AN ECDIS FOR HIGH SPEED CRAFT

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1. INTRODUCTION
The number of high speed craft is steadily growing. Such vessels have become popular as an effective element in the mass transportation system between coastal cities. It has proved to be a competitive alternative to air and ground transportation in a number of areas.

The typical service speed of the high speed ferries built is in the range of 30 - 40 knots. However, new designs have service speeds of about 50 knots. As the number of craft is growing and the speed increasing, it is worth while to concentrate on designing bridge systems which at the same time improves safety as well as efficiency and economy.

We are convinced that ECDIS (Electronic Chart Display and Information System) will be a key element in order to prevent accidents, and hence make the operation of fast marine craft even safer.

In this paper we describe the first ECDIS specifically designed for high speed craft. The first released version of the system has already been installed and is being tested onboard.

The ECDIS described here is the first commercial result of a 3-year research and development program into integrated cockpits for high speed crafts. The program focuses on high speed craft because of the tough operating conditions the operators of such craft are facing every day. On the basis of experience with high speed craft operation, versions are derived for use on ocean-going vessels.

2. HIGH SPEED CRAFT OPERATING CHARACTERISTICS
The requirements for a High Speed Craft ECDIS is based on the special operating characteristics of such craft. Important operational differences between conventional ships and high speed crafts are:

- Higher speed. While the speed of conventional ships typically is around 15 knots, the high speed crafts have service speed up to around 50 knots. The higher speed, of course, translates into a more compressed observation, evaluation, decision, action cycle for the navigator.
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- A larger part of their operation area is in confined and narrow waters. Thus, the distances from the craft to potential navigational hazards are smaller. Aiding the navigation in such waters means providing greater navigational accuracy and integrity, hence there is a need for accurate charts and accurate position fixing of the craft at high speed in real time.

- A larger part of their operation time is spent under more dense traffic conditions.

Figure 1 shows typical waters of a fast ferry route at the west coast of Norway.

![Map of coastal waters](image)

Figure 1. Typical area of operation for fast ferries on the west coast of Norway.

Each of these factors add to the challenge of safe operation. Under severe circumstances, unfortunate combinations of the different factors may bring the total system to the limit of safe operation. A recent fatal high speed craft accident at the west coast of Norway was a serious reminder of this [Havi91].

Safe and accurate navigation is an equally important element for military high speed craft. Operational analyses of the next generation of Norwegian fast patrol boats have shown that speed higher than 50 knots is of great importance both during transit and in an engagement situation. To reduce the probability of detection, the boats should also take advantage of the terrain by operating close to shore. In order to achieve this with minimum staff, an ECDIS will be valuable.

3. PROJECT OUTLINE

The development of the ECDIS was initiated early 1991. The development has been undertaken by NDRE in cooperation with Kvaerner Eureka a.s. The project was coordinated to the development of Kvaerner Fjellstrand's first foil assisted catamaran, the FoilCat, since the FoilCat project awarded Kvaerner Eureka the first commercial ECDIS contract. The FoilCat is designed such that with a service speed of 50 knots in 3 meter waves, without discomfort for the passengers. Operational
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safety has been a key concern in the FoilCat design, and an ECDIS was chosen as a key component of its bridge.

3.1. The FoilCat
The FoilCat is a low flying foil assisted catamaran with a fully submerged active foil system. This takes the FoilCat foilborne from about 30 knots up to its maximum speed of 50 knots. The FoilCat is shown in Figure 2.

![FoilCat](image)

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<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Length overall</td>
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<td>Propulsion</td>
<td>2 water jets</td>
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Figure 2. The FoilCat

The FoilCat was launched last Fall and is currently undergoing an extensive test program. The FoilCat will be put into service on a route between the Danish and Swedish cities of Copenhagen, Helsingborg and Aarhus later this year. The route is shown in Figure 3.

3.2 The FoilCat Bridge
The ECDIS and the other main components of the bridge of the FoilCat are shown in Figure 4. There are two radar systems - one ARPA (Automatic Radar Plotting Aid) connected to the ECDIS and one stand-alone, the ECDIS, an information and monitoring system (FIS) -which also serves as a sensor concentrator, navigation sensors, an autopilot, an automatic foil control system (AFCS), and an engineers station. Figure 5 illustrates the actual bridge layout.
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4. ECDIS

4.1. Overview
Since the ECDIS is foreseen to have a significant lifecycle, and since IMO and IHO regulations and requirements are still under consideration, we expect to do a number of adjustments and modifications in the application software. Hence, special emphasis was put on the environment in which the ECDIS was to be developed. We wanted to take full account of the different industry standards for open computing systems which have emerged in the last years to make the ECDIS-software as hardware independent as possible.

