Technologies for Low-Crew/No-Crew Ships

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"Once a new technology comes rolling along,
you're either part of the steamroller, or part of the road."

Abstract

Related transport engineering sciences show spectacular progress in automation reviving a discussing of unmanned ships using Artificial Intelligence technologies particularly for combatants. The nautical tasks could be largely automated and the commercial expert systems for automatic navigation including collision and grounding avoidance are on the market. Damage control appears to be another promising area for expert systems. Natural language interfaces and gestures allow better man-machine interaction. Machine vision is seen as a frontier technology to enable further automation. Humanoid robots appear rather useless for navy ship operation, but micro-robots and simple fixed robots may be used for assorted tasks. Virtual reality is predominantly attractive as training tool. Transponders will allow automatic ship-ship and ship-shore communication. Transponders may also implanted to humans as a convenient "key" to interact with computers.

1. Technology survey in related transport engineering industries

Computers take over controls in cars, trains and planes:

- Intelligent highways and self-driving 'seeing cars'

Self-driving cars are not a new concept. "Indeed, a working model of an automated highway was the hit of the General Motors pavilion at the 1939 World's Fair in New York City. During the late 1950s and 1960s, researchers at General Motors went on to refine various driveless vehicles. They showed, for example, how robotic trucks could work in open-pit mines. Although these early attempts at automation were valuable research exercises, the results proved too crude to be truly workable. Yet by the late 1980s, advances in microprocessors, wireless communications and various electronic sensors prompted many people to rethink the idea of automated highways. One group, which originally called itself Mobility 2000, convened in 1988 to consider the possibilities. It subsequently formed the Intelligent Vehicle Highway Society of America (later named the Intelligent Transportation Society of America), which now has more than 1000 organizations as members. Its mission is to foster the introduction of various 'intelligent' transportation systems, including automated highways," *Rillings (1997)*. In 1997, a prototype system for an automated highway on a stretch of the California freeway showed how automation might allow existing highways to accommodate a larger number of vehicles, while ensuring a higher degree of safety. The developers target the year 2002 for a commercial introduction of the system.

While the Americans base their system on sensors and signals embedded in the freeway, guiding cars along electronic tracks, German developments of 'seeing cars' are even more spectacular. Researchers around Prof. Ernst Dickmanns have developed self-driving cars that use video and pattern recognition to supply a computer with the necessary data to model the world outside, Fig.1, *Maurer and Dickmanns (1996), www.unibw-muenchen.de/campus/LRT/LRT13*. The actual control - based in part on a knowledge-based systems for traffic rules and other rules for driving a car - is then rather simple as cruise-control has long been established in cars. By 1994, the 'seeing car' drove automatically in Paris on a three-lane freeway at speeds of 130km/h changing lanes and passing other cars. Also in 1994, the ‘seeing car' mastered the problem of turning into intersections. By 1997, the ‘seeing car' recognized street signs and potholes in the street and could drive 180km/h safely. Remaining problems for a commercial introduction will be overcome as computers become smaller and more powerful. It is estimated that in 20 years the necessary computer power to allow automated driving by ‘seeing cars' will have the size of a football and be installed in cars on a standard basis. Simpler systems, that automatically reduce speed if getting too close to the leading car, are already on the market.

- Automatic trains

Trains appear to be particular simple to automate, as the tracks supply automatic guidance leaving mainly the speed control as task. In France, automatic trains are already reality. In Lille, a fully automatic metro has been operated since 1983. In Paris, the ‘Meteor' started service in summer 1998 on a 7km track in the Paris metro system.

- Automatic planes

Prof. Dickmanns, who developed the ‘seeing car', has also applied his technology to planes and helicopters. Cargo and passenger planes are already most of the time flown by an autopilot. The pilots take over controls during take-off and landing, because here visual input is vital. Even during emergencies autopilots usually are superior in flight-handling to human pilots nowadays. Prof. Dickmanns demonstrated that in principle by now also machines can see well enough (during good weather) to supply the necessary information to an autopilot during a landing approach. In fact, a European research program intends to use related techniques to improve the safety of helicopters in bad weather conditions (e.g. snow storms) supplying ‘super-human' vision (outside the bandwidth of wavelengths perceived by humans) to guide the Eurocopter.

Fig.1: Unmanned car developed by Ernst Dickmanns at UniBW München; field tests with speeds up to 180 km/h, automatic passing of cars, automatic avoidance of potholes, automatic turning into cross-roads

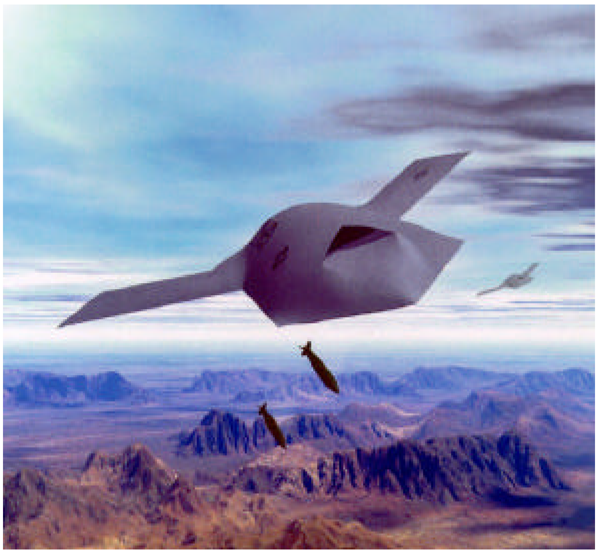

Fig.2: Unmanned combat planes – Artist vision of what became reality in 2001

Unmanned planes have been in use for a long time for military purposes. Remote-controlled ‘drones' have been used for surveillance and cruise missiles fly automatically long-distance with claims of reaching an intended target with a few meters accuracy. During the 1990’s, Lockheed Martin was reported to develop an unmanned fighter plane modifying the aging F-16 A Falcon into F-16/UCAVs (Uninhabited Combat Air Vehicles). The idea was to give the plane ‘electronic brains' so that it could carry out missions on its own or as directed by land-based ‘pilots' via satellite. The plane would also have ‘eyes', smart sensors that can detect e.g. missiles and shoot them down. More advanced UCAVs with stealth capabilities are under development, *Tirpak (1999,2001), Sweetman (2001)*. UCAV research has been active in recent years with companies like Boeing, Lockheed Martin, Raytheon, Northrop Grumman, and others being active in driving the technology. Conventional aircraft technology is combined with Bayesian belief networks, expert systems, and distributed intelligence systems to develop UCAVs where the "individual vehicles within a team can be expected to fly on dissimilar paths, to provide support for each other as needed to achieve primary goals, to sense and evaluate changing scenarios, situations, and environments, and to automatically re-plan missions or interchange leader-follower roles when damage or failure occurs", *Stengel (2000)*. These UCAV will be operated by operators sitting in command centers controlling the planes possibly employing virtual reality technologies. As the UCAVs on their own are able to take off, fly the approach to the target, and return to base, the operator largely is needed to authorize weapon deployment. It is foreseen that one operator may handle up to six UCAVs. In 2001, the first designed-from-the-ground prototype of the UCAV DARPA/Boeing X-45 was built for the air force. Engineering and manufacturing development shall start in 2008. Results from the DARPA/Boing effort have been encouraging enough to support the launch of a program to develop a carrier-based UCAV for the US Navy with prototype flight tests scheduled for late 2004 or early 2005. Initial operating capability is foreseen for the year 2012. Northrop Grumman unveiled in 2001 already the Pegasus naval UCAV demonstrator.

2. Concepts for unmanned ships - A review

In view of these spectacular projects, naturally questions arise if there are comparable developments for ships. Are there equivalents to the 'unmanned car' or the 'intelligent highway' on the water?

In the period from 1860 to 2000, transatlantic cargo ships have reduced necessary crews from 250 to 15. Much of this reduction was due to the progress in machinery, Table I. The first steamships needed much manual labor for feeding coal to the steam boilers. Drastic reductions were achieved with diesel engines which pumped the fuel to the engines. In the 1970s several technical advances started to have also effect on nautical staff. Modern communication techniques had made dedicated radio operators obsolete. In the 1970s, navigational equipment was improved, ARPA (Automated Radar Plotting Aid) and electronic position equipment introduced. The 1980s brought integrated navigation systems with automatic track keeping. The 1990s brought electronic sea-charts (ECDIS) and differential GPS (global positioning system) allowing accurate determination of the ship's position. The technical progress allowed one-man bridge operation. Automatic identification systems (AIS) based on transponders are at the threshold of the next decade allowing to relieve crews of much of the standard communication and improving safety by supplying earlier and more precise information of ship maneuvers.

