does not provide aids for hooking, the selection of the hooked item can be a significant processing task, made more difficult by the need for a short response time. All items which are displayed and meet the current hook criterion (ie items of the correct type) must be tested to see if they are in the hook capture area. The closest of these must then be found.

The use of a diamond-shaped capture area can reduce this task. In this case the "range" of the item from the cursor is calculated as $|\Delta X|+|\Delta Y|$, where ΔX and ΔY are the displacements of the item from the cursor in X and Y screen coordinates. It is preferable that the final selection of the closest item in the region is calculated more accurately, to aid in precise selection of the required item.

11. RESPONSE TIMES AND UPDATE RATES

The determination of maximum response times and minimum update rates for man-machine interactions is a subjective decision and dependent on the particular application. This is reflected in the varying recommendations in references 8,9,13,14,16,17 and 18. Most of these references do not address tactical systems which typically require rapid responses from the operator and system in critical situations.

The following tables contain recommendations for response times and update rates for tactical systems based on the references and our experience with such systems. For some actions both desirable and acceptable figures are suggested. In these cases the desirable figure may be difficult to meet and the effect of degrading the performance to the acceptable figure will not be great for most applications.

RECOMMENDED MAXIMUM RESPONSE TIMES

	Desirable (s)	Acceptable (s)
Keyboard echo (alphanumeric entry)	0.1	-
Item change (addition, modification deletion)	0.2	0.5
Range scale/centre change	0.5	1.0
Hooking (item designation)	0.2	1.0
Category display suppression/enable	0.5	1.0
Display of secondary data (eg amplify)	0.5	1.0

RECOMMENDED MINIMUM UPDATE RATES

	Desirable (Hz)	Acceptable (Hz)
Dynamic item update (tracks, graphical solutions)	1	0.5
PED/Cursor sample and update rate	20	-
Dynamic counter update (eg cursor position)	10	5.0
Normal counter update (eg speed)	1	0.5

It can be seen that the actions and responses fall into four categories:

(a) Dynamic response. The cursor response to the continuous PED input must be rapid to ensure adequate feedback to the operator.

(b) Continuity response. When the operator is entering alphanumeric data (a continuous task), the response should be perceived to be immediate to avoid pauses and errors.

(c) Local change response. This is the response to changes to single items usually designated by the cursor.

(d) Global or remote change response. This response applies to global changes to the display, or changes not in the immediate area of attention.

The responses in the tables are achievable with most modern display systems and most applications, sometimes at the expense of increased effort in the design and programming phases. For example, a detailed understanding of the functions and performance of the display system to be used will often be required. Although some of the relevant information will be available from the documentation supplied with the system, an extended period of experimentation may also be necessary.

12. GRAPHICAL TOOLS AND SOLUTIONS

The design of graphical tools and solutions is highly dependent on the application. In general, these display features provide assistance to the operator in his task by providing a graphic display of the relationship between fundamental display items. Two examples are discussed below.

12.1 Strobes

A strobe is a tool used to indicate the bearing and range of display items from a single designated item. In display terms it is simply a line from the designated item to the cursor, which moves with the cursor, and an associated alphanumeric display of the bearing and range of the cursor from the item. Facilities may be provided to "freeze" the strobe, in which case the bearing and range of one item from another is continuously displayed, and the cursor is freed for other uses.

When implementing one or more strobes, consideration must be paid to the fact that the strobe line/s must be updated at the same rate as the cursor.

12.2 Intercept display

Figure 12 shows an example of the solution to an intercept calculation in the HTDS. The point "I" marks the position at which track 0001 can intercept track 5067 at the current speeds of both tracks, and assuming a constant course for the intercepted track. (Track 0001 will need to change course to achieve the interception.) The graphical solution will normally be associated with alphanumeric data on a secondary display providing the time till intercept, the exact course to steer, etc.

The display for this solution is calculated and updated once each second and will change with the relevant parameters including courses and speeds. If the interceptor's speed is less than that of the interceptee, there is a possibility that there is no solution. Similarly, deletion of either track will invalidate the graphic solution.

