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EU project MORPH: Current Status After 3 Years of Cooperation Under and Above Water

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Abstract: The MORPH project (FP 7, 2012-2016) advances a novel concept of an underwater robotic system composed of a number of spatially separated mobile robot-modules, carrying complementary resources. Instead of being physically coupled, the modules are connected via communication links that allow a limited flow of information among them. Without rigid links, the so called Morph Supra-Vehicle can reconfigure itself and adapt in response to the shape of the terrain, including walls with negative slope.

The MORPH concept requires new concepts in a number of technological fields. Examples are adaptive sensor placement for perception and navigation or environmental modeling in complex environments. As the project enters its final year the basic developments have been achieved. It is still a huge effort to create a system out of components which can be perceived as a supra-vehicle. This paper focuses on a presentation of the current state.

Keywords: complementary navigation, control, architecture, adaptive behaviour, robotic vehicle

1. INTRODUCTION

The exploration of the Ocean is still a challenging task, due to the adverse environmental conditions of the deep. It is well known that Autonomous Underwater Vehicles (AUVs) which work fully unsupervised are maturing and finding their way into application. This is especially visible in hydrographic mapping tasks where the vehicle dives down to the seafloor and performs a survey of the seabed by means of sonars and other sensors. These allow a high resolution view of the underwater world which gives stunning results.

A drawback is the fact that swath width of high resolution sensors operating close to the bottom is quite narrow, in the range of 5 to 100 m. In order to expand the spatial sensor extension, one method is to employ a team of robots which fly in a certain formation. This requires methods of coordinated motion control which is still a hot research topic in the marine community. Projects like GREX (Joerg Kalwa et. al 2006) paved the way for applications of this kind. But due to missing adaptive abilities of the vehicles involved, pre-planned formation flying is limited to more or less flat areas.

Often geologically or biologically interesting areas cover e. g. volcanic areas of the Mid-Atlantic Ridge, coldwater coral reefs or even man made structures like foundations of wind turbines. When irregular surfaces are in the focus, both, sidescan sonars and pre-planned formations are facing its limit. Autonomous vehicles of today are not suitable for operating in challenging unstructured environments. In fact, when the terrain is rough and the environment is hostile, the vehicles can be trapped easily and valuable equipment can be lost, as witnessed in a number of occasions. The Doppler Velocity Log, a fundamental instrument in dead-reckoning navigation techniques used by underwater vehicles fails to provide reliable measurements when operated over uneven or rugged terrains. As a consequence, the vehicle ends up losing its position accuracy.

It is for the above reasons that today only remotely controlled vehicles (ROVs) are employed in these rough and truly three-dimensional terrains. ROVs are connected to a surface

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support ship via an umbilical cable that allows for remote control and immediate access to all payload data. However (and the same happens with currently existing AUVs), accurate global positioning is virtually impossible to achieve when the ROV operates close to complex underwater terrain features (e.g. vertical walls or walls with a negative slope). As a consequence, the region being mapped cannot be properly geo-referenced or be easily relocated in a subsequent dive. Moreover, the cable might become entangled with the surrounding environment, which may also lead to vehicle loss.

Proposing a solution to this problem is the main focus of European Project MORPH. In general, the term "morphing" denotes the physical transformation of the appearance of an object. In the scope of this project we introduce "morphing" as the concept of physically shaping an underwater robot composed of distributed single robotic nodes, each of them offering limited but possibly complementary capabilities.

For orientation and safe motion in rugged terrain an ideal vehicle must have a certain desistance from any objects. Its "eyes" scan the environment for possible threats such as overhanging cliffs or protruding rocks. On the other side, the vehicle should be very close to these objects in order to map fauna and flora of the local area. It is obviously an advantage if sensors like cameras could be decoupled and moved close to the objects of interest. This flexibility can in fact be achieved by removing any rigid links among parts of the vehicle and replace them by information links. This leads to the formation of a supra-vehicle with distributed sensors.

The parts of the overall supra-vehicle must be self-propelled and exhibit some intelligence and information exchange capabilities. This gives them the degrees of freedom that are necessary to adjust themselves according to different geometric formation patterns in response to on-line perceived events so as to optimize the conditions under which scientific observations, measurements, or experiments will be carried out. As they stay in close proximity to each other (several meters) the capabilities of the single nodes can be limited. The subsystems will be small and relatively cheap so that the overall system is competitive against existing underwater robots. When perceived as a whole, the multi-component supra vehicle will have cognitive capabilities that will effectively allow for scene interpretation and complex goal-oriented behaviour.