In view of the technical progress and the shortage of qualified crews, Scandinavian countries advocate crews with just 6 men on certain routes. Crew reductions are desirable for many reasons, foremost the lack of well trained sailors which will aggravate soon looking at the present age structure and (lack of) student enrollment in nautical colleges. The American navy faces a similarly severe manpower shortage. As a result, crew reductions of up to 90% are being sought in specifications for the new destroyer-class DD-21.

Table I: Development of machinery crews for ocean-going cargo ships, *Hochhaus (2000)*

Year	1860	1880	1900	1910	1920	1930	1950	1960	2000
Mach.Crew	230	115	85	75	18	18	12	12	5

Of course, the ultimate in ship automation would of course be the unmanned ship. Unmanned ships have been envisioned for at least three decades now, e.g. *Schönknecht et al. (1973), Lin (1990), Ditizio et al. (1995), Hoyle (1996,1999), Kaeding (1996), Kasai and Bertram (1996), Wilde (1997), Bertram (1998b,c,1999), Wentzell (2000)*. Schönknecht's original vision was: "In this age of rationalization 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, [...] controlling the ship, and will in fact perform the task much more effectively."

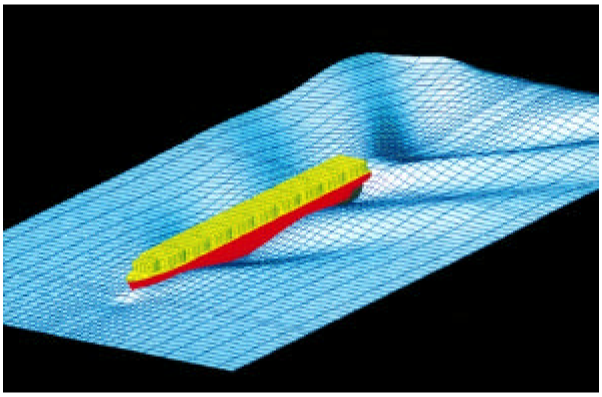

Fig.3: Unmanned containership vision, *Kasai and Bertram (1996)*

Fig.4: Original vision of *Schönknecht et al. (1973)* for master-slave concept

In general, the proposed unmanned ship concepts found in the literature 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, Fig.3
  The ship is equipped with sufficient hardware and software to perform all tasks and decisions autonomously using Artificial Intelligence.

- 'Master/Slave' concept, Fig.4
  Convoys of unmanned 'slave' ships remote-controlled from a highly automated 'master' escort ship have been proposed in Japan, Germany and the USA. While such a concept poses the least technical problems, one large ship with the same crew as the master ship would be simpler and more economical in most applications. However, this concept makes sense if explosives or other dangerous cargo shall be transported apart from the crew. The concept is investigated by navies for mine-sweeping, e.g. in the American Picket Hydrofoil Autonomous PHA, *Meyer et al. (1995)*, and related projects where a mother ship, typically of frigate size, will remote-control smaller unmanned ships for short-term, short-range highly dangerous operations.

In practice, usually 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, the repair of defects is unlikely to be handled satisfactorily. But failures in the ship machinery occur now about once in 100 hours. Approaches to increase reliability include the increased use of electronic sensor and control technology, new materials (e.g. metallo-ceramics), and condition-based maintenance. Condition-based maintenance and fault-diagnosis are the foremost applications of expert systems in marine automation, as surveyed by *Kaeding and Bertram (1997), Bertram (1998a)*. All large diesel manufacturers offer such systems by now.

Drastically reduced crews will mean far less time for predictive maintenance. This will require new design paradigms and possibly more harbor time for maintenance for navy ships. Despite all expected improvements of engine reliability, onboard maintenance and occasional fault repair will most probably still characterize future ship operation. The automatic diagnosis of faults appears quite feasible, the automatic repair of faults not.

Unmanned ships, while technically probably feasible, do not make sense at present for commercial shipping. For naval vessels, economical constraints are less dominant and unmanned operational times could be much shorter. Unmanned naval ships would be useful for a variety of tasks, e.g. mine sweeping or reconnaissance. Follow-up developments of the abandoned arsenal ship project point in this direction, *Hoyle (1996,1999,2000)*. The issue at present is not the unmanned ship, it is the 'intelligent combatant' with drastically reduced crews. Hoyle calls this approach the "autonomic" ship: "A ship where the people decide what to do and the ship makes it happen."[1]

Both concepts "unmanned" and "autonomic" share the task for extending automation. Artificial Intelligence technologies and modern telecommunication are expected to be the key to this envisioned further progress in ship automation. Individual techniques and applications are discussed and highlighted in examples in the following.

Predicting technology is difficult. For the next one or two decades we may base a reasonable extrapolation based on what is now developed in research laboratories, respectively on the research proposals now submitted. It is a safe prediction that computing power will grow for some time still following Moore's law, i.e. doubling in power every 1.5 to 2 years[2]. Predictions beyond that time horizon become speculations or dreams. AI aficionados paint a vision of a "Brave New World" where cyborgs outperform humans, communicate by telepathy, etc., e.g. Kevin Warwick and *Kurzweil (1999)*. Caution is appropriate in judging such visions. We underestimate progress as often as we overestimate it, even if the predictions come from highly competent scientists:

- Nobel laureate and AI expert Herbert Simon predicted in 1965 that machines would be capable of doing any work humans can do by 1985. Yet another 15 years later, we grant a doctorate for teaching a robot how to walk a single step.
- Lord Kelvin, president of the Royal Society, stated in 1895: "Flying machines heavier than air are impossible."

The list of such amusing failures of technology prediction could be continued for pages.

Table II: Instructions per second (IPS) in computers, *Kurzweil (1999)*

Year	Computer	IPS
1939	Zuse 2	1.00 E-00
1941	Zuse 3	3.33 E-00
1946	ENIAC	5.00 E+03
1951	Univac I	8.33 E+03
1953	Univac 1103	3.33 E+04
1959	IBM 7090	2.50 E+05
1964	CDC 6600	5.00 E+06
1977	Cray 1	1.00 E+08
1996	Pentium PC	1.00 E+08
1998	Pentium II	2.00 E+08

[1] The concept is actually ancient: „In the Icelandic saga, Frithiof's ship needed no helmsman; she understood what was said to her and obeyed." *Encyclopaedia Britannica (1959)*

[2] Moore's law is no theoretically derived fundamental law of nature or physics. Gordon Moore, inventor of integrated chips and founder of Intel, observed in 1965 that the size of integrated chips halved roughly every 12 months with the next generation of chips. Later, Moore corrected his "law" later to 18 months and in 1975 to 2 years. Table II gives selected state-of-the-art computers illustrating the exponential growth of computer performance. Others have re-interpreted this "law" as both the number of elements per chips double and the computational speed doubles, the performance of the chip quadruples. Current chip technology based on photolithographic production is expected to reach physical limits in extrapolating Moore's law in 10 to 15 years as then the distance between individual connection lines would be down to a few atoms. Already, the growth rate for individual chips has slowed down over the past 5 years. "Conventional" progress will still be possible using parallel computing architectures. Also 3-d chips rather than current 2-d chips may allow leaps forward, *www.sciam.com/2002/0102issue/0102lee.html*. *Kurzweil (1999)* gives an entertaining overview of future technologies for computers including quantum computers which may enable exponential growth of computer power for decades to come.

It appears more appropriate to focus how to implement the existing and evolving technology for better and safer ships. The issue of automation evokes traditionally emotions. ("You cannot replace a man by a machine.") John Henry is a legendary figure of the American folklore for beating a steam drill in a competition to prove that humans were superior in hammering in spikes in railroad construction, and then dying from over-exertion. Nobody challenged apparently the next generation of steam drills and today we have accepted gracefully that machines can be much stronger than humans. The first industrial revolution is history. But as automation progresses, we encounter similar stances as our forefathers: "A machine will never be able to..." Cyber-ships are bound to evoke strong emotions in the traditional seafaring community.