These considerations, in addition to the requirements for effective graphical processing, made us select a ruggedized rack version of a Silicon Graphic Personal Iris workstation as our ECDIS platform. The same considerations guided our selection of system software tools as well. The ECDIS application software has been implemented utilizing Unix system V with real-time extensions, X11 [X89], Motif [OSF90], and GL. The programming language used is C++. Finally, as is seen in Figure 4, the communication between the ECDIS and its sensors employs an Ethernet using TCP/IP.

GPS/DGPS, log, and gyrocompass provide the measurements for the own craft positioning in the ECDIS. The log and gyrocompass are used in dead reckoning between position updates from the GPS and also used in the case of GPS malfunctioning and possible shadowing of GPS satellites.

Differential GPS (DGPS) utilizes the SATREF-system (Satellite Reference) off the Norwegian coast. In SATREF the differential corrections are broadcasted by radio beacons. Currently, three reference stations and three radio beacons are operational in the area which the FoilCat operates. The current DGPS coverage in SATREF is indicated in Figure 6. As Figure 3 shows, an autopilot is connected to the ECDIS for semi-automatic track-keeping.
Figure 4. Major FoilCat bridge components and their interconnections.

Figure 5. Actual bridge layout of the FoilCat
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Figure 6. Current SATREF DGPS coverage in southern Norway.

Lastly, the ECDIS has a serial interface to the ARPA for communication of ARPA-targets. The electronic navigational charts (ENC) for this ECDIS are provided by the Norwegiand Hydrographic Service (NHS) and the ENC-format is the NHS-format, which was also used in the Seatrans project [Mari91].

4.2 ECDIS Design
Object-oriented techniques used throughout the different phases of software development has in recent years received wide recognition as a possible remedy for some of the pitfalls of software engineering [Rumb91]. The ECDIS was developed using object-oriented methods and techniques throughout all phases of analysis, design and implementation. In the application domain of ECDIS, examples of real world objects are:

- chart objects such as lights, buoys, soundings, or simply geographical points,
- vessels such as own craft and other vessels,
- navigational objects such as routes, bearing lines, variable range markers, and
- sensors such as GPS, log, gyrocompass etc.

The ECDIS was developed around these objects. This is true both for its software and its user interface.

In addition to the real world objects discussed above, the ECDIS software also consists of software design classes which are only meaningful for the application software engineer.

These (internal) classes are concerned with issues like software process realization and communication. For a more thoroughly discussion of the software issues of the ECDIS, see [Nico91].

The user interface of the ECDIS is organized around the real world objects outlined above. Object-oriented, direct manipulation user interfaces have recently become a leading user interface metaphor. This has guided our interface design. Additionally, we wanted adherence to the Motif
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style, and its look, and feel. Consequently, the functional capabilities of the ECDIS available to
the user is grouped around the identified classes. Thus, the user interface based on an object-action
input selection model. Selection of an object is performed by associated software pushbuttons
and/or by pointing to its graphical representation on the chart.

As seen in Figure 7, which shows a sample ECDIS screen, six software pushbuttons are associated
with the chart, the own craft, the navigation sensors, the route plans, an electronic pair of
compasses and the ECDIS (system) itself. Whenever an object is selected, its associated attributes
are displayed. Actions or functions associated with objects become available by pop-up menus for
objects selectable on the chart or in the screen area immediately below the object pushbuttons.

Figure 7 shows further that the screen is divided into two major windows, a quadratic chart
window and an information and user control window. The information and user control window is
further divided into four areas. The content of two of these windows is defined by the selected
objects, and two have fixed content. The content of the areas defined by the selected objects is the
actions and the attributes, respectively. The two areas with fixed layout include information
available to the user at any time and the six pushbuttons.

The user interaction devices of the ECDIS are a trackerball with associated buttons and three
dedicated function keys. The three dedicated function keys are:

- Reset to standard chart display,
- Toggle for display of ARPA-targets on the chart, and
- An alarm acknowledge.