The questions which arise from the formulation of the vision have to be addressed in a highly interdisciplinary way. In respect to motion control and navigation it was unsolved how to keep a formation of simple nodes. How to do local and global navigation? How to "morph" in the sense of performing seamless transformations of the MORPH supra-vehicle as response to the change of the terrain – from flat bottom to vertical and overhanging cliffs? It must be guaranteed that the sensors of the distributed nodes are overlapping in order to create loop closing conditions for local corrections and subsequent good maps. How to establish the information link between nodes? MORPH builds on latest under water communication technologies but an acoustic underwater network between the nodes is nothing one can buy out of the box. Finally the way of planning a mission for a distributed vehicle and visualize the condition while under water is not trivial.

Basic research in many overlapping disciplines is needed. The scale of investment which is necessary in terms of both, human resources and infrastructure, is such that international joint co-operation will be crucial to progress. This is the reason that the 4-years project is co-funded by the FP 7 framework of the EC. The project has started in February 2012 and will find its final climax in a series of sea trials in 2015. The project consortium is composed of nine Partners. They share the work under coordination of the German company Atlas Elektronik GmbH.

- CNR - Consiglio Nazionale delle Ricerche - Istituto di studi sui sistemi intelligenti per l'automazione (Italy)
- Ifremer - Institut français de recherche pour l'exploitation de la mer (France)
- IMAR - Instituto do Mar (University of the Azores, Portugal)
- IST - Institute of Robotics of the Instituto Superior Técnico (Portugal)
- Jacobs Universität Bremen (Germany)
- CMRE - Centre for Maritime Research and Experimentation (Italy)
- IUT - Ilmenau University of Technology, Faculty of Computer Science and Automation (Germany)
- UDG - University of Girona (Spain)

2. THE BASIC CONCEPT

A detailed introduction to the MORPH project has been shown at the NGCUV 2012 conference (Joerg Kalwa et. al 2012) so that here the focus is placed on the current results. Nevertheless the essence of the concept shall be briefly explained.

Mapping underwater habitats in unstructured environments requires high accuracy 3D topology measurements and high definition video imaging. The main payload sensors are multibeam echosounders and high definition cameras, ideally stereo cameras, which need to be placed in consideration of many factors like multibeam swath width, camera angle of view, illumination range, visibility, cost, and risk, to name a few. A possible configuration for the MORPH supra-vehicle results from these considerations is depicted in Figure 1. It shows an initial configuration of nodes flying over a flat bottom.

The core system for mapping the environment is made of one multibeam echosounder onboard of a local sonar vehicle (LSV) and two cameras onboard of camera vehicles (C1V and C2V). Both, the acoustic range and the swath width of multibeam echosounders are in general greater than the camera visibility and coverage, respectively. As such the

LSV flying at a higher altitude can in fact cover the area that is exposed by two (ore more) cameras.

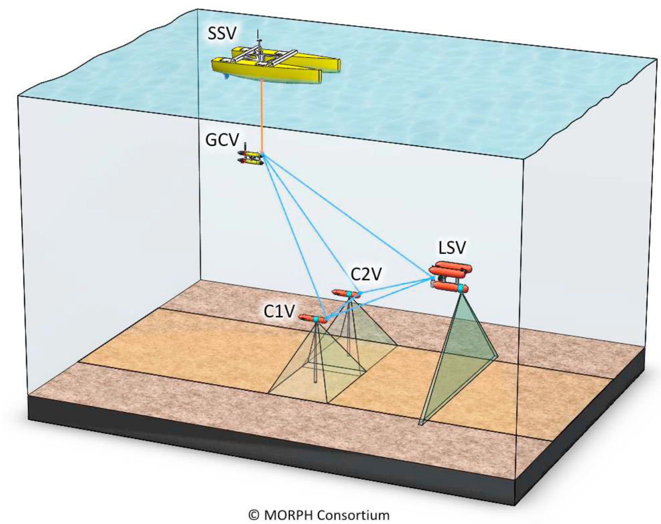

Fig. 1. MORPH 3D Habitat Mapping, flat bottom. Solid blue lines represent direct path between the modems. The bottom coverage is highlighted.

