Ship Automation for the 21st Century

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September 1996
Expert Systems in Marine Automation – An Introduction
Volker Bertram
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Recent research in all high-tech shipbuilding nations has aimed at drastic further reductions of crew levels for both cargo and navy vessels. All approaches see Artificial Intelligence, especially expert systems, as the key to achieve this ambitious target. Unmanned ship transport is discussed and shown to be unlikely due to economic and social aspects. The elements necessary for automatic cargo and navy ship operation (nautical, machinery, communication, cargo, damage control and combat control) are discussed in turn showing state of the art and trends. An appendix gives a compilation of expert systems for marine automation.

The Intelligent Ship: Automatic Navigation
Hironao Kasai
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Within the Japanese 'Intelligent Ship' project, a knowledge-based system has been developed for a ship’s integrated on-board navigation control including autonomous piloting, collision avoidance, data communication management and supervisory control of a variety of automation subsystems on board with substantially no human assistance by an operator. Knowledge was acquired through listening to shipmasters’ expertise together with the traffic rules and regulations. On-line/real-time voyage simulations were carried out for a container liner taking also into account 'unexpected’ occurrence of accidents. Results show the basic applicability of the system’s autonomous function to actual ship control and on-board management. A full-scale ship trial was carried out using an experimental prototype of the system demonstrating its basic autonomous functions, foremost its automatic collision and grounding avoidance. The prototype was expanded and has been installed under the name SuperBridge on a VLCC.

Ship Automation – Ship Safety: A Classification Society’s View
Hans Payer
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Present day ship-automation is well advanced. What is said about the navigation of modern aircraft, namely ”don’t fly the airplane, fly the computer” is practically true also for the ship with the one-man bridge. And we may even go further: using the capabilities of automation, data acquisition, telecommunication technology in combination with Artificial Intelligence, we can imagine an unmanned, computer guided ship, just as we are thinking about the pilotless airplane. Such a system is feasible today, but does it have pronounced advantages? A realistic question today is, how can we sensibly use these capabilities to improve the safety of ship operations, and to what extent. Technical and practical aspects of further automation are adressed pointing out potentials and pitfalls. The implications for ship operation are discussed. Further progress will require action from all parties concerned. Here emphasis is given to the work of ship classification societies and the contributions to be expected from them. It is the main concern of ship classification societies to continuously improve ship safety by reducing any risk in the operation of ships. This includes normal operation as well as such dangers as overloading, collision and grounding. Quality checks, the reliability of automation systems, and the procedures for approval and certification are dealt with.
In the R&D project SHOPSY, the basics for an improvement of ship’s operation as well as a contribution for the increase of safety should be provided by the introduction of a new information technology on board of sea-going vessels. Special concentration was put on the development of intelligent diagnosis systems and information systems. With the introduction of model based diagnosis methods, fundamentals have been provided for a new generation of ship control and monitoring systems. With the linkage of generic expert’s knowledge with the conditions of a special ship’s system, knowledge-based diagnosis systems can be provided, which go far beyond the capabilities of existing monitoring systems. Another main item of the project has been the development of nautical information systems, which are integratable under a common user interface. This includes systems like route control systems, route planning systems as well as systems for automatic collision avoidance. Basic analysis of the documentation of ship’s operational systems and components, which are essential for proper maintenance and safe operation, have been performed to achieve a standardized documentation as well as an optimal administration. For the introduction of new maintenance strategies, methods for the assessment of the technical condition of main components based on the analysis of structure-borne noise signature have been developed and adjusted to the onboard conditions.

The Autonomic Ship
Scott Hoyle
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The Autonomic Ship concept as developed by the Carderock Division, Naval Surface Warfare Center’s Innovation Center addresses leveraging advanced computer technology to achieve total systems integration, automation and manning reduction in future navy ships. The concept integrates distributed architecture, information technologies, and modular systems that utilize the four Autonomic principles: fault tolerant systems, software objects, ubiquitous computing, and task and functional analysis. Simply the vision of the Autonomic Ship can be described as a ship where the people decide what to do and the ship makes it happen. The study shows how the current crew of 359 on a DDG 51 destroyer could be reduced to 101 by applying autonomic principles.
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1. Introduction

Around 1900, ocean-going cargoships had crews of 100 men. This has been reduced to typically 15 to 16 men today, with levels as low as 6 men advocated by some Scandinavian countries. Further reductions in crewing level are desirable due to the shortage of qualified seamen, a problem which is amplified by the current age structure in seamen. For reasons of economy, safety, but also work quality for seamen, further automation is strived for worldwide by all high-tech shipbuilding nations. The ultimate in crew reduction would of course be an unmanned ship.