The three trackerball associated buttons are selection, action, and close.

4.3 ECDIS features
The ECDIS has been designed to meet the provisional performance standards of IMO [IMO89].
The functional presentation is organized according to the classes described above:

- Presentation of current own craft, ARPA targets and navigational objects on the electronic chart
display.

- The chart may be presented in true motion and true motion fixed mode either north- or course-
up. The own craft position remains fixed on the screen while the chart scrolls according to own
craft motion in the true motion fixed mode. The fixed own craft position may be offset to allow
for a better look ahead capability.

- The chart can be zoomed, and the availability of more than one chart scale in a given area is
notified to the user.

- Chart objects, such as light and light-sectors, buoys, soundings, text, etc. can be presented or
suppressed on the chart. Moreover, the chart can be presented with or without a grid and
different time-of-day colours.

- Attributes of ENC- and other navigational objects can be presented by selecting their graphical
representation. Attributes common to all objects are bearing and range from own craft.
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- An electronic form of a pair of compasses is available to provide electronic bearing lines and variable range markers between any two selected objects in the chart. The bearing line and range ring are dynamically updated according to the selected object movements.

- During route monitoring, routes can be selected and displayed. During route planning, routes can be selected, presented, created, deleted, copied, reversed (reversing the ordering of route waypoints) and renamed. A route is edited by manipulating (adding, deleting and moving) its waypoints. When defining waypoints, the route is checked for possible conflict with an own craft safety depth contour to avoid routes in conflict with soundings, depth contours, and shorelines.

During route planning another chart area may be selected by specifying a geographical position or by scrolling the chart to the desired area.

- The own craft motion state vector for the last 8 hours is stored and the past track can be displayed. When own craft position is determined by dead reckoning, its position can be reinitialized. The own craft position is monitored to provide anti-grounding alarms. Own craft can be set in track-keeping mode with respect to a planned route. Then, the ECDIS communicates crosstrack errors and course to steer messages to the autopilot, notifies the user at the approach of wheel over points and sounds an alarm when a predetermined deviation limit from the track is violated.

- Attributes values of the ECDIS itself can be updated and an overview of the ENC's currently in the ECDIS is provided.

5. PROJECT STATUS

The FoilCat with its ECDIS installation is currently undergoing an extensive test program in the "Hardangerfjorden" close to the city of Bergen in Norway. The ECDIS is in continuous use, with a chart database provided by the Norwegian Hydrographic Service (NHS). Two new 1:50 000 chart cells were produced to cover the FoilCat test area.

The general impression so far is quite positive, and valuable operational experience is fed back to the development team for further enhancements and optimization.

Arrangements have also been made with NHS to provide the ENC's for the Copenhagen - Aarhus route. This will be done in cooperation with the Swedish and the Danish Hydrographic Services. The ENC's for the route area are to be produced in the IHO DX-90 format.

The ENC production is being done by the newly established Digitale Kartsystemer A/S (DIKAS), Oslo, Norway, partly owned by Kværner Eureka a.s. on behalf of NHS. DIKAS has also been awarded a development contract from the Norwegian Government and the NHS to establish digital chart production and maintenance facilities. The production of the ENC's for the FoilCat route has been selected as a first case for this production facility.

Our preparations to read DX-90 formatted charts have confirmed that our software design structure complies well with the IHO object catalogue. When DX-90 charts become available, the object oriented interface can also be more fully exploited by utilizing the rich attribute set available for the objects. In our current sea trials, the available ENC's are in the NHS format. DIKAS has produced a NHS format to DX-90 translator.
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A version of the ECDIS has been configured to be installed in an ocean-going vessel. The first integrated navigation system will be installed in the gas tanker "Hera" which operates between Teeside in the UK and Rafnes on the southern coast of Norway. Onboard the "Hera", the ECDIS system will be fully integrated with an Anschütz auto pilot and two Racal Decca radars. The "Hera" installation will be operational in the second quarter of 1992.

6. EXPERIENCE SO FAR

Although the development and operational test of the ECDIS are not yet finalized, a number of lessons both with respect to the design of the ECDIS and ECDIS on high speed crafts have been learned. Some of these are summarized in this section.

