SCHRIFTENREIHE SCHIFFBAU

LESEPROBE

Technische Universität Hamburg
Artificial Intelligence for Ship Automation - Technical and Economical Aspects of Reduced Crews

Patrick Kaeding
Volker Bertram

Oktober 1996
Copyright Institut für Schiffbau
der Universität Hamburg
Lämmersieth 90
D-22305 Hamburg
## Contents

1. Introduction 2

2. Introduction to Artificial Intelligence and Expert Systems 5

3. Navigation 9
   3.1 Collision and Grounding Avoidance 9
   3.2 Berthing 14
   3.3 Routing 16

4. Machinery Operation 19
   4.1 Recent Trends 19
   4.2 Fault Diagnosis Systems 24
   4.3 Fault Diagnosis Systems with Maintenance Functions 25
   4.4 Other Systems 28

5. Communication 29

6. Cargo and Domestic Work 31

7. Damage Control and Combat Systems 33

8. Integrated Operation Control 36

9. Case Study: A Panmax Containership 40
   9.1 Basic Considerations and General Arrangement 41
   9.2 Weight Calculation 42
   9.3 Container Capacity 42
   9.4 Economic Comparison 43
   9.5 Economic Aspects of Further Automation of Manned Ships 44

10. Conclusion 49

    References 51

    Appendix: Expert Systems Survey 56

---

### Abstract

A survey of recent developments and proposals for ship automation has the focus on approaches involving Artificial Intelligence, especially expert systems. Unmanned ship transport is discussed and shown to be unlikely due to economic reasons. A major problem lies in creating economic and at the same time highly reliable ship machinery. An appendix gives a compilation of expert systems for ship automation.
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, all high-tech shipbuilding nations strive for further automation.

The ultimate stage in ship automation would be unmanned ships. The idea of zero-crew ships is not as far-fetched as it may sound to many. Automation has made great progress in the field of transportation. The automotive industry has prototypes of cars that automatically reduce speed when approaching curves or other vehicles. Passenger flights with remote controlled airplanes were seriously discussed on the Aerospace Asia tradefair in Singapore in 1996. (Remote controlled airplanes for military purposes are already reality.) Also for trains and subways there is a reported tendency to 'unmanned' (no operator) transport. In light of this general tendency, it is not too surprising that a literature survey revealed that unmanned ships have been discussed in one form or another in various publications, e.g.:

Munk (1989) states that it "is of course possible to remove the crew completely", and Lin (1990) outlines the direction to reach this aim: "The integration of the meta-expert system, conventional computer software system, and programmable logic controller (PLC) communication system is the cornerstone toward the man zero (M0) fully computerized automation." Shimoyama and Yamagami (1990) deal with "a future intelligent (unmanned, full automatic) ship" and Janeba (1990) shows a conceptual diagram on manning development from 1950 that points to zero-manning approximately at 2010, Fig.1. Ditizio et al. (1995) propose for navy ships: "Should mission requirements dictate zero crew size, satellite linkups could be used."

![Fig.1: Conceptual diagram on manning development, Janeba (1990)](image)

Little has changed in today's view of the issue of ship automation from the vision of Schönknecht et al. (1983): "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 of Schönknecht et al. (1983) 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. The Japanese 'Intelligent Ship' project "aims at bringing about 'intelligent ships' that can function without help from the crew". 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 the repair of faulty equipment and piracy.

- 'Master/Slave' concept
  Convoys of unmanned 'slave ships' remote controlled from a highly automated 'master' escort ship have been proposed in Germany and Japan, e.g. in a leaflet of the Japan Marine Machinery Development Association: "The use of robot ship fleets may be seen as an advanced, yet highly practical development in international shipping for the 21st century. The concept envisages a fleet consisting of a 'mother' ship, carrying a crew of 20-30, and 4-5 remote-control slave barges", Fig.2. 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. Only if the convoys split up to different harbours when getting near to coast, or in war if just some 'slave ships' are destroyed, there may be advantages of this concept.