A rational, engineering approach may help making the discussion less emotional. A rational approach to ship automation appears to be:

- Machines should do what machines do better than humans.
- Humans should do what humans do better than machines.
- Machines should support humans.

The technological progress will (or should) shift more and more tasks from humans to machines. However, navies have their particular inertia and combatants are designed often 10 years before entering service. As a result, more tasks than necessary are performed by humans and efforts concentrate on making humans machine-like rather than shifting the tasks to machines.

Machines are superior to humans in the following aspects, *Schneiderman (1992):*

- perform repetitive preprogrammed actions reliably
- exert great, highly controlled physical force
- monitor pre-specified events, especially infrequent
- perform several activities simultaneously
- count or measure physical quantities
- make rapid and consistent responses to input signals
- operate in life-threatening environment

Humans are (at present) superior to machines in the following aspects:

- act in unanticipated and novel situations (common sense)
- reason inductively: generalize from observations
- take actions for self repairing
- interact socially with other humans
- perform acts of fine motorics

Originally, the list of human superiority included detecting, especially using vision. In view of the recent progress of machine vision, this has to be modified. Machines appear by now to have sometimes better, sometimes worse in pattern recognition capabilities, depending on the particular application.

In order to progress with automation, one should review all crew members asking:

- What are the functions of this crew member?
- Can functions be performed on shore or via telecommunication from shore?
- Can functions be performed by machine (computer) as well or better?

Such an analysis may include both large task packages (macro-automation) and small tasks that are short, but performed very often, e.g. retrieving certain information, logging into systems etc. (micro automation). Macro automation focuses on making certain people on board obsolete, micro automation making the remaining more efficient. In performing this analysis, it is important to break own functions to sufficient detail to reveal potential reduction, e.g. to separate knowledge in diagnosis and treatment/repair. Diagnosis may require expert knowledge, but can be performed often via telepresence, therapy may involve simple manual tasks which can be performed by anybody with eyes and hands and the ability to listen to given instructions.

4. Lessons of the USS Yorktown

Even if a reasonable approach to automation is taken with prototyping in steps and field-testing, there will opposition, driven by irrational technological phobias or by rational business interest, as the case of the USS "Yorktown" illustrates. In 1995, the USS "Yorktown" was selected as platform for the "smart ship" ideas developed in the 1990s, *www.chinfo.navy.mil/navpalib/allhands/ah0997/pg20.html*. Several automatic systems helped reducing crew size drastically with subsequent need to re-design work assignments on-board, e.g. with flexible damage control teams instead of traditional general quarters concepts. Lookouts were eliminated as one realized that the lookouts seldomly spotted a contact before the signalman or officer of the deck.[3] Maintenance was found as a bottle-neck in crew size until (installed, but unused) engine room automation was used.

In 1998, a major computer crash on board the "Yorktown", Fig.5, brought the ship back into the headlines, *www.sciam.com/130.94.24.217/1998/1198issue/1198techbus2.html.* After a crew member mistakenly entered a zero in a data field of an application, the computer system proceeded to divide another quantity by that zero. The operation caused a buffer overflow, in which data leak from a temporary storage space in memory, and the error eventually brought down the ship's propulsion system. The "Yorktown" was dead in the water for more than two hours. The incident provided ample ammunition for the critics of automation. This is not surprising. It seems to be part of human nature to enjoy failure in others, particularly if computers fail. There are also financial interests involved on the side of traditional fractions in the navy and supply industry. Cozy relationships are at risk when new technologies based on commercial-of-the-shelf products appear.

In essence, the "Yorktown" can still be seen as a success story for smart ships. It implemented part of the saving potential between traditional ship operation and future ship operation. Teething problems are to be expected in a technology demonstrator. This is exactly one of the reason why we employ such test installations. Navies and developers should be prepared for extensive continued learning. The error behind the "Yorktown" system crash was found and removed. In fairness, one should then list human and mechanical failures in the history of the navies. The track record of computers and advanced automation system is then comparably good. At the same time, we must look at procedures to introduce new systems. Simulations can detect many bugs in "risk-free" laboratories that are less embarrassing than failures on-board.

Automation will progress in steps. With anything new, there is a period of acceptance. Initially, there will be back-ups for manual control, human confirmation required, etc. until there is sufficient confidence in the technology that the back-ups are considered more of a hindrance. This may then again open the door for better performance as it is suspected that in some cases manual back-ups or semi-automatic systems lead to more complex designs which are more error-prone than fully automatic designs could be. The first cars ("horse-less carriages") were accompanied by a horse as back-up. When steamships came up, ships had also sails as there was not sufficient confidence in the "new" technology, Fig.6. Such hybrid ships with sails and engine were operated for 100 years, *Foster (1986)*, perhaps due to the greater inertia of the shipping community. But eventually there is sufficient reliability of systems and sufficient confidence also on the side of the users to go abandon obsolete back-up options.

[3] The commanding officer is quoted with: "Is it because our lookouts are all bad people? No. It's because the lookout watch is the most boring watch in the United States Navy. You spend 85% of your time looking at open ocean and it's not something that motivates a young Sailor." Indeed, such watch-keeping should be shifted to machines.

Fig.5: USS Yorktown, test ship for the smart ship philosophy, encountered some teething problems

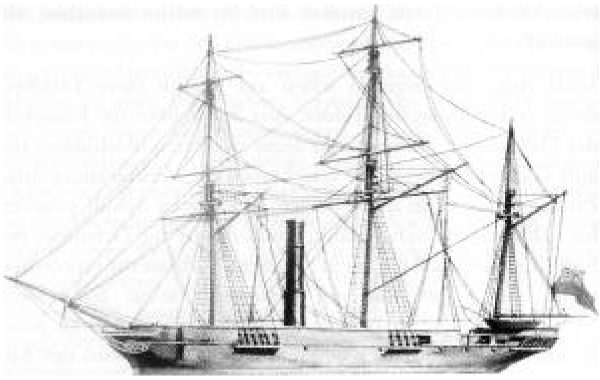

Fig.6: The “Rattler”: Steamships continued having sails as back-up for almost a century

3. Artificial Intelligence offers key technologies for future combatants

The tasks involved for further ship automation and faster threat response share many characteristics with the quest for safer and more effective cockpits for airplanes[4]:

- to understand the abstract goals of a (flight) mission
- to asses needed information about mission, [ship or] aircraft environment and [ship or] aircraft system
- to interpret the (flight) situation in the light of the mission
- to detect pilots' [or captains'] intent and possible errors
- to support necessary re-planning and decision making
- to know which information the crew needs and how to present it to the crew in the most effective way

The above tasks involve knowledge processing, improved man-machine interaction, and “intelligent” sensor interpretation. Many of these tasks will involve techniques commonly grouped under the label “Artificial Intelligence” (AI).

It is generally considered that the discipline of Artificial Intelligence began in the summer of 1956, at the now famous conference held at Dartmouth College in Hanover, New Hampshire. The conference was to debate the possibilities of producing computer programs with the ability to accurately simulate human reasoning and behavior. The major organizer of the conference was John McCarthy, then an assistant professor of mathematics at Dartmouth. McCarthy is also generally created with coining the term 'Artificial Intelligence'. The scope of AI is not clearly defined. In its broadest sense, AI is concerned with the investigation and simulation of human intelligence with the ambition to replicate the processes in machines. A (not exhaustive) list of branches of AI encompasses:

- knowledge-based systems / expert systems/case-based reasoning/Bayesian networks
- natural language processing
- machine vision
- robotics
- machine learning
- artificial neural nets
- ...

Selected branches of AI and their potential or actual applications to (navy) ship operation will be discussed in the following.

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[4] The following list was found on a subpage of *www.unibw-muenchen.de/campus/LRT/LRT13* concerning flight deck automation.

