EURODOCKER - From design to construction

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Introduction

The EURODOCKER project has the objective of developing an unmanned support system for autonomous underwater vehicles (AUVs), to permit docking, data downloading and battery recharging activities to be carried out underwater. This system shall overcome two of the principal current restrictions to the use of AUVs, tied to their limited independence from expensive surface support, and the risks of loss or damage inherent to continuous surface launch and recovery operations.

The solution developed entails a submerged docking station for AUVs, that may be deployed either as part of an unmanned underwater platform on the seabed or lowered from a support ship from the surface. The system shall be suited to various AUVs that are now under successful development and aims at becoming a standard subsystem of any AUV support spread.

The main objective of the EURODOCKER project is to develop and demonstrate in water the technologies necessary to automatically dock an AUV to an underwater station, whether it is ship-supported or based on an unmanned underwater platform. In addition the system shall be suited to various AUVs that are already on the market or under successful development, and thus aims at becoming a standard subsystem of the AUV support spread.

This project, supported by the EC MAST programme, is a joint RTD venture by five Partners: Maridan AS (DK); The Institute of Automation IAU at the Technical University of Denmark (DK); Studio Tre Ingegneria (IT); Orca Instrumentation (FR); and the Underwater Technology Center of IW at Hannover University (DE) which is also the Co-ordinator. The project started in December 1997, and is due to end in November 2000.

System analysis

The system analysis phase of the project entailed a number of activities, the main ones being:

- Identification of the foreseen operative scenarios
- State of the art analysis of AUV's and of their docking requirements
- Definition of the functional requirements and concept selection for design

Operative scenarios

The definition of the operative scenarios that have been used as reference during the development of the EURODOCKER Project has been based on: current use of AUV's in operation; the objectives of AUV's under development; and specific investigations within the industry as to the foreseen developments in AUV use. The above have led to the definition of three principal scenarios for use of the EURODOCKER:

1. Ship supported at any water depth: As can be seen in Fig. 1, this scenario foresees the use of the EURODOCKER as a support to AUV's that are deployed and recovered from dedicated or chartered ships. It is foreseen that the EURODOCKER be launched from the ship integrated with the AUV, which shall then commence its mission, once the EURODOCKER has reached a suitable depth. Within this scenario the AUV may perform repeat missions without the requirement to be recovered on board the ship, as once docked to the EURODOCKER all the activities of recharging and data downloading may be performed at the deployment and docking depth.

2. Open water missions from Coastal waters: as illustrated in Fig. 2, this foresees the use of the EURODOCKER for missions in open waters as in the case of 1 above, however in this scenario the EURODOCKER shall be placed on the ocean floor and not be deployed from a ship. The AUV shall treat the EURODOCKER as a subsea home base from whence it shall emerge to perform its mission, and to which it shall redock at the end of the mission for data downloading and recharging. The initial hypothesis is that the location on the seabed is in relatively shallow waters and therefore this scenario has been defined as from 'Coastal or Continental Shelf waters'. The main challenge for this solution shall be reliability, however the potential is for significant operational cost savings.

3 Ice infested waters: From the analysis of the state of the art and the interviews held with the principal manufacturers and operators of AUV's it has become apparent that one of the most promising applications for AUV's is considered to be their use in Ice infested waters. In particular the development of AUV's is considered one of the essential 'technological packages' for the exploration and exploitation of Arctic and Antarctic waters. Two AUV's (ARCS and SARA) have already been developed to this end, however both are restricted to the use of a surface support vessel. This scenario, illustrated in Fig. 3, shall have obvious cost and availability advantages.

S*tate of the art of AUV's and their docking systems*

The main functions of the EURODOCKER will be to re-charge the power system of the vehicle, download mission data and upload changes to operations management data after each mission. Extensive market analyses were performed to determine both the state of the art and more specific AUV docking requirements, through contacts with the main European constructors of AUV’s as well as contacts with the North American and Japanese AUV industry. The docking requirements were defined with regard to the homing procedure in terms of both localisation and guidance, the latching and aligning methods, the garage concept, the dynamics and control, the communications systems, and the Launch and Recovery system.

Conceptual design

The conceptual design phase of the project therefore analyses possible architectural solutions for the various systems of the EURODOCKER, covering the principal activities involved in docking an AUV, namely:

- how the AUV shall home into the EURODOCKER;
- how the EURODOCKER shall actually mate with the AUV;
- if and how the AUV shall be garaged.
- how the docking system shall be launched and recovered.

The most promising solutions for each function have been selected based on the operative scenarios described above and on the basis of the following aspects:

- Compatibility with different AUV's on the market
- Ease and cost of construction
- Adaptability to different Operative Scenarios
- Ease of operation, in particular for launch and recovery
- Robustness to operation (operative reliability)
- Adaptability to future innovations in AUV's

In addition the impact of a number of supplementary aspects have been considered during the solution selection, namely: modular vs. self-contained architecture for the EURODOCKER; hovering vs. non-hovering AUV; and near term vs. long term use. The following solution have been selected:

AUV Homing Systems.

