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MISSION MANAGEMENT SYSTEM FOR AN AUTONOMOUS UNDERWATER VEHICLE

Henrik Østergaard Madsen

Maridan ApS, Usserød Kongevej 31, P.O.Box 247, DK-2970 Hørsholm, Denmark.
E-mail: hom@maridan.dk

Abstract: The unmanned, autonomous underwater vehicle (AUV) MARTIN is being developed for offshore applications such as cable and pipeline inspections, environmental surveys and seabed mapping.

The vehicle is equipped with a distributed control system consisting of 20 microcontroller based local nodes for the hardware interface and up to four industrial PCs running OS9000 for high level control. The nodes are connected by a CAN bus. The CAN bus is furthermore connected to the operator's PC and control box onboard the mother ship through a radio link or an acoustic modem.

The long range and high precision survey demands require an extensive diagnosis system and a fault tolerant control system. The distributed, multi-processor control system is designed modular and reconfigurable. The overall control is managed by a Mission Management System, consisting of a Diagnosis System, a Mission Executor, a Vehicle Support System and a Mission Control.

Keywords: Autonomous vehicles, Diagnosis, Distributed control, Fault tolerance, Management systems, Computer controlled systems.

1. INTRODUCTION

The AUV (Autonomous Underwater Vehicle) MARTIN was developed in 1995 for oceanographic and industrial surveys down to 100 metres (Bjerrum *et al.*, 1995). MARTIN is a 4.5 metre long, flatfish shaped vehicle a dry weight of 1.2 tonnes. The range capability is 80 km at 1 m/s. The depth capability is 100 metres. An upgraded version is planned with a range capability of 500 km at 1 m/s and a depth capability of 2000 metres. The hull and basic power and propulsion systems are based on the prototype vehicle MARIUS (Egeskov *et al.*, 1994) developed in 1992 under the European Community programme MAST (Marine Science and Technology). Tank tests and sea trials with MARIUS and MARTIN have proved the excellent manoeuvrability of the flatfish shaped, low-drag hull (Pascoal *et al.*, 1993, Aage and Larsen, 1997, Fig. 1).

The hull is primarily designed for cruising at 1-2.5 m/s (2-5 kn). Furthermore the six thrusters allow for hovering and precise manoeuvring at low speed. Two bowfins can lift the vehicle quickly enough to avoid obstacles when flying close to the bottom.

Great effort has been put into the navigation and positioning system to meet industry requirements. An advanced Mission Management System (MMS) will guide the vehicle during the pre-programmed surveys and maintain vehicle integrity. The system is being developed in collaboration between Maridan ApS, Institute for Automation at the Technical University of Denmark, and Risø National Laboratory. The system is modularly constructed and runs in a multiprocessor and multitasking environment. It will be described in details below.

MARTIN is currently being operated in UUV-mode (Unmanned Untethered Vehicle), as failure handling may require operator interference. In the future, operations will be performed in true AUV-mode, i.e. without on-line communication to the surface. Operations in AUV-mode are of particular interest for deep surveys and surveys under ice, but for many types of oceanographic and industrial surveys there is no demand for operating without a mother ship. On the other hand, the lack of tether makes it possible to operate the vehicle from an occasional ship.

With its accurate positioning and precise attitude and azimuth control, MARTIN is expected to be a

