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Function-oriented failure diagnosis generation for autonomous submarine navigation

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Abstract

The on-board diagnostic facilities of an unmanned vehicle for submarine inspection of pipes and cables are described. There is a local diagnostic mechanism for each module in the control hierarchy overlooking the levels below itself. In case of ambiguities and conflicts a global diagnosis system will be interrogated. The global diagnosis mechanism applies a general GTST functional diagram for the missions to be carried out by the vehicle. The mission plan is written in a specially constructed macro language downloaded to the vehicle computer network before each new launch. Each command of this language will correspond to a well defined set of the functions available in the GTST diagram. When a diagnosis of an execution failure for one of the mission language commands must be handled, the reasoning in a diagnosis knowledge base can follow the hierarchy of the GTST diagram.

1. Introduction

The first and preliminary GTST model for the vehicle MARTIN, see fig.1, was presented at the 4th FM-workshop in Athens in June 1996[1]. The vehicle can be described shortly as follows: MARTIN is an unmanned submarine for autonomous inspection of oil- and gas pipelines and electrical cables. It is being developed in a Danish research project by Maridan ApS, the Danish Technical University (DTU), Risø National Laboratory, and the companies Reson A/S, SEAS A/S, and Em. Svitzer A/S. Autonomous operation of the vehicle offers a potential for economical benefits compared to the use of tethered vehicles or divers because of less dependence on weather and less demands to the sophistication of the mother ship. Therefore, it will be of great interest to operators of submarine pipelines and cables which need periodical inspection in order to detect position, damage, corrosion or changes in the surrounding sea bed.

However, in order to be of interest to potential users the vehicle must be able to perform its autonomous missions reliably and to react correctly to foreseen - and unforeseen - disturbances, such as obstacles not indicated on the charts. Therefore, a large effort has been put into designing the control system, starting with a functional analysis of the tasks to be performed by the vehicle during a mission. The analysis comprised all aspects of a mission, including the identification of potential external hazards which have to be catered for, e.g. various kinds of obstacles in the water or at the sea bed.

The MARTIN vehicle has a 4.5 meter long flatfish shaped, low-drag hull with two main thrusters aft[2]. It has three vertical and one horizontal thruster for low speed, and fins, rudders and an elevator for normal speed manoeuvring. The hull is open, and all electronics is placed in watertight compartments. Propulsion energy comes from 5 kWh lead-acid batteries. The maximum speed is 2.5 m/s, the range capacity 80 kilometres, and the maximum depth 100 meters. It was based on the MARIUS vehicle developed under the European MAST programme[3]. Existing projects will add a 3 kW Stirling engine to extend the range to 500 km, and the depth rating will be upgraded to 2000 meters in future versions.

MARTIN is currently being operated in UUV-mode (Unmanned Underwater Vehicle), e.g. supervised by an operator onboard a mother ship using radio or acoustic modem, but will be upgraded to fully autonomous mode (AUV mode). It has a distributed control system centred around four PCs running the OS9000 multitasking operating system for the high level control, and 20 locally placed microcontroller boards for the low level hardware[4].They are connected by a CAN bus network, which is extended via radio or acoustic modem to an operator on the mother ship. The onboard sensors include inertia platform, DGPS, echo sounder, Doppler log and imaging sonar[5].