3.1. Knowledge based systems and related techniques

Knowledge-based systems are arguably the most widely established branch of AI, at least in naval applications, *Bertram (2000)*. The terms 'knowledge-based system' and 'expert system' are often used synonymously. Some reserve 'expert systems' to such knowledge-based systems incorporating expert heuristic knowledge not documented explicitly in books. Knowledge-based systems (KBS) are, as their name suggests, systems which use knowledge and reasoning to arrive at conclusions, *http://best.me.berkeley.edu/~aagognino/me290m/s99*. They differ from traditional data-processing computer programs in their expressive power and their method of operation. In traditional programs, a predetermined sequence of actions must be followed, i.e. they are deterministic. Conventional programs are also optimized for numeric-processing, whereas the knowledge-based system concentrates on the representation and manipulation of information as symbols. Another noteworthy feature of KBS is their suitability or large and complex problem solution characterized by inexact, incomplete and uncertain information. Their structure includes an explicit body of embedded knowledge and a separate, identifiable inference mechanism. Using these facilities, the KBS builder is able to construct a mechanism capable of 'mimicking' human reasoning (the inference mechanism or inference engine), and the knowledge engineer is able to elicit and code expert knowledge which the inference mechanism may use to provide solutions to problems in a similar fashion to a comparable human expert. In spite of all this, however, knowledge-based systems are merely computer programs which have been written in a different way, in a deliberate attempt to isolate the various components of human (expert) problem-solving. The isolation of the program flow directives which represent components of knowledge most often in the form of rules permits an explicit body of knowledge to be created and enlarged/modified in a way which would be difficult in conventional data-processing programs.

- Monitoring of machinery and ship

The monitoring of engines and the ship itself involves the automatic observation of a flood of data which has to be checked against acceptable or expected values. For the machinery, early detection of deviations from standard values is already used to support predictive maintenance and fault diagnosis. Similar tasks are involved in detecting fires or the risk of a collision in dense traffic. The individual tasks are simple and the amount of data and the need for constant vigilance make it clearly a task better handled by computers. The performance of diagnosis systems depends on the (sensor) input. E.g. for the risk of collision, 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 in the late 1980s were not successful. The recent successes with 'seeing cars' described above may re-open the discussion about the feasibility of this approach. However, the problem is better solved by making transponders mandatory. Transponders would allow determination of ship types, detection of wooden or plastic boats and even special treatments for ships with hazardous cargo or ships with problems like blocked rudders.

- Advisory systems for maintenance and repair of engines and other systems

The monitoring involves just the detection of a problem. Increasingly, also decision support systems, often based on expert system technology, are used to advise the crew what to do if such a problem occurs. This may involve fault diagnosis for machinery coupled to an 'electronic manual' that tells the crew what to do to remove the problem, i.e. guide the repair. The trend is to make maintenance and trouble-spotting easier rather than avoiding faults at all cost. The system of the future will have a self-diagnosis function which instructs the operator how to repair the malfunction. This will drastically reduce time needed to find the reason for malfunction and allow multi-purpose crews to perform jobs now requiring experienced specialists. Similar systems for weapon systems have been occasionally reported.

- Collision avoidance

For collision (and grounding) avoidance, the analogous task is planning an avoidance route. In restricted waters, this should also include grounding avoidance. Collision-avoidance systems use expert systems to incorporate traffic rules and regulations, but also the experience of ship masters. An avoidance route is automatically selected usually based on the criteria of minimum collision risk, length of avoidance route, and steering action. In Japan ship trials 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 judgment and actions appeared reasonable, even though crude compared to an experienced helmsman. Further refinements resulted in the commercial "SuperBridge" system installed for the first time in the 258,000 tdw tanker "Cosmo Delphinus", Fig.7, *Kanamaru et al. (1994)*. "SuperBridge" continuously monitors the dangers of grounding and collision on the basis of the electronic chart (checking for shallows) and radar/ARPA (detecting surrounding ships). The expert system determines secure avoidance route based on maritime traffic regulations and good seamanship practice. For legal reasons, "SuperBridge" is an advisory system requiring a confirmation of the system's decisions by the helmsman. By 2002, 14 systems were installed including 7 voice-controlled Superbridge-X systems.

Over the past decade, the USA has developed and installed a number of comparably mature ‘intelligent’ navigational decision aids, *http://maple.lemoyne.edu/~grabowsk/*. The ‘Exxon Valdez' accident triggered the development of the Shipboard Piloting Expert System (SPES) which was operated and tested on Exxon Shipping tankers since 1992. Since 1995, the experience gained was used to develop the Navigation and Piloting Expert System (NPES) for the San Francisco Bay as part of the SmartBridge program. A SmartBridge prototype was installed on the “Chevron Colorado”, a 70000 tdw tanker, in 1997. By the end of the 1990s development of distributed intelligent piloting systems (DIPS) started, *Grabowski (1996,1999), Sudendhar and Grabowski (1996)*. "These systems have grown from stand alone intelligent piloting aids to embedded intelligent systems within a distributed information system, i.e., ship and shore-based information systems. Originally, these decision aids focussed on enhancing the performance of individual vessels and pilots in the waterway. Currently, they also coordinate traffic interaction between multiple vessels on the waterway as well as distribute intelligent reasoning which underlies this coordination to all concerned parties on the waterway: to vessels currently on the waterway, to vessel traffic controllers facilitating the flow of traffic, and to vessels planning to be on the waterway in the near future," *Grabowski (1996)*.

Fig.7: “Cosmo Delphinus”: First tanker to be equipped with Japanese collision avoidance expert system SuperBridge; further development to natural language system SuperBridge-X

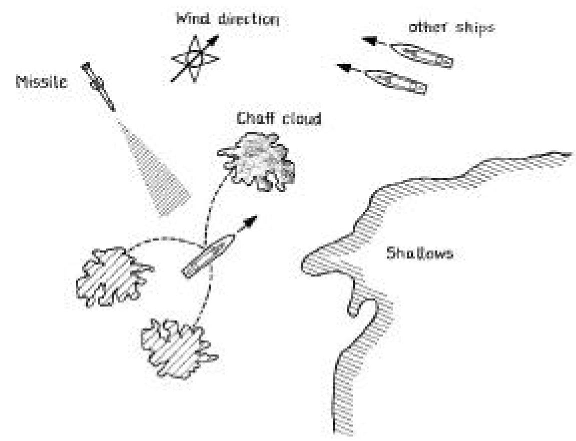

Fig.8: Expert systems for navies detect threat, consider collision and grounding and effect of counter measures like chaff

All collision-avoidance systems are advisory systems requiring a human confirmation of the system's decision. This appears 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 ‘watch’ 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. Quite possibly, we will see de facto fully automatic operation long before regulations follows reality.

- Emergency response / Damage control

The conventional approach to damage control relies on human intervention under crisis conditions to integrate, evaluate and initiate actions. The contingency plans and emergency procedures are often distributed into several manuals like a 'Damage Control Booklet', 'Bridge Procedures', 'Emergency Check Lists' and 'Ship Fire Fighting Manual'. The 'booklet' for damage control may typically comprise several hundred pages covering a wide range of possible cases. Information retrieval from each of these sources is time consuming and error-prone under stress. Expert systems have been developed to improve this situation. Expert systems may incorporate 'early failure' detection or event trending to establish 'pattern recognition'. More advanced systems cross-reference functionalities, e.g. fire fighting and ballasting ("What are the relative priorities between attacking a fire, drain off water from compartments or even flooding them to preserve ship stability"), Fig.8.

Similar systems have been developed by advanced navies. Decision aids will allow rapid and remote reconfiguration of auxiliary systems in response to damaged ship scenarios. The systems know the particulars and characteristics of inbound missiles. These data along with characteristics of the ship and tactical scenarios are processed in a damage prediction model. Based on the model output, systems predicted to be damaged will be reconfigured or rerouted to minimize impact in the ship's ability to operate, *Ditizio et al. (1995), Hoyle (1996,1999,2000)*. Due to sensor limitations and time constraints it is not always possible to make decisions with absolute certainty about what threats are being faced. Also, often conflicts occur such that weapons systems cannot fire at two or more different targets as ideally desired. New systems are able to resolve these conflicts and produce an optimal solution working around the physical constraints on the self defense assets in 'real-time'. Such systems incorporating uncertainty in Artificial Intelligence are under development, see also the next subsection on Bayesian Networks.

Both the UK Royal Navy and the US Navy are already introducing first-generation combat advice systems, *Scott (1995)*. These offer tactically correct defensive recommendations - derived from an embedded rule base - allowing the command to focus on the application of human reasoning and intuition. *Meyrowitz (1999)* reports that an initial collaborative data fusion system for the US navy has been constructed and employed in complex tactical simulations to perform situation assessment at multiple levels of data fusion in 1996. Further ahead, work is progressing on the development of more advanced automated planning and decision aids designed to support situation assessment, resource allocation and weapon coordination at both single-ship and force level. However, the currently prevalent view is that "the task of making tactical decisions in a naval context is too complex to be accomplished effectively by humans or computers alone", *Kushnier et al. (1996)*. Instead, systems are developed where humans and computers work together and assist each other in doing what each does best.