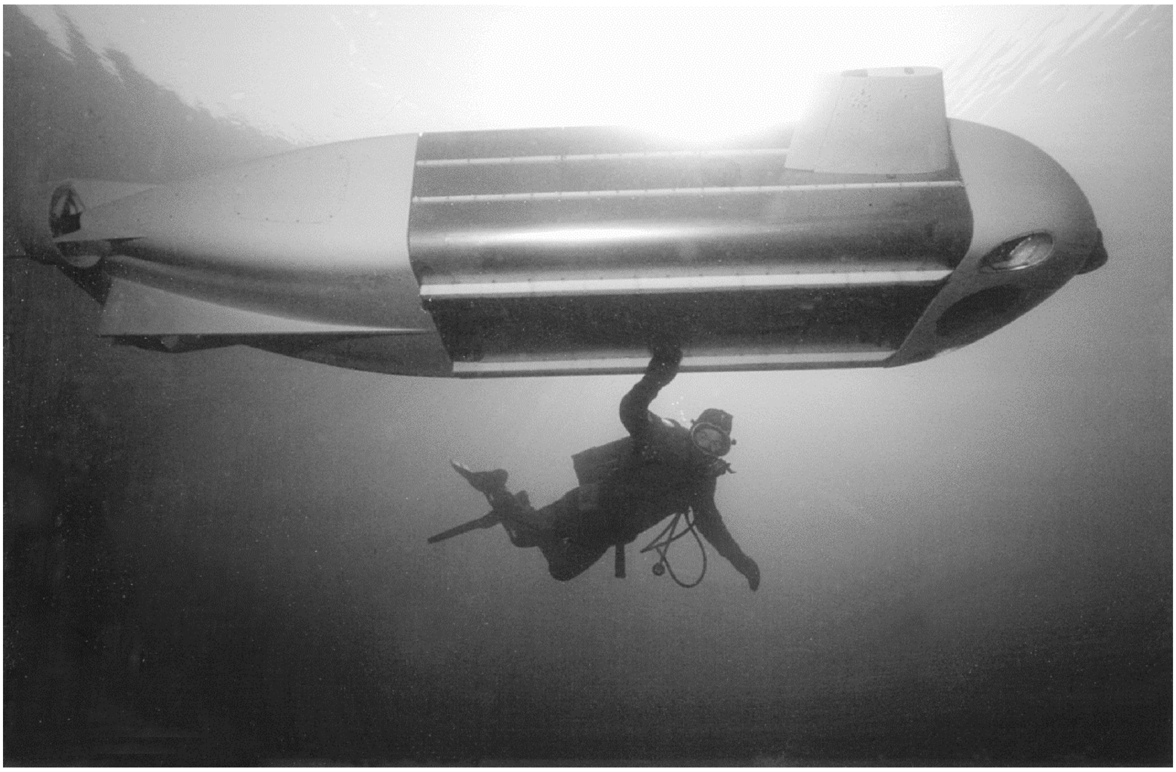

Fig. 1. The MARTIN vehicle.

suitable carrier for several types of surveys requiring high-density data collection equipment. Payload may include pipe-tracking equipment, video, multi-beam echo sounder, side-scan sonar, laser radar, sub-bottom profiler and any user-specified sensors as required for the survey. A typical application could be a pre-construction survey for subsea wellhead installations and associated pipelines and cables (Bjerrum, 1996).

2. THE CONTROL SYSTEM.

The control system is based on the distributed control system concept developed by NIST and NASA (Albus *et al.*, 1989), and it consists of *modules* arranged in a Control Hierarchy (Madsen *et al.*, 1996, Fig. 2). The modules at the base of the hierarchy are 80C517 microcontroller-based boards (CIP boards), placed locally at the controlled hardware. The other modules (see Fig. 2) are located on Industrial PC104 i486 and Pentium computers running the OS-9000 multitasking, pre-emptive real-time operating system. All PC's and CIP boards are connected by a CAN bus, known for its reliability from the automobile industry. The vehicle communicates with the operator's PC and control box on the mother ship using a radio link (when near the surface, data rate 10 kb/s) or an acoustic modem (when submerged data rate 1 kb/s). Data transfer by radio or modem works as an extension of the CAN bus, but the transmitted data are filtered and prioritised due to the reduced bandwidth. This ensures the transmission of crucial information and commands. An Ethernet further connects the PC's for less time-critical transfers of large data files and on-line debugging using a wireless Ethernet connection to a PC on the mother ship.

All inter-module communication takes place using broadcasts on the CAN bus. This allows the CAN bus to be used as a 'virtual' shared memory or blackboard (Albus *et al.*, 1989). The architecture supports the transfer of modules between PC's on the fly in case of failures or uneven CPU utilisation.

3. THE MISSION MANAGEMENT SYSTEM

The Mission Management System (MMS) is a group of modules and routines controlling the survey execution and the vehicle integrity. This includes the high-level functions (see Fig. 3):

- Mission Control, the 'Captain'
- Mission Execution, which controls the survey plan execution
- Diagnosis, which monitors and diagnoses the vehicle status.

Below each part of the MMS will be described in detail. Furthermore, the MMS includes a number of support functions:

- PC Management
- Control Hierarchy Management
- Operator Communication

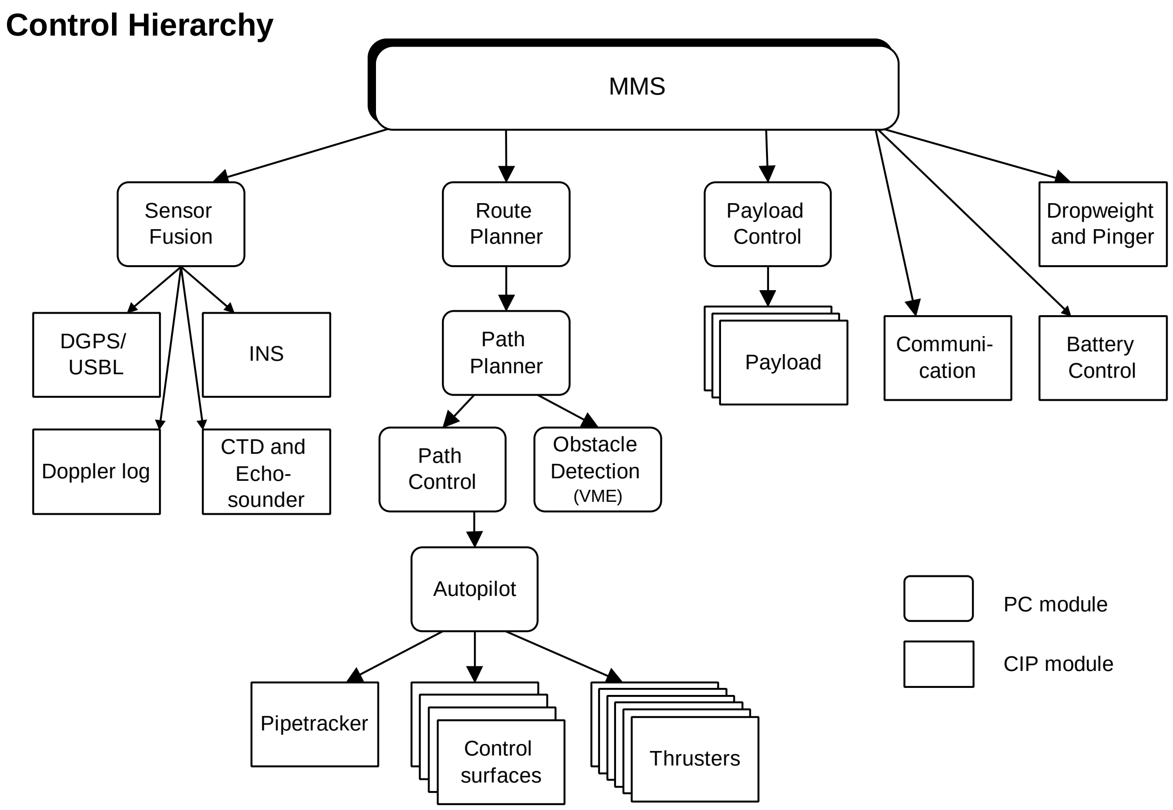

Fig. 2.The Control Hierarchy. The modules of the Mission Management System are not explicitly shown, see Fig. 3. The arrows indicate the flow of commands.

4. THE CONTROL HIERARCHY

The arrangement of modules in the Control Hierarchy resembles the flow of data (upward) and commands (downward). Each module has a master, from which it receives commands, and most modules have one or more children, from which they receive data. The topmost module is the Control Hierarchy Manager (CHM), which is responsible for creating and maintaining the hierarchy.

When the system is started, all modules will be requested by the CHM to acknowledge their presence. They are then chained according to a predefined hierarchy structure. If a module does not respond (missing or faulty), the modules supposed to be its children are set to correspond directly to the master of the missing module. A similar procedure will be used if a module stops functioning later, causing the Control Hierarchy to be reconnected. If a faulty module starts functioning again later, it will be re-entered into the Control Hierarchy

This scheme allows for a flexible self-configuration of the vehicle with varying instrumentation. If the modules have emergency routines for controlling the children of their children, the vehicle can recover from failing modules without loosing control, but with reduced performance. Furthermore, it creates an organised scheme for monitoring the functioning of all modules, as every master and child will monitor each other.

The CIP boards contain only one module, as they do not have an operating system. However, on a PC, several modules can run simultaneously managed by a special module, the PC Manager. The PC Manager starts and stops modules on request from the CHM, and is furthermore responsible for monitoring the PC performance and status.

5. THE DIAGNOSIS SYSTEM

The Diagnosis System consists of three parts:

1. A distributed Local Diagnosis System, included in each module
2. A central, model-based diagnosis system will detect any malfunctions in the hydrodynamic performance of the vehicle
3. A Main Diagnosis System combines the results to a complete vehicle status information

5.1. The local diagnosis

Each module is designed as an "agent" (Lewis and Gwin, 1991). The module will perform an intelligent validation of all input received from other modules or hardware, both regarding sensor data and commands, and invalid input is reported to the Main

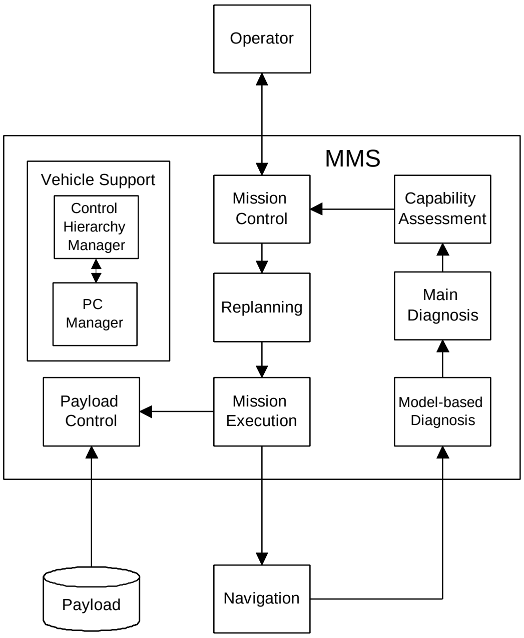

Fig. 3. The Mission Management system structure.