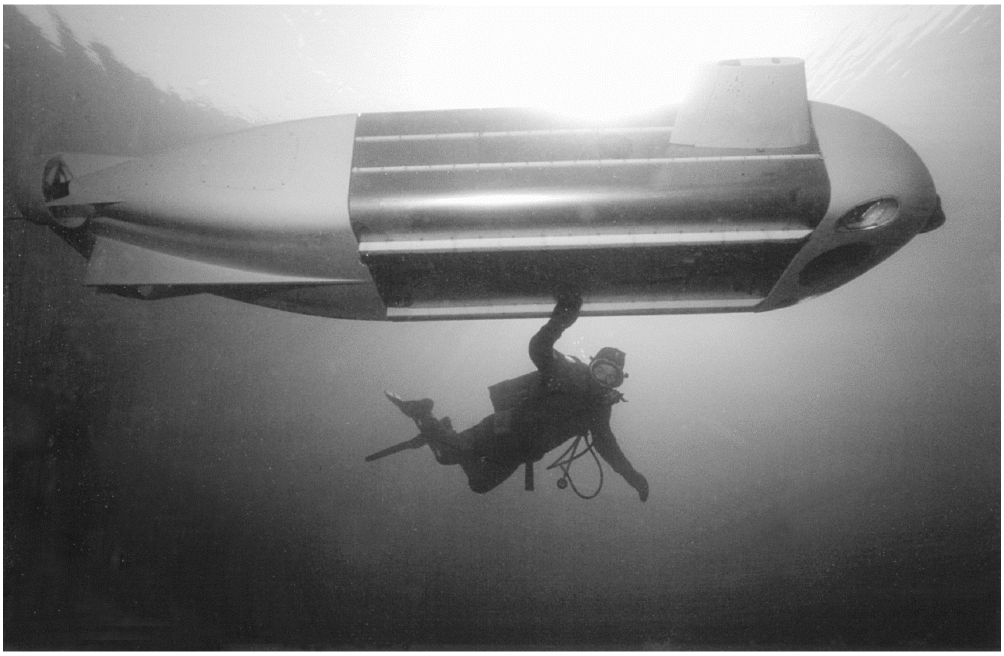

Fig.1 MARTIN

The vehicle is aimed at environmental surveys and cable and pipeline inspections, which require high precision positioning and a high degree of data quality assurance. The long range requires a flexible and fault tolerant control system, capable of detecting and compensating for failures. The control system is based on the NIST model[6] with multiple levels of modules with increasing level of abstraction. The modules are independent and can be moved between the PCs. They are organised in a control hierarchy structure, which can be restructured on-the-fly in case of failure or reconfiguration. They can be divided into three groups: The Sensor part, including sensor interface and sensor fusion, which obtains the vehicle's position, the Vehicle Control part, mainly consisting of the conning system, which steers the vehicle, and finally the Mission Management System (MMS).

2. Project status.

The project started early 1996 and it was fairly soon realized that a formal function-oriented breakdown could be very useful as a basis for a design check list, i.e. for checking that all functions have been implemented during the design phase. GTST is well suited for creating an easily understandable model for this purpose. Further GTST is a fairly straightforward hierarchical method for which system diagnosis has been demonstrated by Kim and Modarres[7] by reasoning in a knowledge base, a facility which will also be implemented in this vehicle.

In comparison with the earlier paper[1] considerable changes have been introduced into the GTST model. Originally the more general mission of flying and carrying a payload was considered in the same way as the three functions of an airline pilot, i.e. "navigating", "communicating", and "flying". In this vehicle there is no human pilot on board and this makes the original concept too narrow, first of all relying on the pilot's capabilities of handling unforeseen problems is not a possibility, and all possible situations must be foreseen and catered for in the Mission Management System. The model has become more general, and it has been changed in the direction of a more detailed breakdown of the navigational functions in order to facilitate the collaboration between the latter and the Mission Management System. It will appear from fig. 2 that the conning part, i.e. the part responsible for propulsion and steering of the vehicle, have been split into four modes as the vehicle actually has four quite different ways of "sailing".