Case-based reasoning (CBR) system are another form of knowledge-based systems. The principle is related to rule-based production systems. Instead of a knowledge base, there is a case base. Instead of an inference engine, there is a case-based reasoner employing a similarity function to select related cases, *Aha et al. (1999)*. Conversational CBR are the most successful CBR technique and commercial shells are available. CBR systems have been investigated as an alternative, or at least adjunct, to rule-based reasoning, *www.aic.nrl.navy.mil/~aha/cbr/ccbr-research.html*. In 1995, the US navy's Fleet Technical Service Centers deployed an application of a conversational CBR for trouble-shooting a weapon system (MK41 vertical launch system). Subsequent research has focussed on simplifying the application of CBR and widening the applications. One of the results has been the NaCoDAE (Navy Conversational Decision Aids Environment) as a retrieval tool. However, the applications appear to be few and the technology less mature than rule-based expert systems.

3.2. Bayesian Networks

Bayesian networks can be regarded as a sub-branch of knowledge-based systems incorporating aspects of uncertainty and probability, *www.cs.berkeley.edu/~murphyk/Bayes/bayes.html*. There are several introductory textbooks, e.g. *Jensen (1996)*. Bayesian networks get their name from the Reverend Thomas Bayes who wrote an essay, posthumously published in 1763, that offered a mathematical formula for calculating probabilities among several variables that are causally related. The mathematical formula is known as Bayes' theorem. Bayesian networks were long an obscure sub-branch of mathematics, and only with the wide availability of sufficiently powerful computers in the 1980s Bayesian networks with enough variables to be useful in practical applications became feasible.

Bayesian networks are in principle simple diagrams that organize the knowledge in any given area by mapping out cause-and-effect relationships among key variables and encoding them with numbers that represent the extent to which one variable is likely to affect another. Programmed into computers, these systems can automatically generate optimal predictions or decisions even when key pieces of information are missing.

In the late 1970s and 1980s, the predominant approach to knowledge-based problems was based on expert systems representing the knowledge in if-then rules. These so-called production systems are still popular and quite widely used in ship operation and fault diagnosis systems. But these systems were time-consuming to develop, and problems involving uncertainties (which appeared in all cases where you could not answer all the computer's questions clearly) were not as easily handled as in Bayesian nets. After some mathematical breakthroughs by Danish scientists and successful pilot applications by Professor Judea Pearl (UCLA) in the late 1980s, Bayesian networks were perceived by an ever growing community of scientists as an efficient way to deal with lack or ambiguity of information.

The real breakthrough for Bayesian networks happened when it became public that Microsoft saw it as a future technology and invested heavily into research and development of Bayesian network applications in the mid-1990s to support their software. Bayesian networks are reported to being used to develop next-generation user-friendly software interfaces. The latest version of Microsoft Office software uses the technology to offer a user help based on past experience, how the mouse is being moved and what task is performed. General Electric is reported to use Bayesian networks to develop a system that will take information from sensors attached to an engine and, based on expert knowledge built into the system as well as vast amounts of data on past engine performance, pinpoint emerging problems (*Los Angeles Times, 28.10.96*).

Ray Rimey at the University of Rochester, New York, has combined Bayesian networks with machine vision for robots. A robot equipped with two video cameras resorted to Bayesian networks to extract relevant clues, set them in relation to each other and draw conclusions, (*www.rimey.com/ray*). Rimey selected the analysis of a dinner table as application, teaching the robot to analyze and make conclusions about different type of place settings. In principle, the problem is how to teach a computer to scan a scene and zero in on the most important information. Honeywell is reported to be interested in Rimey's system to analyze infrared images taken by roving vehicles. For many problems, the world is too complex to enable a system to see every detail at all times and then act with sufficient speed. So the system must be selective in where to put its attention. Rimey's work is a contribution to having automatically prioritize where to look and how to look.

Bayesian networks have been applied to automated target recognition by Ulf Grenander and Anuj Srivastava, *www.dam.brown.edu/mptc/atrcdrom.php3.*

Bayesian networks are also applied or proposed to ship applications. Scott Musman, director of the Intelligent Systems Division at Integrated Management Services, has developed a Bayesian network for the US Navy that can identify enemy missiles, aircraft and vessels and recommend which weapons could be used most advantageously against incoming targets, (Ship Self Defense Tactics Engine), *Musman and Lehner (1999)*. The work draws on early work to identify ships, *Musman and Chang (1993), Musman et al. (1990,1993)*.

In Denmark, Professor Peter F. Hansen and his colleagues at the Danish Technical University have applied Bayesian networks to various ship-related problems, including risk analysis for solo watch keeping in ship operation, *Hansen and Pedersen (1999)*, maintenance scheduling connected to fatigue strength and crack propagation, *Friis-Hansen (2000)*.

3.3. Natural language processing and other new Man-Machine Interfaces

The issue of communication between man and machine is crucial for progress in automation. Integrated bridges with one common interface increase user-friendliness and thus safety. Still, the officer of the bridge typically has to type in commands and view screens to interact with the machine. This can lead to stressful situations in one-man bridge operation.

Such stressful situations can be analyzed in the risk-free environment of a ship simulator to derive recommendations for future bridge systems. The Japanese have done this and developed a new navigation system called SuperBridge-X which is based on natural language as a new element in human machine interfacing in ships. The master is addressing the system by speaking (e.g. ordering changes in speed or course, changing displays on computers, etc.) and the system is announcing via a loudspeaker relevant information (e.g. confirmations of accepted orders, warnings and alarms, etc.). The voice-operated SuperBridge-X system allows in principle 'no-touch' operation of the ship, *Bertram (1997), Nagaya (1997), Fukuto et al. (1998), Yamamoto (1999)*, and has been installed so far on two ships. The advantages of keeping the ship master's view free to monitor his environment are obvious. SuperBridge-X has in its 1998 version a capability of approximately 80 announcements (for replies, warnings and alarms) and approximately 30 commands or inquiries. This suffices for the most important monitor and control functions in ship handling. Commands concern changes of course and speed and visual displays on the bridge. A typical control sequence may look like this:

Human: Course 5 degree starboard!
Computer: Course 5 degree starboard, OK?
Human: OK!
Computer: Course has been set 5 degree starboard.

The computer thus always repeats a command and waits for a confirmation before execution. Alternatively to voice confirmation, a key on a keyboard may be pressed. Alarms interrupt normal dialog sequences. All alarms are also displayed on a screen.

The system is based on two microphones, one directly at the commanding officer and one in the room. Comparison of input signals to both microphones allows to filter out the commands of the commanding officer. Back-ground noise and also conversation by other people on the bridge posed no problem to system in trials. The voice recognition is not tuned to one particular speaker and does thus not require retraining at each change of the shift. Initial tests with the system were performed with 19 test persons (10 male, 9 female) who had no experience with voice recognition. Initial success rates in speech recognition of 93% were increased to 100% by reformulating critical command sequences. By 2002, 7 such systems were installed in cargo ships. The system is so far based only on Japanese as language, but English language are commercially available and should be relatively easily connected to the rest of the system.

The advantages of voice-operation are obvious: The hands and eyes are free for other tasks, e.g. watching the traffic and checking sea charts. The interaction with the bridge system then becomes more like the traditional way of interacting with other humans on the bridge. Speech-control is important when hands are otherwise busy (controlling e.g. an object) or when vision is impaired (e.g. wearing a virtual reality helmet). It is also a useful technology to reduce space for keyboards.

People have cognitive limitations that make them sensitive to interruption. These limitations can cause people to make mistakes when interrupted. This is particularly an issue for navy ship operations in combat situations. Future man-machine interfaces will therefore use knowledge about the importance of an information and the importance of a current activity of a user to decide whether to interrupt or “leave a message”. The HAIL project (Human Alerting and Interruption Logistics) points in this direction, *www.aic.nrl.navy.mil/hail/index.html*.

Despite recent advances in robustness, speech recognizers are known to degrade considerably in noisy environments. High noise levels on navy ships are known to degrade human listening performance and are likely to affect even more severely automatic recognition systems. Research has been devoted to improve performance of navy speech recognizers in noisy environments. Alternatively, other modes of communications may be employed.