Diagnosis System. Furthermore, the module will test its output before submitting it on the CAN bus, as well as it will perform self-tests in the internal algorithms where applicable. The module diagnosis is thus mainly carried out by the module itself, which allows for rather thorough diagnosis algorithms, as the internal structures as well as intermediate results are available. However, the master of each module will also perform a check on the module performance, based on the commands sent. This is a similar but more crude check to detect situations, where the internal diagnosis has stopped working.

When a problem in a module or hardware is detected, other modules may not be able to carry out commands correctly. Therefore, the modules can report bad system performance as a reason for their own failure, and this information is compiled by the Main Diagnosis System to isolate the true problems. The Local Diagnosis is expected to locate single sensor failures, motor and servo failures, software failures, etc.

5.2. The Model-based Diagnosis

The Model-based Diagnosis System shall detect any malfunctions in the vehicle hydrodynamic properties. This includes wave interference, hull damage, and entanglement by wires, seaweed, fishing net, etc.

The hydrodynamic model of the vehicle uses as input the current state of the vehicle hardware, e.g. thruster speed, fin angles, etc. The outputs are, among others, the vehicle position and speed, which are compared with the corresponding data from the Sensor Fusion (basically a Kalman filter compiling sensor data to a position etc.). Large discrepancies will be interpreted as a failure, whereas small discrepancies are used to update the model to keep it on track (observer type model).

When a large discrepancy is detected, a Hypothesis Generator will select a number of probable causes, taking the type of discrepancy and situation into account. The Hypothesis Generator will be based on a functional model of the vehicle converted to a rule-based expert system written in CLIPS (Christensen *et al.*, 1997).

The hypothesises are then tested one by one using a similar hydrodynamic model with cashed input data covering the deviation. The ability of each hypothesis to explain the discrepancy is evaluated, and the best hypothesis is selected. The vehicle status is updated accordingly by the Main Diagnosis System, and the Mission Controller is informed.

6. MISSION CONTROL

The Mission Controller is the topmost module (when disregarding the CHM), and functions like a Captain on a ship. It controls the mission start and stop, the replanning needed underway, and the emergency actions during failures. Furthermore it communicates with the operator onboard the mother ship.

When a fault is detected by the Diagnosis System, it will be examined by a Consequence Analyser and compared to the survey plan. The results are sent to a Replanner, which will suggest changes to the survey plan. The Mission Controller can then apply the new plan by sending it on to the Mission Executor. Both the Consequence Analyser and the Replanner are based on the functional model also used in the Diagnosis System (Christensen at al., 1997).

The vehicle is currently used in UUV-mode with a man-in-the-loop. The Mission Controller will inform the operator of failures, and the operator will decide upon change of plans. The Replanner will be used only in the event of a communication failure, and then limited to deciding how to surface (using the emergency dropweight or by a controlled ascend).

7. MISSION EXECUTION

The Mission Executor accepts a survey plan containing details on waypoints, mode control and payload control. The plan is passed through the Route Planner, which will create a more detailed plan with closer waypoints, taking information about time, energy, currents, known obstacles, etc., into account. During the survey, the local part of the detailed plan is sent to the Conning System (Madsen *et al.*, 1996), which will navigate the vehicle accordingly, avoiding sonar detected obstacles as they are found.

The Route Planner will update the detailed plan regularly as needed, and the Mission Executor will keep track of the execution of the original plan and control the payload accordingly.

Initially the operator can download a seabed map, which is used as a basis for the Route Planner. During the survey, the Map Manager will keep this map updated with measured data, e.g. depth and stationary obstacles.

8. CURRENT STATUS

The vehicle was upgraded from using only CIP boards to including a PC in June 1997. It now has the PC Manager, the CHM and a simple Mission Executor and Mission Controller running. The Main Diagnosis System is under development, and part of the local diagnosis is now incorporated in the modules (Course Control, Path Control, Sensor Fusion, etc.). The functional model is developed, and is currently being converted to CLIPS. A full-scale survey is planned in the spring 1998, but the systems are tested regularly during sea trials in Roskilde Fjord, Denmark.

9. ACKNOWLEDGEMENTS

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