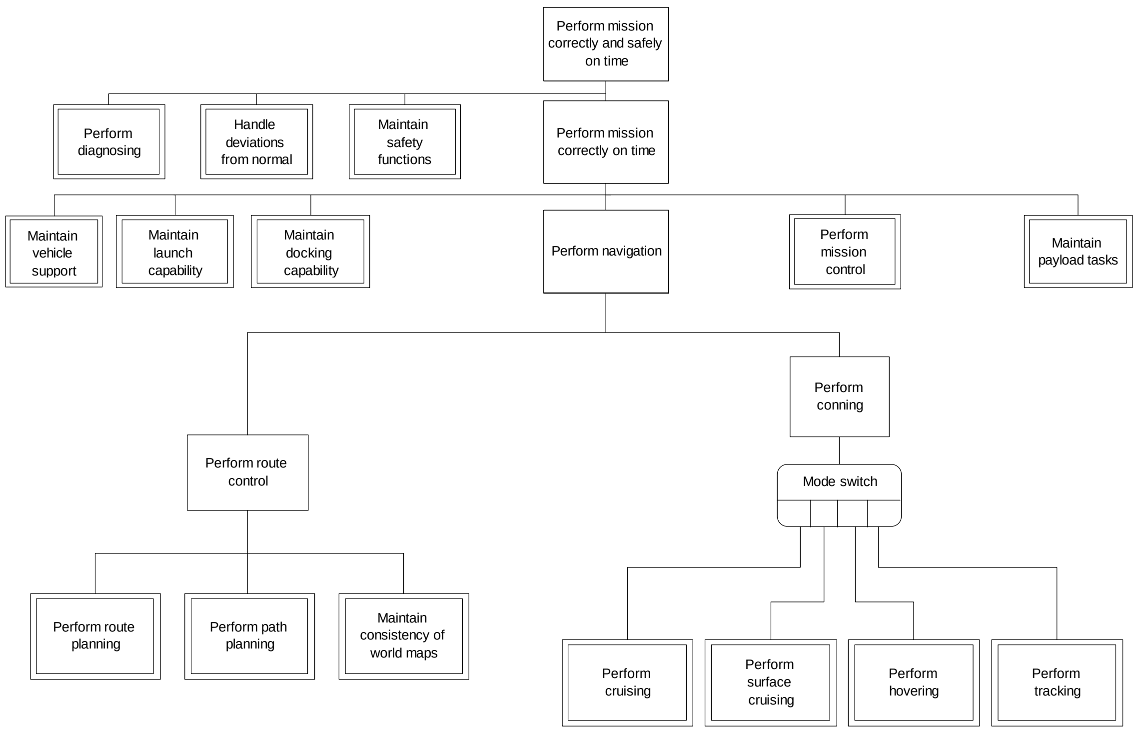

Fig. 2. First steps in the GTST modelling

The first steps of this breakdown are shown in figure 2. The notation used in the GTST diagrams is the following: basically all goals and functions are shown as boxes, and the connections downwards in the diagram are implicitly AND gates, i.e. all lower level functions must be fulfilled in order for a given function to be fulfilled. Due to the limits of the paper we have introduced a double-box as the notation for a function which is expanded elsewhere. In figure 2 we use a "mode switch" which will be explained later.In fig. 3 “Perform cruising” is further developed down to the bottom of the goal tree and the top of the success tree.

GTST cannot directly model dynamics, so for each mode of a system a separate set of GTST diagrams should be drawn. The mode switch used here is not a “logic device” in the tree, but a simple formalism to avoid exessive drawing efforts.

3. Diagnosis at local and global level. Interaction with the Mission Management System.

The control system of the vehicle is structured in a hierarchy of modules. Each level features an internal check mechanism observing the input and output of the module. In case of observed malfunction a simple local diagnosis is initiated. If an unambigous result is produced the diagnosis result is passed to the MMS. If not, the observed state parameters are passed directly to the global diagnosis system. Apart from the state messages from faulty control modules the global diagnosis system is supplied with data from the mission execution modules and all dynamic information about the immediate environment and the movements of the vehicle.

The global diagnosis will be carried out as a reasoning in a knowledge base, and will be expected to present either none, one or more suggestions to the MMS for further decisions on the future of the current survey, i.e. either to do some reconfiguration before continuation or to stop.