Gestures may be used to communicate with computers and robots. Siemens and IBM develop virtual keyboards: The computer traces hand motions of users via a small camera. Users can either unroll a plastic-foil template with a keyboard layout, or tap on screens, or use a laser-projected virtual keyboard. The user may also interact with programs, e.g. turning or shifting objects by corresponding hand motions. This safes weight and space and allows hygienic and indestructible keyboards. It supports also extremely small, portable computers. Communication by gestures is also important as an alternative to speech in very noisy environments or in situations where silence is of tactical importance. *Meyrowitz (1999)* reports a combined natural language and gestural interface to a mobile robot. Ambiguities in language directions are resolved by gesture understanding, and ambiguities in gesture are resolved by language understanding.

3.4. Robotics

The Encyclopaedia Britannica defines a robot as follows: “Derived from the Czech word robit (“work”), it passed into popular use after 1923 to describe [...] mechanical devices so ingenious as to be almost human.” Naturally one may then be tempted to just substitute human crew members by “ingenious” and “almost human” machines in a quest to reduce crew size. Indeed, *Katagi and Hashimoto (1990)* predicted ships with robots with sensors, ability of movement and "judgment similar to or better than those of man". At the beginning of the 21^{st} century, this appears still like science fiction. However, robotics develop rapidly. A study of the United Nations Economic Commission for Europe predicts 250,000 vacuum cleaning robots by the year 2003 and health care robots for elderly and sick people by the year 2013, *Sparmann (2001)*.

Humanoid robots are envisioned for a variety of application domains including health care, domestic services, and entertainment. Humanoid robots with sensor (vision, hearing, and even tactile sensing) are under development worldwide and attract considerable public and media attention:

- KISMET is an autonomous robot designed by the MIT for social interaction with humans, Fig.9. KISMET perceives a variety of natural cues from visual and auditory channels and signals himself through gaze direction, facial expression, body posture, and vocal babbles. Its vision system was funded by a research grant from ONR and DARPA..
(*www.ai.mit.edu/projects/sociable/kismet.html)*
- COG is another robot developed at the MIT. COG is arguably the most human of the MIT developments and has also been dubbed as ‘robo sapiens’. “Avoiding flighty anthropomorphism, you can consider Cog to be a set of sensors and actuators which tries to approximate the sensory and motor dynamics of a human body. Except for legs and a flexible spine, the major degrees of motor freedom in the trunk, head, and arms are all there. Sight exists, in the form of video cameras. Hearing and touch are on the drawing board. Proprioception in the form of joint position and torque is already in place; a vestibular system [maintains eye fixation while head or torso move] is on the way. Hands are being built as you read this, and a system for vocalization is also in the works. Cog is a single hardware platform which seeks to bring together each of the many subfields

of Artificial Intelligence into one unified, coherent, functional whole.“ (*www.ai.mit.edu/projects/humanoid-robotics-group/cog/cog.html*)

- COCO is a gorilla-like robot with walking ability and a vestibular system using gyroscopes and gravitometer to measure the acceleration and orientation of his head with respect to the ground, Fig.10. Research is in progress to add force control to COCO’s suite of capabilities. *www.ai.mit.edu/ humanoid-robotics-group/coco/coco.html*
- Tokyo University has presented the walking humanoid robot H7 to the public on 12 March 2001, *Sparmann (2001).* H7 is capable of climbing stairs and grasping objects, but remote controlled via joystick.
- After 14 years of research and development, Honda presented the humanoid robot P3 in the year 2000: P3 walks forward, backward, sideward, upstairs and downstairs. The partially autonomous humanoid robot can open doors and follow a prescribed track. His visual system can detect prescribed simple objects. (*www.honda-p3.com*)
- Asimo is the successor of P3, lighter, smaller, more agile, Fig.11. Honda’s “i-WALK-technology” allows a softer, nimbler fine-motoric walk that is considered as leading-edge state-of-the-art worldwide. Asimo is constructed predominantly of ultra-light lithium alloys and still is quite heavy with 43 kg for a height of 1.20 m. Its batteries last for about 25 minutes of operation. (*www.world.honda.com*)
- The German research agency DFG has started a special research program “Learning and cooperating humanoid robots” in July 2001 equipped with a budget of 5.5 million Euro for three years.

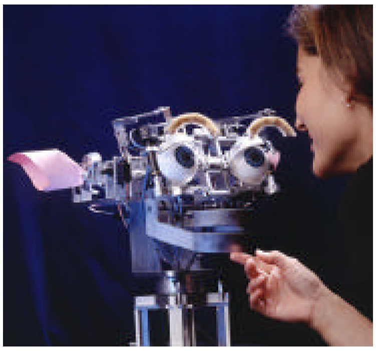

Fig.9: KISMET: MIT robot

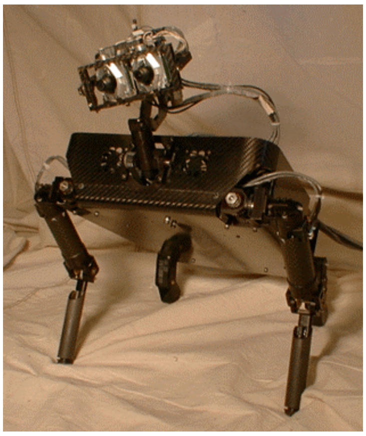

Fig.10: COCO: MIT robot

Fig.11: ASIMO: Japanese robot

Humanoid robots are still in an infant stage. Walking on two legs is an extremely difficult task on uneven or moving terrain (e.g. on a ship). Humanoid robots with advanced sensor capabilities are usually immobile, and walking robots are often remote controlled. Three-year old humans out-perform so far all humanoid robots in terms of walking capability and sensor capability, often also in terms of strength. The Forschungszentrum Informatik[5] of the University of Karlsruhe has compiled an overview of walking machines and robots with many links and short informations on the individual robots: *www.fzi.de/divisions/ipt/WMC/preface/walking_machines_katalog/walking_machines_katalog.html*
There is a noticeable increase in research activities for walking robots over the past 5 years worldwide based on the references given on this website.

For most tasks robot do not have to resemble humans. Humanoid robots may be useful for entertainment and social/health care purposes. Design follows purpose. For navy purposes, robots will look differently depending on the respective function. Thus robots on board of ships will look rather like industry robots, often without moving capability. In 2001, an estimated 800,000 industry robots were implemented, every tenth in Germany. Mostly, these robots are articulated arms e.g. for welding in the car industry or in dangerous environments like chemical and nuclear processing. The trend is towards ‘seeing’ robots, i.e. the robot evaluates input from one or more digital cameras to form a model of the

[5] Research center for computer science

world. This development is strongly coupled to developments discussed below in the sub-section on machine vision. A practical application of present technology could be e.g. "robotic arms equipped with binocular viewers will provide virtual presence in machinery spaces", *Ditizio et al. (1995)*, for fire fighting.

At the Navy Center for Applied Research in Artificial Intelligence (NCARAI), several projects were concerned with robotics for navy applications as reviewed by *Meyrowitz (2000)* in the previous forum, *www.aic.nrl.navy.mil*. A variety of robotic behaviors of interest has been investigated, including obstacle avoidance (including fields of floating mines), path planning, tracking, and cooperative mapping for flocks of robots. Robots can learn behavior in virtual worlds and improved behaviors observed in simulation carry over to improved behaviors when the software is placed on real mobile robots, *Schultz et al. (1996).*

Bertram (1999) lists as one of the advantages of humans over machines that human “take action for self-repairing”. While not yet as “self-repairing” as humans, robots can learn to cope with partial system failures. NCARAI has conducted experiments using simulated and real mobile robots performing navigation and tracking tasks, wherein a software module monitored changes in the operational environment as well as changes in the robot’s own capabilities (such as sensor failures). The robot was able to learn alternative rules for accomplishing its mission and adaptation to recurring failure modes was rapid. The long-term objective is for learning to be embedded and continuous. The techniques for coping with sensor failures applies to mobile robots as well as other robots or general systems of the ship.

Movable robots do not always have to have advanced sensor capabilities as outlined above for the humanoid robot research. Robots for cleaning floors, cleaning swimming pools and mowing lawns orient themselves roughly, e.g. detecting obstacles using ultra-sonic sensors. Such service robots are expected to be soon mass-produced with subsequent drastically reduced price levels. Cleaning robots have been investigated in the context of non-toxic anti-fouling alternatives, Fig.12.