Fig.2: Japanese proposal of master/slave concept for sail-assisted convey of bulk-carriers
While most of the above authors are rather optimistic concerning the technical feasibility of unmanned seatransport, little attention has been paid so far to the economy of unmanned ships. Our own research confirms Levander (1994): "A ship without a crew is certainly technically feasible, but is it also economically profitable? [...] A reduction in the crew cost by investment in sophisticated technique both onboard the ship and ashore might add more costs, than what is saved on having no crew onboard. It is today more realistic to concentrate on a minimum manning of 4...6 crew onboard and shore based maintenance and support. With advanced design, this is a realistic goal [...]. Thompson (1990) addresses in addition the issue of piracy: "A logical train of thought would suggest that such progress would inevitably ensure that the fully automated ship becomes a possibility and perhaps a probability, but in reality to have valuable cargoes shipped around the world in almost as valuable hulls, unguarded and unattended, would seem to stretch the imagination to the limits in this rather embattled world. Such an event could become a terrorist’s or a pirate’s paradise, and [...] is unlikely to occur in the foreseeable future.” Indeed we will show in a case study for an unmanned container vessel that, legal restrictions apart, the concept is at least at present not economically sensible.

However, the technical aspects of fully-automatic ship operation are nevertheless very interesting, even if future ships will still feature crews due to regulations or economic inefficiency of unmanned ships. "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”, Schönknecht et al. (1983). Automation offers the possibility for crew reduction, but also for improving safety. The rapid development of the technology in this field concerns regulatory bodies, classification societies, and mercantile marine training institutes. 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).

There appears to be wide consensus that the next stage of ship automation will employ 'Artificial Intelligence' (AI) techniques, namely expert systems, to shift routine work (like watch keeping) from men to machines and to increase safety in stressful situations (damage control, collision avoidance in dense traffic). Some of these 'next generation' automation systems are already in practical service, some have prototype demonstrators, and many more are under development. Ship designers should have at least a passive understanding of these systems. This report is intended to give a comprehensive introduction to the rapidly developing state of the art in ship automation (based to a large extent on expert systems). We will briefly introduce relevant AI terminology before reviewing the individual areas of ship automation. For a panmax container vessel, we will demonstrate why unmanned seatransport will not be economically attractive in the foreseeable future.
2. Introduction to Artificial Intelligence and Expert Systems

New words and abbreviations can impress – or annoy. Many readers will not be familiar with some of the terminology of this report. We will give here a short introduction to Artificial Intelligence (AI) and particularly expert systems. For further studies of expert systems we recommend Frenzel (1987) or Waterman (1986).

There is no universal opinion about what AI is, but we will summarize the general idea. AI is a branch of computer science. It tries to capture human expertise and to emulate the thought processes of the human brain. The complex nature of our thinking makes the task difficult and AI applications have stayed behind initial expectations or promises both in terms of capability and economic importance. However, they gain in importance and are useful for selective applications. AI comprises different techniques. Although it may be difficult to distinguish between these techniques exactly, we provide a compilation of some relevant terms. Fairhead and Hall (1995) also give a short survey of AI techniques.

**Neural Networks**

Short introductions to neural networks are included e.g. in Hobday et al. (1993), Lihovd and Rasmussen (1993), and Tiano et al. (1990). Neural networks are very abstract models of the neurons (nerve interfaces in the brain responsible for transmitting impulses) and their interconnections in the human brain. Each single processing element (artificial neuron) receives many input signals and combines them usually by weighted summation. The weights represent the strength of connection between the processing elements. A transfer function determines the output from the result of this summation. The output is connected to other processing elements which perform the combination process with different weights again. Neural networks have a parallel structure, the single elements are arranged in layers, Fig.3. The elements in the input layer obtain information directly from outside the network, the ones in the output layer present the results of the whole processing. The layers between are called hidden layers because their in- and outputs are internal to the network.

![Fig.3: Principal structure of neural network (three-layered network with one hidden layer)](image)

Neural networks are able to learn from examples by tuning the summation weights. They are trained by presenting sets of input and desired output data. The network processes results from the input data and these results are compared with the desired ones. In an iterative procedure the summation weights are changed according to error minimization. Applications of neural networks are seen e.g. in pattern recognition and diagnostic systems. Neural networks are able to classify data sets that are not in the training sets and to recognize partly damaged patterns. As the processing information is distributed over the processing elements, they are also fault tolerant. Thus they can be used within reconfigurable systems. They have the potential for high execution speed, but they need (often excessively) great amounts of data and time for training.