The difficulty in designing such graphics solutions does not tend to be in the display of the solution, which is relatively straightforward with a low update rate, but in the handling of exceptional circumstances such as those described above. Simplistic approaches such as aborting the solution may not be desirable. For example, the result of the solution may be used as an input to an autopilot, and the exceptional condition may be temporary, as in a momentary reduction in the speed of the interceptor. To require the operator to re-establish the calculation under such circumstances may be unwarranted. In any case, the operator should be alerted to changes in status or abnormal termination of graphic solutions.

13. PROTOTYPING TACTICAL DISPLAYS

The development of a prototype of the displays and operator interactions of a proposed tactical system can be extremely beneficial to the performance of the final system(ref.23).

Where a new display system is being used, it is unlikely that the performance of a proposed implementation can be successfully gauged from the documentation supplied with the system. Experimentation and experience with the equipment are essential to understand the intricacies and limitations when applied to a new application.

Perhaps more importantly, it is very difficult to design a complex man-machine interface successfully at the first attempt. Realization of the design in the form of actual displays and controls can detect many errors and suggest improvements, resulting in design changes that could have seriously disrupted the project if introduced at a later stage.

A display prototype also allows the potential user to see and use the system at an early stage, rather than attempt to make all decisions on the basis of a paper design. This may highlight errors in the requirements specifications for the system, and will inevitably lead to suggestions for improvement.

14. CONCLUSIONS

The design and development of a tactical display system is a complex task. Typically, the design process involves a multitude of trade-off decisions regarding user preferences, equipment flexibility, processing power and other factors.

This paper has examined many of the functional characteristics which are common in modern tactical display systems. Alternative implementations for these functions have been discussed, and the basis for choosing an alternative, as well as the possible consequences, have been addressed.

Where possible, guidelines have been suggested on the basis of the relevant literature and the author's experiences in this field. Some aspects, such as the choice of display colours and the design of text displays, are comprehensively covered in several of the references and have therefore not been addressed in detail in this paper.

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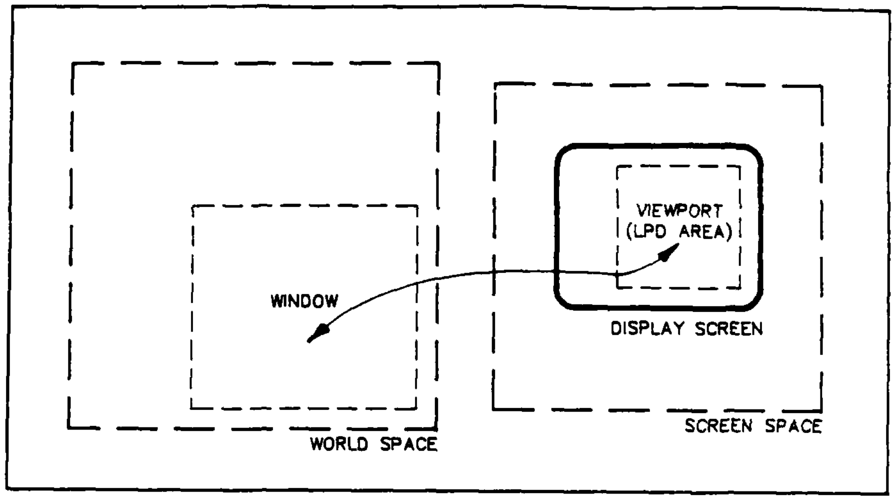