Having major navigation sensors on board, The LSV keeps a safe distance from the bottom and is responsible to lead the pack. It is in charge to detect and recognize the environmental situation and trigger the formation adaptation .

The mapping task requires a high accuracy in cooperative navigation of the nodes a) in order to geo-reference the scientific data and b) to bring the nodes very close to each other. The only way of referencing the data with a global position is using GPS installed on a surface support vessel (SSV). In principle this vehicle could be used to measure positions to the underwater systems using a standard ultrashort baseline system (USBL). But accuracy decreases significantly with depth and sea state. A solution to the problem is to “anchor” the MORPH supra-vehicle to a special underwater node, far from the influence of sea waves, devoted to improving the navigation accuracy and relaying communications – the global communication vehicle (GCV). In the particular case of overhanging cliffs the usage of the GCV will be instrumental in establishing the link between the nodes under the cliff and the SSV.

During a mission the LSV follows a desired path at a given speed, staying at a pre-selected, desired altitude to acquire multibeam sonar-data. The GCV follows the LSV at a given speed, staying well above terrain features.

The LSV does its own local navigation (with DVL) and carries a USBL transceiver to measure GCV’s position with good accuracy because the range is small .The LSV broadcasts that position periodically (at a slow rate) allowing the GCVs to track the path of LSV.

C1V and C2V stay back and on each side of LSV, using range measurements only, while doing close bottom following. The range based navigation allows keeping the costs of the navigation system low.

All vehicles use their own depth information to feed their Navigation System and improve the position estimate in the vertical axis.

3. STATE OF THE WORK IN 2014

To reach the ambitious goals of the project while minimizing risk the work is divided into several workpackages, which are addressed in the following.

At the beginning there was a phase for specifications, feasibility studies and basic research. Until end of 2012 the **application scenarios** have been elaborated and condensed towards a final demonstration scenario. This result still acts as lighthouse for the current development and research phase and helps to focus on the direction of research.

A **user interface** for programming and visualization is being created by IUT on the basis of QGIS (http://www.qgis.org). The geographical system allows using georeferenced data as underlying graphics for mission planning. Such data may be any seachart or even sonardata or results from previous missions.. A plug-in has been implemented which allows to initiate a goal oriented mission of the morph system. Further additions have been made for mission monitoring and evaluation.

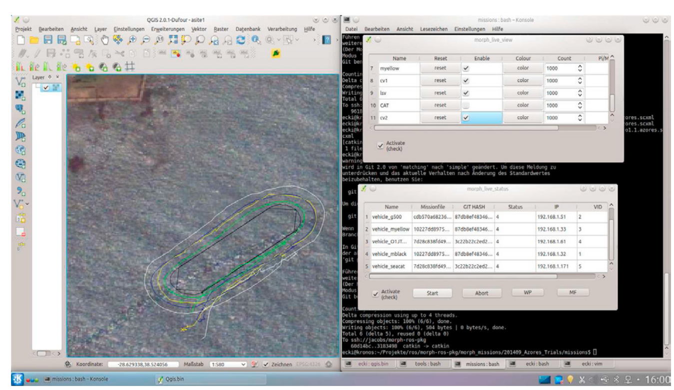

Fig. 2. Example of the mission monitoring system during trials. The Information is transmitted via acoustics or WLAN buoys, towed behind the nodes.

The resulting mission plan must be understandable by all parts of the supra-vehicle. Therefore a **general mission plan handler**, forming the core of the MOPRH software suite, has been created by IUT which runs inside the individual nodes. The concept is described in detail in Eckstein 2013.

The backbone of all functionalities is a **communication system** which has been established by CMRE which allows the exchange of data as necessary. An acoustic system provides an underwater network with limited bandwidth. It is based on off-the-shelf underwater acoustic modems. The network uses time division multiplexed access, which is useful for a small number of nodes (n < 10). As by-product of the acoustic communication the distance between the modems can be calculated by measuring time of flight of the data packets. The network is complemented by wireless LAN if available, which is the case when the nodes are surfaced.

Fig. 3. The Underwater USBL Modem, installed at the SeaCat AUV.

Taking into account the limited possibilities of underwater communication a **common control architecture** for the nodes has been created under leadership of IST, supported by Jacobs University and CNR and is still under development. Topics cover prominent keywords such as viewplanning, local path- and motion planning, and collision avoidance.