The base case for the tracking of the AUV's shall be utilising GPS-LBL buoys (GIB) for first circle re-entry. These shall be deployed in a set of four, typically 0.5-1 km from the EURODOCKER system, providing an accuracy of ± 3 m. Once the AUV is within 50 metres from the EURODOCKER, a USBL (Ultra Short Base Line) acoustic system shall be used for the close range approach. This will narrow the position accuracy typically to ± 20 cm, at a rate of 2-4 fixes per second, improving as long as the range reduces. Acoustic communication has been selected as it is featured by most AUVs identified as possible clients (except SARA).

AUV Mating Concepts

A number of mating systems for the AUV's to the docking component of the EURODOCKER have been considered:

- Articulated arm
- Guide wire with nose cone
- Garage
- Catch wire
- Free swimming

In order to select the most suitable mating system it has been necessary to identify the other operative functions that must be catered for by the mating solution, principally:

- fine guidance during docking;
- the system for reeling in the AUV when a nose cone is used;
- the manner in which the AUV is protected during docking and launch and recovery;
- the system for connecting the DDLR connector to the AUV;
- and the manner in which the AUV is released for its next mission.

These aspects have led to a preference for the garage system, which provides the simplest system for both guiding the AUV in the final approach and providing a suitable location during the period that the AUV is docked. A garage shall also provide the function of protecting the AUV after docking, during recharging and/or Launch and Recovery.

It is essential that the garage concept selected minimises the required supplementary vehicle hardware, which would impact the vehicle hydrodynamics, which have great importance during docking due to the necessity to match orientation.

A number of basic concepts and variants have been considered in the analysis, with the selection going to a framed modular garage, which has a low added mass relative to the storage volume enveloped. This concept consists of a frame made of tubular beams, segmented transversely and longitudinally, hosting four guidance curved bumpers, shaped to cope with the AUV cross section (Fig. 4). Connecting the bumpers to the structure with resilient elements shall provide shock absorption, while giving the bumpers a low angle conical configuration shall perform braking of the AUV within the garage.

The release and expulsion of the vehicle from the garage shall be performed by permitting the garage structure to open up or down (respectively when sea bottom or ship supported) so that the AUV can swim away under its own power.

Launch and recovery Concepts

Although the Launch and recovery system is not strictly part of the supply of the EURODOCKER project, it is considered to be a critical system to the design and development of the EURODOCKER concept for the Operational Scenario 1, which is considered to be the nearest commercial application. This system has therefore been analysed in depth to provide the most suitable solution for a correct specification of the EURODOCKER.

A number of different concepts have been analysed looking at deployment from either the stern of the vessel or from the side. From the stern of the vessel solutions ranging from the use of a stinger, to a slipway, to an A-frame crane have been considered. A stinger and a tilting A-frame solution have also been considered from the side of the vessel as well as the use of davits.

The most promising solution that has been identified utilises guide wires and a dead weight, in order to reduce the horizontal motions of the EURODOCKER while crossing the splash zone.

The system may be deployed from the aft of the ship, with a guide wire deployed at each side of the garage and the dead-weight perpendicular to the ship‘s longitudinal axis, or deployed from the side of the ship, with the garage heading inclined respect to the ship, but aligning itself passively when the ship moves forward.

Detailed Design and Construction

The detailed design and construction was performed ensuring that all the components were designed matching the targets given by the specification document.

The overall concept was identified as the design of an AUV specialized support structure and the design of various universal modules. A graphical visualization of the design concept is shown in Fig. 5.

Docking Station

The design of the docking station included the design of the control unit and the platform consisting of a support structure, bumpers to ensure that the AUV is not damaged during docking and to help keep the AUV in position (see Fig. 6), a reference device that ensures that the AUV is positioned within very tight tolerances within the docking station to facilitate in the connector mating (see Fig. 7), permanent buoys, a variable buoyancy system and a release system including a locking and connector mating device.

All actuators are driven by a developed sea water hydraulic system. A 2,2 kW sea water pump provides a differential pressure of up to 0,78 MPa. Both pressure and flow can easily be adjusted for each seawater hydraulic component via an orifice plate and/or a bypass. The optimum constellation for each component was examined during the laboratory test phase.

Battery Management System

A battery system has been developed including battery cells housed within dedicated water tight housings, and a Battery Management System called MARBAT.

***Docking Connector*.**

A wet mateable connector has designed, constructed and tested. It has five 12 A contacts and one additional contact for providing a signal whether the connector is connected or not. The linear connector consists of a pressure balanced receptacle with socket contacts which are arranged one by one on the socket diameter and a pressure balanced plug with contact pin on which the corresponding pin contacts are arranged (see Fig. 8).