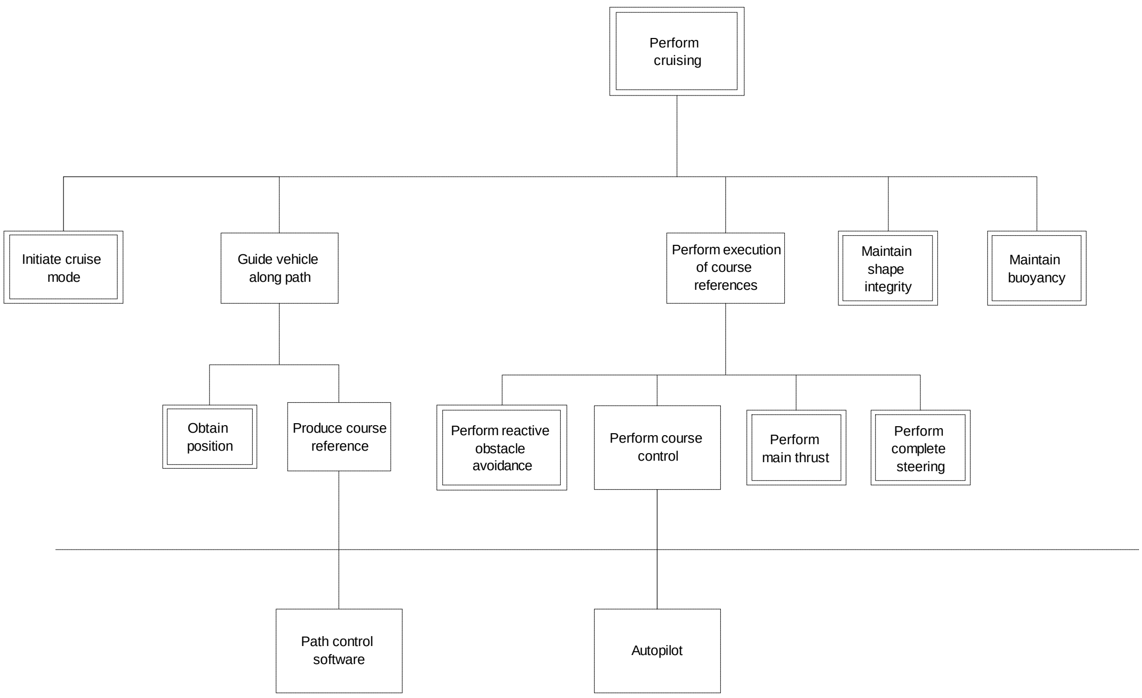

Fig.3. GTST breakdown to the Success level.

4. Survey commands and GTST functional modules.

The survey plan is sequentially structured within a hierarchy of Tasks, Phases, and Operations. Within each survey plan operation some necessary "preconditions" are attached and may be represented as attributes. An example of a survey plan command is shown in fig. 4.

Operation 3.1.4 Move along pipe at specified altitude and desired direction
Precondition: Logging proceeding
Postcondition: Tracking conditions OK
Command: **Track**
Arguments: <target params, target presumed position (visible/non visible), stop criteria(time/position/lenght)>

Fig. 4. Operation 3.1.4, i.e. operation 4 in task 1 in phase 3 of the survey is **"Track"**.

The GTST representation features a means-end description, the "end" being represented by goals and functions while the "means" are represented by resources.

When a thorough complementarity exist between each single operation for use in the survey plan and the functional resources of the GTST diagram, i.e. each step of the operation can be mapped on one or more functional resources of the GTST diagram, it will be possible to do the diagnostic reasoning using the GTST structure. This may be implemented by means of the method[8] developed at the DTU.

A typical scenario would consist of the following phases, the names of which should be self explanatory.

- Downloading of mission information to the vehicle
- Launch of the vehicle
- Precise measurement of position
- Diving and cruising to the starting point for the survey
- Finding the pipeline
- Cruising along the pipeline and making video recording
- Determining when the end of the section to be inspected is reached
- Cruising back to the mother vessel
- Docking
- Retrieval of survey results

6. Reasoning mechanism.

The knowledge base and its reasoning mechanism for the global diagnosis is under development. It will refer to the tree structure of the GTST diagram. Each goal-box will be considered a node, and it will be given a number of attributes to define its facilities and propagation properties to other nodes. The reasoning will be bottom-up, based on the principle that a node having the output value TRUE will propagate a TRUE condition upwards in the tree[8]. Diagnostically this will mean that as long as nodes under consideration keep the TRUE value the error must be looked for at a higher level or in a different branch of the tree.

7. Conclusion.

The early adoption of a function oriented modelling as the basis for the definition of the diagnostic system of the vehicle has proved very valuable during planning discussions as a common reference of the whole system. The progress with the diagnosis knowledge based system indicates that the GTST model is a very useful tool in this work.

8. Acknowledgement.

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