In fact, unmanned ships have been proposed in one form or another in various publications, Schölknecht et al. (1983), Lin (1990), Shimoyama and Yamagami (1990), Janeba (1990), Ditzio et al. (1995), Kasai and Bertram (1996). Little has changed in today’s view of this issue from Schölknecht’s vision: "In this age of rationalisation and automation it would not be difficult to imagine a ship without a crew. [...] It is indeed quite possible that at some distant future date the captain will perform his duties in an office building on shore. In his place he will leave a computer on board ship which will undertake all the tasks of the navigator’s art, or [...] controlling the ship, and will in fact perform the task much more effectively. [...] But we shall be well into the next century before any of this has come to pass.” The proposed unmanned ship concepts can be classified into:

- 'Shore Captain’ concept
  This is the concept outlined in the quote above. The control system is transferred ashore. The ship retains only a largely self-regulating propulsion plant together with the equipment needed for reception, transmission, and decoding of the control signals received from the shore and supervision of onboard systems.

- 'Captain Computer’ concept
  The ship is equipped with sufficient hardware and software to perform all tasks and decisions autonomously using 'Artificial Intelligence' (AI). In practice, a mix of local and remote control will be employed with redundancy for vital systems in case the communication link breaks down or local systems fail. Even if such a system could cope with all normal conditions for a voyage from quai to quai, some problems are unlikely to be handled satisfactorily by either of the first two concepts. This includes on one hand the repair of faulty equipment, on the other hand piracy.

- 'Master/Slave’ concept
  Convoys of unmanned 'slave ships' remote-controlled from a highly automated 'master' escort ship have been proposed in Japan and Germany. Such a concept would solve the issues of repairs and piracy, but one large ship with the same crew as on the master ship would be simpler and more economical.

In summary, an unmanned ship appears at present not to be economical, even though many of the technical obstacles could be overcome in a short time. A more detailed analysis of this hypothesis is subject to current investigations. Navies may see special applications (mine sweeping, reconnaissance, etc) for unmanned ships. The American prototype of a Picket Hydrofoil Autonomous PHA ship points in this direction, Meyer et al. (1995).

Fully-automatic ship operation is never-the-less interesting for commercial shipping, even if future ships will still feature crews. "In the foreseeable future, [...] we shall be dealing with highly automated ships, on which the computer will be one of the captain’s most important aids”, Schölknecht et al. (1983).
Automation offers the possibility for crew reduction, but even more for improving safety. The rapid development of the technology in this field should concern regulatory bodies, classification societies, mercantile marine training institutes, but also navies.

I will discuss various aspects of ship operation with respect to automation (problems involved, frontier applications):

- **Navigation** in the widest sense which includes also berthing/anchoring and route planning
- **Machinery Operation**, i.e. control and maintenance of the main and auxiliary machinery
- **Communications**, which includes the usual ship/shore communication as known today and additional external and internal data communication necessary for an autonomic ship
- **Cargo and Domestic Work**, which includes cargo keeping, loading/ discharging, cargo administrative work and administration, medical care, catering, etc.
- **Damage Control and Combat Control** which affect primarily navy ships

2. **Navigation**

Open-sea navigation comprises the typical tasks of a control process: planning, executing, and monitoring which are repeated in cycles. The execution of steering involves the tasks of a conventional autopilot widely in use on modern ships and needs no further discussion.

Route planning consists of

- **Long-distance route planning** (routing)
  
  Initial routing systems simply aimed at avoiding tropical hurricanes. Modern weather satellites and improved algorithms allow today the economic optimisation of the voyage. Such routing systems are already in practical use, but further refinements are subject to current research. Most routing systems are based on conventional programming approaches. The late 80's saw the first developments to add heuristic and learning capabilities to the existing voyage planning approaches. "The aim is to devise on an optimum voyage plan subject to constraints such as legislation, charter party details, route and weather, ship condition and ship responses to motion", Katsoulakos and Hornsby (1989). The Expert Seakeeping Guidance System (ESGS), Dumbleton (1990), Hornsby (1990), uses real-time measurements (power, rpm, speed, heading, environmental conditions, motions) and empirical relations to minimize the total voyage cost. The expert knowledge largely refers to the selection of the optimum route accounting for specific ship loading, motion behaviour, and charter/liner contract considerations. ESGS has been installed on several container vessels of APL (American President Lines). "The Expert Voyage Pilot (EVP) is a prototype route optimisation system, making use of numerical algorithms for speedkeeping and ship responses, and adding to this heuristic reasoning for route optimisation using predicted and statistical weather information, navigating to minimise total voyage cost and the risk of heavy weather damage", Hornsby (1990). Application of expert systems to routing is possible, but I do not see it as compelling or even very beneficial.