Figure 1. Spaces, windows and viewports

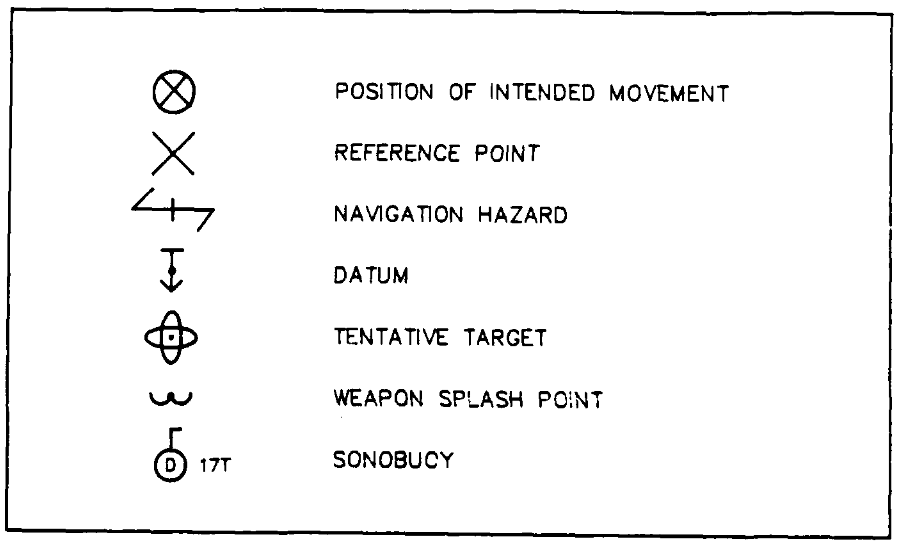

Figure 2. HTDS positional data items

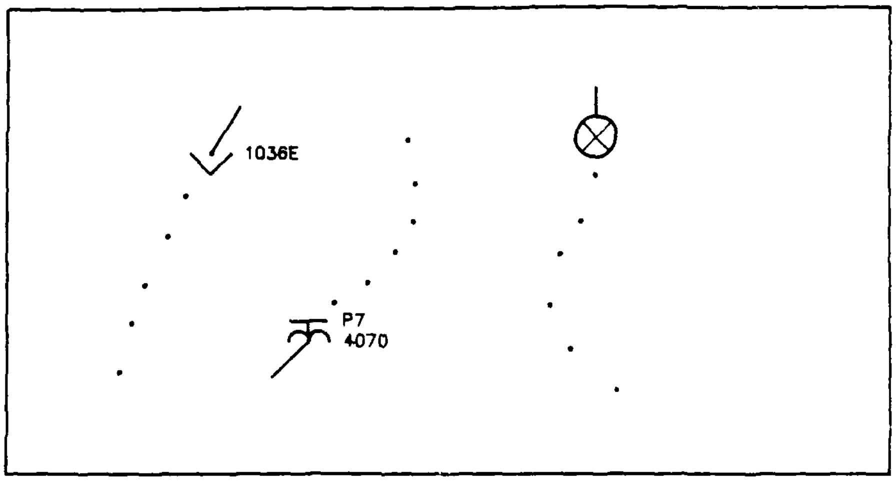

Figure 3. Examples of tracks

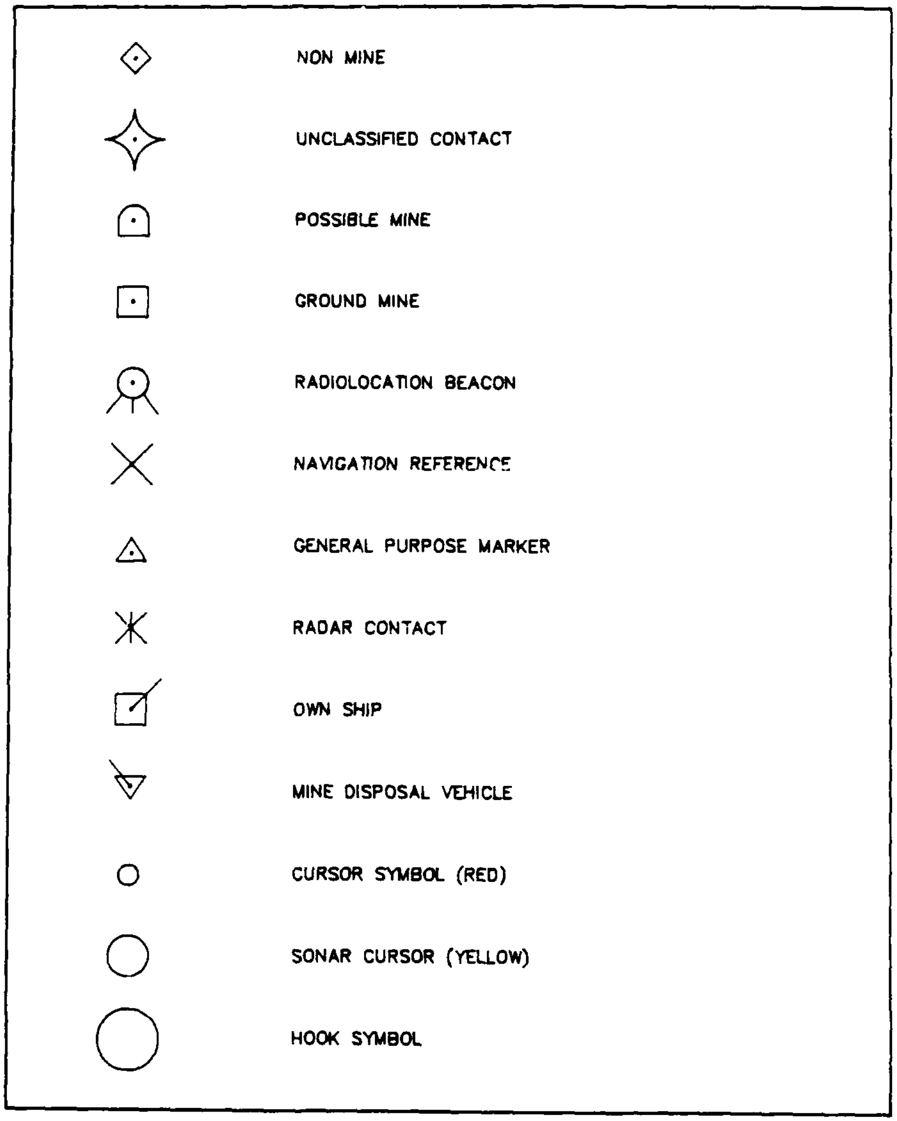

Figure 4. Minehunter (MHWS) symbology

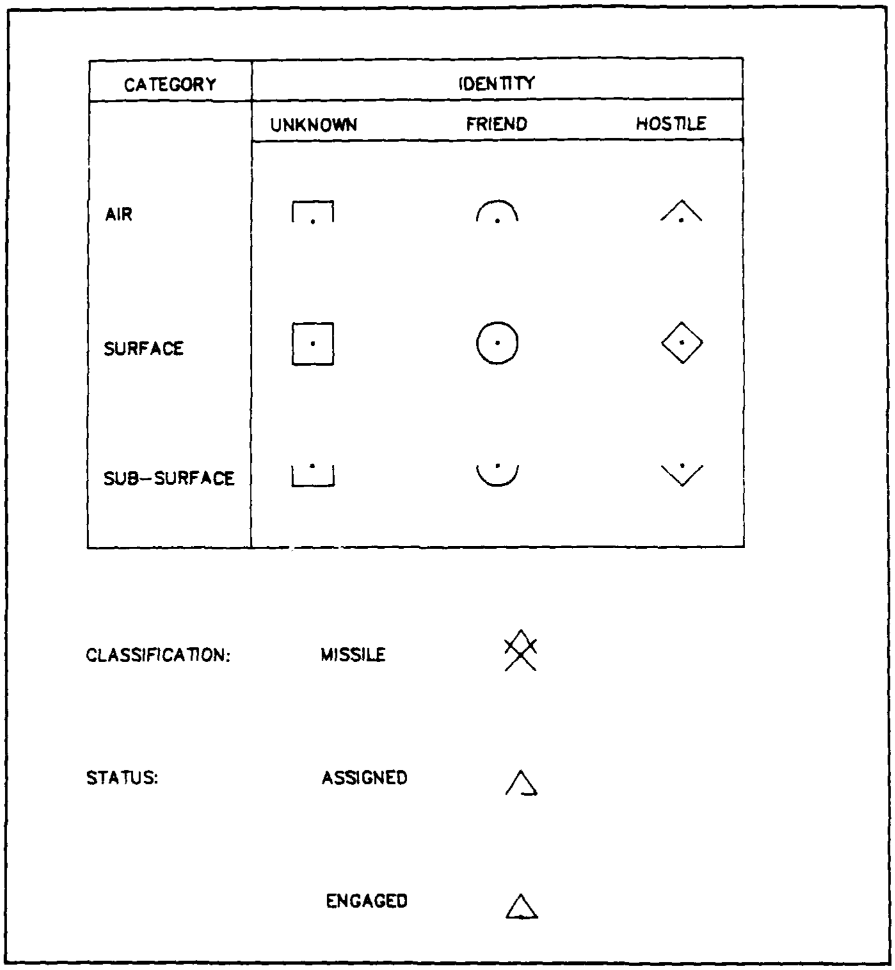

Figure 5. NCDS symbology

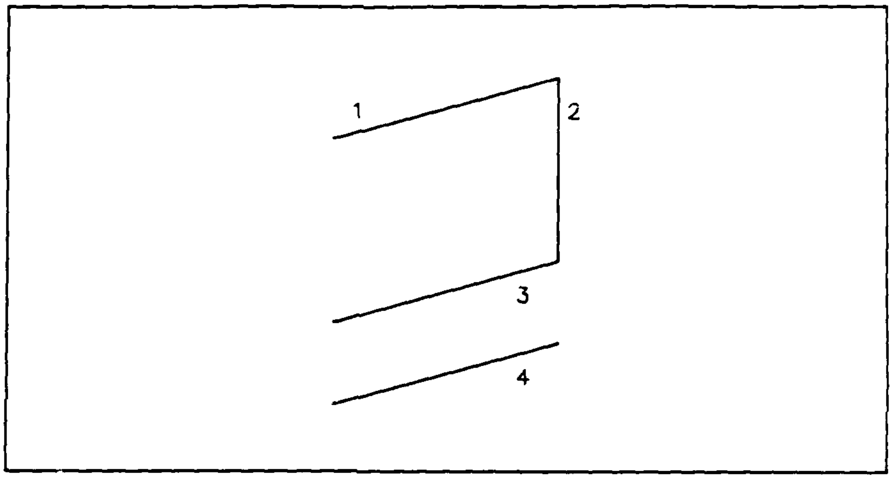

Figure 6. MHWS laptrack annotation

REF NO	LAT	LONG	DEPTH	CB	CLA
4007	13.55.100S	136.20.471E	33	–	UCC