A relatively large part of the software development time has been spent with the issue of transforming the ENC database provided by the NHS to an SENC to speed up the reading from disc, the application processing and the graphical processing. The transformation does not involve any data reduction or compression, only restructuring and formatting. We agree with the opinion expressed in [Mar:91], that data reduction or compression should be done on the original ENC database in order to eliminate potential quality problems for the ECDIS manufacturer. Our resultant data structure employs a kind of quadtree and the different software processes access it using pointers into semaphored shared memories. The transformation also involves a partitioning of large closed polygons and detection of crossing lines in the closed polygons.

For an ECDIS on high speed crafts, double buffering should be utilized to provide acceptable performance when a fixed mode or course-up/head-up display mode is utilized. It may seem that the fixed mode is especially appropriate for high speed craft ECDIS, but further evaluations are needed before any final conclusions may be drawn.

The organization and sequencing of the user dialogue itself is appropriate and we have had positive user feedback concerning this.

The location of the physical interaction devices in the cockpit plays an important role in the design of an easy to use manoeuvring and navigation system. It is our experience that the trackerball and all the associated keys should be integrated in the armrest of the chair.

In order to ensure that ECDIS improves high speed craft safety, it is our experience that the following issues must be controlled:

- Chart scale and accuracy. Scale 1:50 000 is inappropriate in many areas.
- Positioning accuracy and real-time performance, including not only the nominal values for GPS/DGPS accuracy, but also taking into account the measurement update intervals, dead reckoning sensors accuracies, and processing update intervals and delays.
- Own craft dynamic characteristics, including speed, turn rate, and safety stop distance.

The ECDIS prime function is to enhance safety. In order to do this properly, it is important that the operator at all times is aware of navigation accuracy and quality. In order to achieve this, we shall include a navigation accuracy estimation facility. If the accuracy is outside the safe limits, the navigator shall be properly warned so he can make his own operational decisions.
7. NEW DIRECTIONS
The FoilCat bridge is our first installation of a new generation integrated control systems for high speed craft. It marks a first step in improvement in operational and safety aspects compared to conventional designs where, typically, the instruments provided by different manufactures are located on the bridge to be within reach of the pilots, but the overall design is done in a more or less ad hoc fashion. More importantly, the different manufacturers normally have their own principles for operation, information presentation, and systems architecture. The latter leads to the fact that very limited information can be integrated in a way which is meaningful to the operator.

As more and more components are computerized, several of the subsystems offer the same kind of functionality. An example is route planning which often is found in GPS-receivers, ARPA radars, and now also in ECDIS.

We believe that a much more unified and overall perspective on the bridge design of high speed crafts are required. The development of the ECDIS and the FoilCat bridge marks the beginning of a research program into integrated control systems and cockpit design for high speed crafts. This research is sponsored by the Royal Norwegian Council for Scientific and Industrial Research and is part of a larger research program on maritime information technology focusing on automation and integrated bridges for both conventional ships and high speed crafts. Kvemser Eureka a/s is the prime contractor for the high speed craft part with NDRE as their primary research partner.

The development of complex man-machine systems is an extremely challenging task. Our approach is "user-centred" and is based upon a blend of both experiments and formal analysis. The experimental part includes prototyping, user participation, -testing, and -evaluation. The Foil Cat bridge and laboratory prototype simulators provide an infrastructure for the experiments. In the simulators we are able to run man-in-the-loop real-time simulations of the key functions to be performed on the bridge of a high speed craft, including navigation. The navigation sensors are simulated and failure situations can be introduced, either by predefined scripts or interactively during run-time.

ECDIS is only one of the navigation components to be integrated in a high speed craft cockpit. In our continued research we emphasise integration between radar and ECDIS, including correlation of chart and radar images as an independent navigation method, the use of ENC-data for anti-collision calculations, decision support tools both in route planning and route monitoring process, and more automatic situation adaption with respect to display options.

Although we have had limited operational experience with the ECDIS on the FoilCat, we have learned the lesson that special care and consideration should be given to the special requirements of high speed craft. We believe that our experience should influence the ongoing process of establishing performance standards for ECDIS and possible special requirements that may be made applicable for high speed craft. Such standards should be based on operational tests and evaluations. Some of the tests and evaluations which are to be performed in this project in the near future could prove to be very valuable in this respect.
REFERENCES