One of the advantages of robots is that they can be built in different dimension. Robots have been developed to search for survivors of earthquakes. One such model is reported from Japan that resembles rather a snake or a giant worm and can crawl through tight spaces. *www.snakerobots.com* gives an idea of such robots, Fig.13. Other robots look rather like insects. Sandia National Laboratories have built a mini-robot that “parks on a dime and turns on a nickel”. The robot moves on caterpillars and is equipped with a thermo-sensor, Fig.14, *www.sandia.gov/media/NewsRel/NR2001/minirobot.htm*. In future, the robot shall be equipped with mini-camera, microphone, and chemical sensors. Such a robot or flocks of such robots could e.g. inspect pipes, etc.

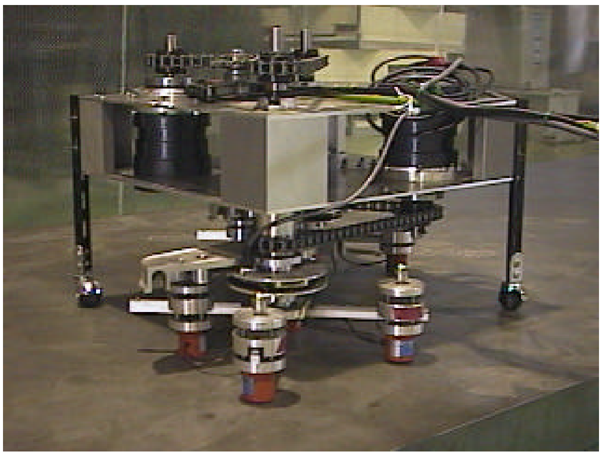

Fig.12: Hull cleaning robot, Hiroshima Univ.
www.naoe.hiroshima-u.ac.jp/staffs/hirata/img

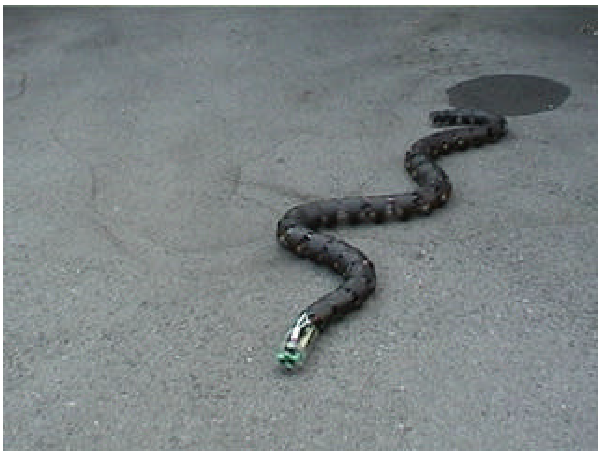

Fig.13: Snake-like robots may be employed to move in narrow spaces, e.g. tracing survivors in collapsed structures

Robots with sufficient agility, sensor capability, and robustness to replace human work will not be available for some time to come and then the first such robots would probably be more expensive than humans. Mobile robots are usually weak, fragile, and need power sources. Realistically, robotics seems to be more interesting for land-based applications and for remote operating vehicles than for the operation of ships. However, research is active and the technology should be monitored and promoted. Robots may already be used for tasks like mine hunting and mine removing, or reconnaissance tasks, opening new operational aspects for navies.

3.5. Machine vision and neural nets

A decade ago, Japanese researchers failed to employ machine vision for the task of detecting dangers of collisions. Machine vision is a field that has progressed considerable, and while the problem of collision avoidance seems to be solved by now using other sensors, machine vision offers many options in improving performance of machines.

Machine vision is interesting in combination with robotics. "Among various sensors to be used in conjunction with robot control, vision has a number of advantages: it is low cost, fast, [...]", *Lamiroy et al. (2000)*. Following this philosophy, visually guided robots to weld ship structures have been developed to prototype demonstrators, *www.inrialpes.fr/VIGOR*. The scientists at INRIA Grenoble, *www.inrialpes.fr,* investigated particularly techniques where the robots carry their own cameras and alternatively techniques where the robot uses images supplied from external cameras in a room. The general background is that one may plan e.g. a robot track off-line based on a CAD model, but if there are any changes between CAD model and real world (e.g. now there is an obstacle in the path), the robot should be able to detect this change and its relevance to the initial path planning. In short: Autonomously moving robots for our applications need some sort of vision.

Fig.14: Mini-robot developed by Sandia National Laboratories

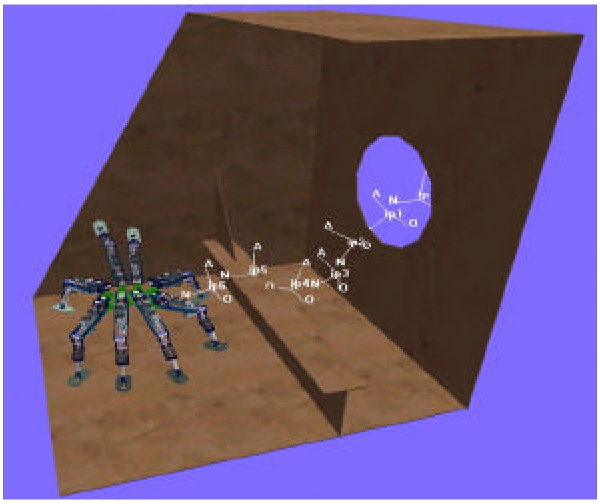

Fig.15: Visually guided robot walking through ship structure, *Vincze et al. (2000)*

Autonomous robots hold a CAD map of ship and may use landmarks such as walls or stiffeners for navigation. The robot assumes a rough position and matches the landmarks of its CAD map to those detected by the vision system. "The main problems are a changing background and high computational demands. For example, a space application where the background is dark and the object consists of parts of different surface characteristics, requires dedicated hardware to run at frame rate [...]. Probably the most successful system that uses vision to control a mechanism is the automatic car and air-vehicle approach using dynamic vision, *Fuerst and Dickmanns (1999)*. It integrates the dynamic aspects of a continuously operating system and image data to update the model description of the world.", *Vincze et al. (2000)*.

The European research project ROBVISION has developed vision systems to allow guiding a walking robot through a ship structure, e.g. a double bottom, Fig.15, *Vincze et al. (2000)*. A welding robot would thus be able to orient itself inside ship structures usually difficult to assess for humans, using a CAD model of the structure ('map') and his own vision. One of the objectives is a visual processing robust to deviations in parts and environmental conditions. To achieve this goal a technique is developed that integrates different cues of images to obtain confidence of the measurement result. The project develops an integrated vision system capable of providing adequate information to guide an advanced robotic vehicle through a complex structure. The final demonstration will see the walking robot enter and climb the vessel structure, *robvision.infa.tuwien.ac.at/rvision.htm.*

NCARAI has combined range-based vision with intensity-based vision using tripod operators. The system recognizes an object among 25 similar shapes in a cluttered scene, with very few false positives, *Meyrowitz (1999).*Typical time to find a given shape was tens of milliseconds in 1994.

Machine vision may employ neural network techniques to learn to identify patterns, *Ripley (1996), Hinton (1992), www.cs.stir.ac.uk/~lss/NNIntro/InvSlides.html.*This has been used for a variety of applications, both civilian and military. The pattern recognition has advanced much beyond the initial primitive applications. E.g. commercial systems to identify faces based on video input are available e.g. for security systems, *www.miros.com.*

Machines may employ e.g. radar images or infra-red images as well as the usual light wave length perceived by the human eye. *Meyrowitz (1999)* reports research of the Naval Research Laboratory (NRL) on pattern recognition of aircraft approaching aircraft carriers, employing neural networks to identify aircraft types from infra-red images, Fig.16: "Additional neural network research has recently yielded innovative techniques for automatically extracting objects of interest from their background (in infrared images, for instance), and for training networks so that they are capable of rejecting deficient input data in images. This technology provides a solution to the problem of reliably but passively recognizing aircraft approaching carriers or approaching more general battle spaces. The trained networks are able to avoid processing input before aircraft are close enough for image classification, and can avoid confusing noise such as cloud formations with actual aircraft."