401	13.55.463S	136.21.243E	37	321	POM
402	13.54.217S	136.20.322E	30	063	GMN
403	13.53.111S	136.22.983E	41	005	GMD
404	13.54.261S	136.22.945E	25	110	GMD

TOTE DISPLAY WITHOUT LPD SYMBOLOGY

CONTACT	LAT	LONG	DEPTH
 4007	13.55.100S	136.20.471E	33
 401	13.55.463S	136.21.243E	37
 402	13.54.217S	136.20.322E	30
 403	13.53.111S	136.22.983E	41
 404	13.54.261S	136.22.945E	25

TOTE DISPLAY USING LPD SYMBOLOGY

THE EXAMPLE SHOWS A LIST OF UNDERWATER CONTACTS. IN THE LOWER PANEL THE BEARING OF CLASSIFICATION (CB) AND THE CLASSIFICATION (CLA) ARE SHOWN SYMBOLICALLY RATHER THAN BY USING ALPHANUMERICS.

Figure 7. Use of symbolic information in TOTE displays

```
MINEHUNTING

PLOTTER CONTROL

   1   SCALE                  :  5000

   2   ORIENTATION            :  90

   3   CENTRE    LAT          :   13.55.000S
       (H)       LONG         :  136.20.322E

   4  GRID SPACING LAT        :  2
                   LONG       :  2

   D   RETURN
```