In the unplugged condition the receptacle is closed by a spring-loaded plug. The receptacle is filled with silicon-oil and is pressure-balanced by a ring-shaped diaphragm. The plug with the pin contact contains a guide bush with a corresponding bezel which carries out the alignment between the receptacle and the mounted plug in the balance system.

The guide-bush seals the pin against seawater and is hydraulically mated by a coaxial mating system. As soon as the guiding between plug and receptacle occurs, the mating process starts hydraulically and the pin contact is inserted in the socket. A spring supports the retracting of the plug in the guide bush. The plug with the pin contacts is connected to a cable in a moulded housing.

A test contact according to the pin position shuts the resistor in the receptacle (R2= 1 KΩ; pin contact retracted) or in the resistor in the plug system (R1 = 10 KΩ; pin contact extracted) against ground. In case of a short circuit, the system amounts to the resistance 0 Ω. Consequently, the current flow signalises the plug system the pin position in an undoubted manner.

A balance system is fixed to the garage and allows a maximum tolerance between plug- and receptacle of ±25 mm on the plain and ±2" in the connecting axis. The balance system consists of a disk to which the plug-in-system is universally fixed and two half-shells linked to the garage. The disk is moveable, mounted in the half-shells and permits a horizontal movement on the surface of the half-shells. 8 springs centre the disk. The disk is universally fixed at the plug-in-system in a ball-shaped bearing and allows a misalignment of ±2° to the connecting axis. The reset force for centralization is delivered by two O-rings.

The system is completely filled with silicon-oil to be protected from corrosion and underwater growth. Two horizontally operating bellows close the two pieces moving against each other and equalize the pressure of the interior balance system and the sea water.

Testing of the system has been completed on a stand alone basis and integration testing shall be performed in the near future.

System Control

The developed low level control essentially regards the actuators of the different components of the docking station. For this both hardware and software have been developed.

The concept of the EURODOCKER control system is shown in form of an elementary circuit diagram in Fig. 9. The centre of the control unit consists of a single-board computer (size of a check card). Its 8-bit micro controller is externally pulsed by an 8 MHz crystal oscillator. The computer provides an 32 Kbytes EPROM which stores the operating system and user-programs permanently. The micro controller's analogue-to-digital (A/D) converter system uses an all-capacitive charge-redistribution technique for conversions. The A/D system is an 8-channel, 8-bit, successive approximation converter with ± 1/2 least significant bit (LSB) accuracy over the complete operating temperature range. Because of the charge-redistribution technique, no external sample and hold circuits are required. A 512 Byte EEPROM is included and also 256 Byte RAM. For the address bus two 8-bit ports are used.

The CAN-controller is connected to the micro controller and receives and interprets the data from the surface control unit using the CAN protocol, specified in co-operation with the development of the operator interface. The data will be transferred via DC-isolated power supply (DC/DC converter) and transceiver to a two-wire circuit (CAN bus).

Simulation of Docking

The aim was to develop a simulation tool capable of simulating docking operations involving the underwater vehicle and the docking station. To achieve an accurate imitation of the AUV's behaviour an advanced hydrodynamic model was obtained and incorporated into the simulator. Similarly, to achieve a truthful appearance of the vehicle and the docking station, accurate CAD drawings were adapted to the simulator.

The simulator is designed in a spirit of modularity, allowing easy incorporation of new visual or dynamical models of the vehicle, the docking station and the environment. By using dedicated and widespread tools for both simulation and visualisation, modelling of the simulated entities is greatly facilitated. The result is a generic and modular simulation and visualisation environment that can easily be adapted to new scenarios involving different entities and surroundings.

The dynamical modelling is performed in Simulink for Matlab. As it is possible to communicate over a network (or the local computer) from Simulink using sockets, the model can be run in parallel and communicate with other programs on any other platform supporting sockets.

The selected visualisation tool, VRML, provides a similar modularity and generality (see Fig.10). Firstly, tools exist to convert almost any CAD format to VRML, enabling geometric models to be easily imported from whatever format they already exist in without having to redraw these. And, equally important, VRML 3D browsers can be installed as free plug-ins within common free 2D browsers, such as Netscape or Internet Explorer. Furthermore, as VRML can exchange messages with external programs written in Java, scenes can be enhanced with Java's powerful computational and network facilities. For instance, positional data can be received via sockets either from the web or from other programs on the local computer, interpreted and treated in Java and then finally routed to the VRML scene.

All communication between different blocks in the simulation is performed according to the IEEE standard for Distributed Interactive Simulation, DIS. This standard is written for military simulations involving large number of entities distributed over a network. DIS defines standardised protocols to communicate simulation parameters and entity positions with a minimum of overhead. By complying with this standard, compatibility with other researchers in the fields of computer simulation and autonomous underwater vehicles is achieved.

Future activities

Completion of the construction and integration activities is foreseen during the second quarter of 2000, following which sea trials shall be held both for final testing and for demonstration. The project shall be completed in November of the year 2000, following the prototype sea trials.

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