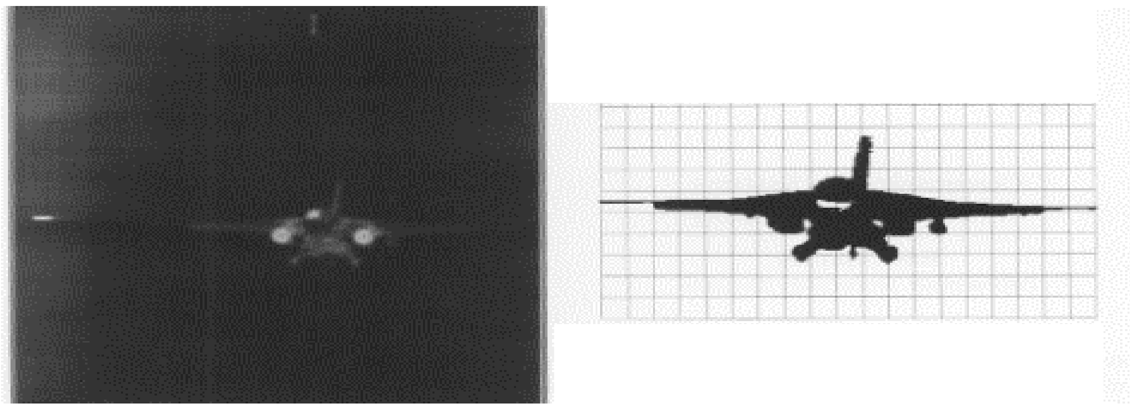

Fig.16: Original infra-red intensity image and extracted aircraft using NRL developed automated technique

3.6. Virtual Reality

Virtual reality (VR) initially referred to immersive technologies, *Beier (2000), www-VRL.umich.edu.* Today, the meaning of VR has broadened and includes semi-immersive and non-immersive techniques. VR models require an underlying CAD model of their world which then offers fly-through or walk-through capabilities. The VR models may be viewed using head-mounted displays with stereoscopic vision or plain PC screens. Sound may be added as needed. The resulting illusion of being fully immersed on an artificial world can be quite convincing. However, increased reality and model size comes at a price. Pragmatic applications have just the necessary level of detail to allow sufficiently fast responses on common hardware platforms.

Fig.17: VR view of ship passageway


Fig.18: VR view of glove atavar opening door

There is a wide scope of VR applications, potential and implemented. VR can be used as training tool, both as a "poor-man's" ship simulator (with underlying maneuvering model), and as a training tool to familiarize new crews without interfering with operations and to train damage control personnel. The NCARAI has developed InterShip, a VR tool to familiarize personnel with the layout of a ship, Figs.17 and 18, (implemented for the Ex-USS Shadwell, a decommissioned ship now used as platform for research and training). InterShip combines VR techniques with a knowledge-based route planner (shows how to get from one compartment to another) and speech control (user can e.g. open door by command; user can query system for information, e.g. invoking route planner.) Using the head-mounted display and a hand-held joystick, users could walk through portions of the Shadwell and ask questions about compartment names, numbers and locations. ("What compartment is this?", "Which deck is the communications center on?")


Fig.19: VR view of engine room


Fig.20: VR view of simulated fire, NRL

NRL has investigated employing this technique to improve performance of firefighters, Figs.19 and 20, *Tate et al. (1995,1997)*, *www.chemistry.nrl.navy.mil/damagecontrol/vr.html*. The virtual environment included a dynamically generated virtual fire made up of approximately 500 polygons. Using a mixture of physically based modeling and fractal techniques, the fire changed color and transparency levels to simulate the appearance of real flames. The density of simulated smoke varied with distance to the simulated fire and could be changed by operator control. There was a measurable improvement in the performance of firefighters that used VR training over firefighters without such training. VR trained firefighters made fewer wrong turns and reached the fire faster than untrained firefighters.

Firefighters might also benefit from another VR application, not yet implemented: Firefighters might have a virtual view of the ship and fire projected on a screen in their helmets blocking out all smoke.

The fire may be projected based on infrared sensors. Thus an augmented reality could be created for a firefighter allowing easier and faster fire fighting.

The Naval Research Laboratory (NRL) has also developed a rather sophisticated interface to VIEWER, a simulation playback system developed by NRL's Tactical Electronic Warfare division. In this system the user views the simulation through a suspended binocular display ("boom"), and navigates using controls on the display housing. Using verbal commands, the user can control the simulation playback and the display characteristics, and can move from one location or object to another by name and description. Essentially, this is again a training application to familiarize crew with certain tasks.

VR is also envisaged to fly remote-controlled unmanned aircraft, similar to state-of-the-art training missions for fighter pilots of manned aircraft.

4. Telecommunications

Communication is an important and often underestimated topic of ship automation. Much of the currently human based standard communication could be done by transponders. Automatic identification systems (AIS) based on transponder technology could reduce the human communication load both for ship-to-shore and ship-to-ship communication. The Distributed Intelligent Piloting System (DIPS), *Grabowski (1996,1999)*, may be a first indication of how future civilian shipping will be based largely on communication between machines. Similar systems could also be applied for navies.

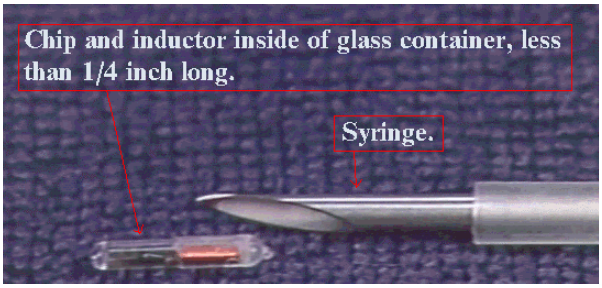

Fig.21: Implanted biochips have been developed

Fig.22: Solar powered chip placed on 1 cent coin, *www.deafblind.com/implant.html*

As we progress into the 21st century, crew members may have transponders on their wrist, as badges, or even fitted under their skin. These devices could carry entire medical records, security clearance, etc, Fig.21. In 1998, Kevin Warwick, *www2.cyber.rdg.ac.uk/kevinwarwick/home.htm*, had a silicon chip transponder surgically implanted in his left arm. The implant sent a signal to the computer which identified Warwick tracking his movements within the university. The system greeted him at the main entrance, opened doors, turned lights on depending where he was etc. The American company Applied Digital Solutions (ADS), *www.digitalangel.net/home.asp*, offered commercially by the year 2000 a penny-sized chip integrated in a wrist watch, called "Digital Angel". The chip allows tracing of persons (kidnapped children or fugitive convicts) integrating wireless internet technology with GPS. The Digital Angel can also transmit selected biological functions like heart frequency and blood pressure, even a sudden fall sensor is offered. This chip could also be implanted under the skin deriving its necessary energy through natural motion of the body muscles or body heat, *GEO (2000)*, but Digital Angels withdraw the pursuit of this offer due to public pressure in the USA.

Using this commercially available technology, crew members could be traced everywhere on board automatically. Computers could automatically ascertain casualties after an attack which will be particularly useful in matters of damage control, e.g. whether to flood a room with inert gas, whether to close compartments, where medical assistance is needed, etc.

The end of miniaturization of biochips is not yet in sight. Research at MIT and Harvard Medical School started in 1989 for the retinal implant project, aiming at developing a silicon chip eye implant restoring vision in blind patients. The implants are rest on the inside of the retina and have a tiny solar power chip supplying the energy, Fig.22. By early 2002, research supported by ONR at University of Southern California, Los Angeles, had progressed to enabling reading of large letters and recognizing faces.

5. Conclusion

Artificial Intelligence has been described as the science of people who research stuff that has been around for ages in the science fiction movies, *Kurzweil (1999)*. Artificial intelligence has also been described as a manic-depressive exercise. It appears that in several areas AI has progressed to the point of being a regular tool for engineers. The state of the art is characterized by island solutions for individual problems which already allow to reduce human work onboard ships considerably.

Major advances in automated intelligent systems will result from integrating competencies now addressed individually. Merge reasoning with vision, merge diagnosis with executing, cross-reference sensors and knowledge, and you will eliminate yet more tasks now performed by humans. If these tasks are performed on common hardware platforms instead of dedicated boxes supplied by individual suppliers, there should also be some reductions in weight and space possible, but the main advantage would be modular design concepts allowing continuing upgrades over the lifetime of ships. Fuel and weapon capacity may in the future be the driving forces determining combatant size.

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