Figure 8. MHWS text menu example

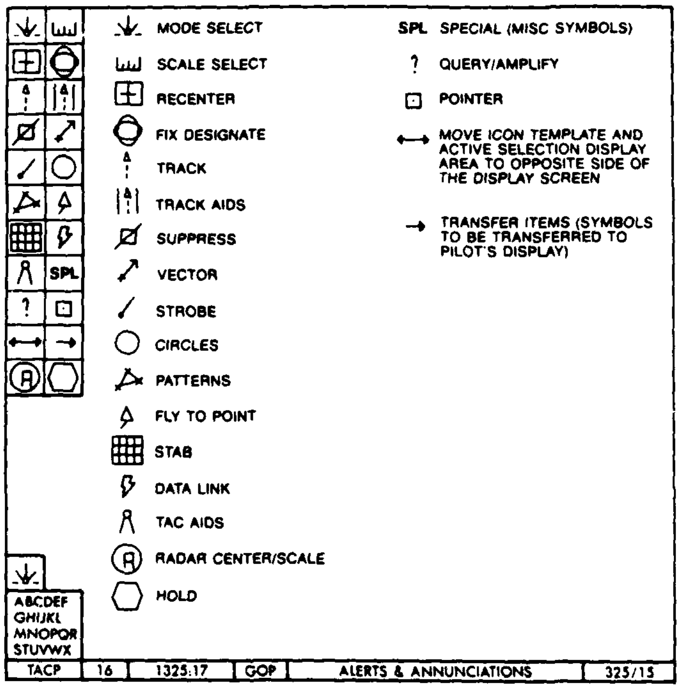

Figure 9. HTDS symbolic (Icon) menu example

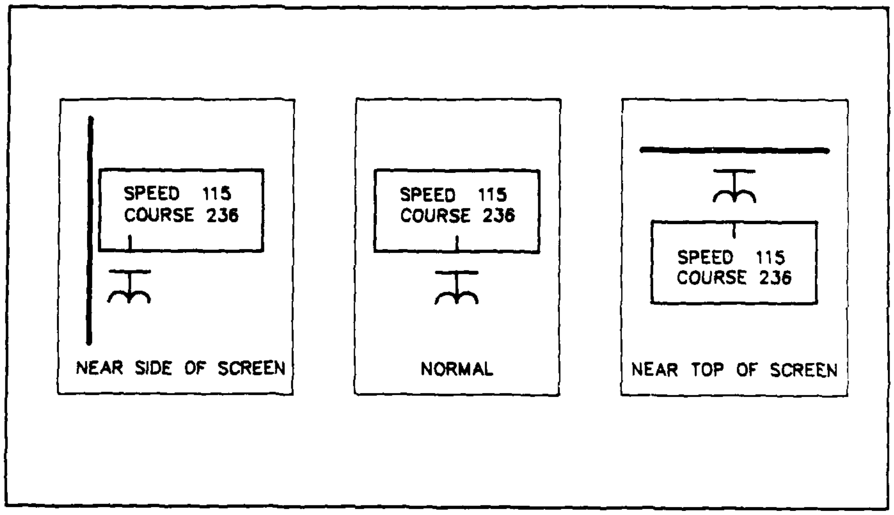

Figure 10. Amplification box positioning

MINEHUNTING

LPD CATEGORY SELECTION

1 SHIPS HISTORY

2 WATER DEPTH / BOTTOM CLASS

3 GEN PURPOSE MARKERS

4 NON MINE CONTACTS

5 SAFETY CIRCLE

6 BOUNDARIES

7 SYMBOL / SEGMENT NO

8 MINE REF NO

9 SONAR CURSOR

Figure 11. MHWS declutter menu

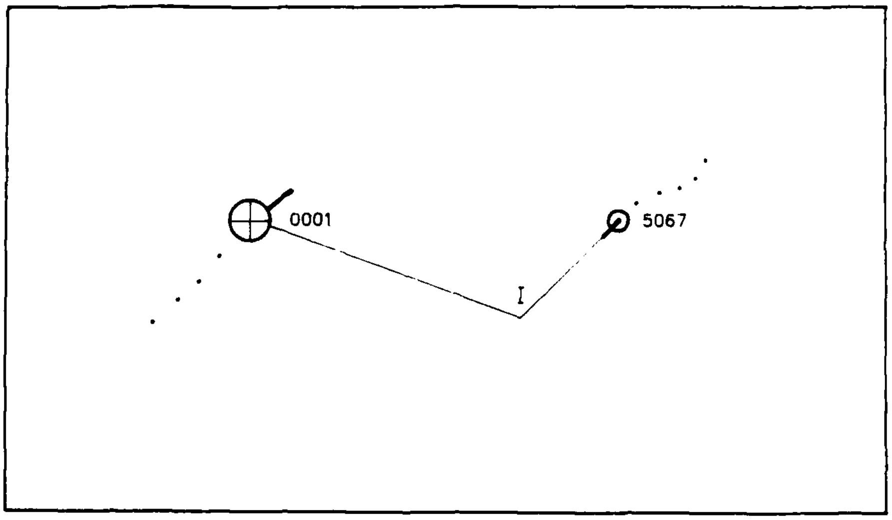

Figure 12. Display of intercept graphical solution (HTDS)

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17 SUMMARY OR ABSTRACT
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Computer generated tactical displays are now commonly used in presenting information to aid decision making in military command and control systems. Similar displays are used in non-military applications, particularly air traffic control. This paper examines the functional characteristics of such displays with the aims of establishing a baseline from which decisions of equipment selection and more importantly functional design or specification may be made.

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