- **Short-distance route planning** (collision/grounding avoidance)

  Collision-avoidance systems use expert systems to incorporate traffic rules and regulations, but also the experience of ship masters. The route of the own ship is checked against other 'target' ships as supplied by onboard ARPA (Automatic Radar Plotting Aid) and restricted areas (e.g. shallows) in an electronic sea chart. If the danger of collision or grounding is diagnosed, an avoidance route is automatically selected usually based on the criteria of minimum collision risk, length of avoidance route, and steering action. Several such systems are world-wide under development, e.g. Froese and Mathes-Thiele (1994), Froese (1995), Kasai (1996). Grounding is
avoided using electronic charts which are under development. German electronic chart systems have been tested successfully in ferry operations on the Baltic Sea. Electronic charts need further standardisation and we have yet to cover all major commercial sea routes by electronic charts, but work is active in this field and there are no fundamental problems in sight.

The main monitoring tasks comprise the position of the own and other ships in addition to some ship state parameters such as propeller rpm, rudder angle, etc. The own ship’s position and speed can be obtained from Loran-C, Decca, GPS, DGPS, Doppler log, or electro-magnetic log. The position can be determined with an accuracy of about 100m on the open sea, and 10m near coastlines using advanced differential GPS (global position system). This should be sufficient for practical purposes. ARPA is used to determine the relative positions, headings, and speeds of target ships. However, ARPA’s automatic target acquisition reliability is limited. Small ships/boats are sometimes not detected. Furthermore, ARPA cannot diagnose the type of ship, e.g. sailing ship, which is a vital information for certain rules of collision avoidance. Japanese attempts to use video cameras and pattern recognition for this issue were not successful. So the target sensor technology needs further improvement for a fully automatic system. IMO is preparing the introduction of radio transponders which would solve most of the current problems in this area, Petterson (1995). Transponders would allow determination of ship types, detection of wooden or plastic boats, and even special treatments for ships with hazardous cargo.

Apparently we are close to see integrated systems for fully automatic navigation including collision-avoidance. Japan is most advanced in terms of implementation in this field. A real-ship trial with an automatic collision avoidance system was performed near the Bay of Tokyo in an area of dense traffic, e.g. Kasai and Bertram (1996). The ship steered safely in the congested sea traffic solving all collision risk problems. The avoidance judgements and actions appeared reasonable, even though crude compared to an experienced helmsman. Further refinements resulted in the commercial SuperBridge system installed in the VLCC 'Cosmo Delphinus'. SuperBridge is an advisory system requiring a human confirmation of the system’s decision. This appears to be a natural first step in the introduction of these systems. With growing confidence in the automatic processes, the adoption of ‘unmanned’ bridges at night and on open sea (probably with a ‘fireman’ resting on the bridge only to get into action if alarmed by the system), and ultimately the use of such a system during all times also in congested waters with dense traffic seems feasible.

Similar systems could be employed by navy vessels: "An enhanced autopilot, part of the single navigation resource, will be linked to the self-defense system to provide an Autonomic response. Upon detecting an inbound missile, the Autonomic Ship will change course in a direction that will optimize chaff use with the wind conditions and present the missile with the most challenging target profile, yet avoid shoal waters and mine fields", Ditizio et al. (1995). Similarly, the automatic navigation system would react if fire is detected onboard. In computer simulations for a containership, the system was fed with the information indicating a fire aft. The system turned the ship to bring the fire source downwind and initiated further countermeasures, Kasai and Bertram (1996).

Quai-to-quai transport requires more than just automatic route planning. Further problems to be solved are automated berthing and mooring. Fully automatic berthing/unberthing has been proven possible in field tests, Ohtsu et al. (1991), Kasai and Bertram (1996), but requires some special installations also on the harbour-side. Automatic berthing could work as follow. An electro-optical system determines the distance and the relative angle to the berth. An onboard transmitter directs an optical signal to the target system on the berth. The signal is then reflected by a prism and returns to the transmitter. The distance ship-berth follows from the phase difference between transmitted and received signals. At the same time, the projector in the target on the berth transmits an optical guidance signal which the position sensor on board tracks to align towards the direction of the target berth.

Conventional mooring work requires considerable manpower. A highly automatic ship must be designed for automatic paying out and winding up of the mooring lines to save manpower. For anchoring,