There are two main concepts which are exploited for controlling the supra-vehicle, i. e. Cooperative Path Following (CPF) and Range Only Formation control (ROF).

Cooperative Path Following steps on the results of the GREX project (Vanni 2008). The underlying principle is that each vehicle in the team follows its own path while adjusting the speed according to estimations and measurements of the relative spatial progress. Here each node should have an estimate of its global position to perform its own track control. Thus, this method is limited to LSV, GCV and SSV, which are well interconnected and form the basis for ROF-performing CxVs.

ROF (Soares 2013) exploits the regular acoustic data exchange between all nodes. When data is transmitted, the time of flight of the signals is measured. This allows determination of distances to the anchor nodes and a subsequent estimation of the relative position.

In summary the control system allows a very tight group of nodes traveling together along the seafloor in order to map the environment.

The **system to perceive the environment** comprises sonar and video data processing and mosaicking. Coarse-level-mapping is achieved on the LSV's multibeam sonar thanks to a work lead by UDG. The data is evaluated online in order to perceive obstacles on the seafloor. If big rocks are on the path of the camera vehicles, a new set point for the ROF controller is propagated through the network, allowing the CxVs to prevent a collision.

It has been found that an Octomap representation of the environment extracted from single scanned swath is sufficient for obstacle avoidance, although it will differ from the real world because of the drift error inherent in any dead-reckoning navigation. A solution for that is to implement a realtime SLAM framework to build and update the octree map. Although future work at the UdG will deal with this topic, at this point only Terrain Based Navigation (localization with a known map) has been implemented as a preliminary step before attempting a full SLAM

In an offline stage there are methods available allowing detailed high resolution mapping and sensor fusion to fulfill the needs of the end user. These tasks are mainly performed by Jacobs University and University of Girona.

Fig. 4. Example of a 3D underwater video mosaic. The white spot is missing data due to overhanging rocks

A final results validation and demonstration will be performed in a challenging real life environment. The current planning foresees activities in the area around Monte Da Guia, which is a volcano caldera on the island of Faial, Horta. It will be shown that the morph concept is feasible and applicable to marine science as represented by Ifremer and IMAR.

4. IMPLEMENTATION AND TESTS OF THE MORPH CONCEPT USING HETEROGENEOUS VEHICLES

As funds of the project are limited the experimental realization of the MORPH concept relies on vehicles already owned by the project partners. The systems have very different properties which makes the suitable for the different roles in the supra-vehicles:

Surface Support Vessels (SSV):

- Charlie (CNR),

- MEDUSA(S) (IST)

Local Sonar or Global Communication Vehicle (LSV, GCV):

- MEDUSA(D) (IST)
- Girona 500 (UDG)
- SeaCat (ATLAS)

Camera Vehicles (CxV):

- SeaCat (ATLAS)
- AUVortex (IFREMER)

In order for each of the pre-existing vehicles to become a MORPH node, additional software and hardware components have to be installed. As exploited in the GREX project the basic idea is to not change existing control software for the single autonomous vehicle. The MORPH methods are implemented in an open source communication framework called ROS (Robot Operating System, www.ros.org) which proved very convenient for distributed joint development. An embedded computer runs the dedicated software and talks to the vehicle-specific control system via a single interface.

An important aspect of the project is that the concepts have to be proved in real environmental conditions and not merely by simulations. Although simulations are a valuable tool and necessary part of the project, the numerical reality is rather simplified. Bringing the system to sea adds a complexity which is unexpected for most researchers. Beneath technical limitations rooted in watertight packages, limited access to software and sometimes low availability of the complete (experimental) vehicle system, there are environmental influences like weather, seastate, water currents, underwater objects, and ship traffic. The full problems of running vehicles outdoor and in water are suddenly present. In summary this is the ultimate proof that systems are working as intended.

In MORPH we decided to split initial testing into a surface segment (LSV, GCV and SSV) and a bottom segment (LSV, GCV and CxV). A lot of small scale and valuable testing had been performed by the individual partners. But to achieve the goals of the project joint trials were required. Initial tests started early 2013 in La Spezia, Italy, by testing underwater communication between the AUV SeaCat and a surface craft, proving that USBL system is working and can be used as backbone for the communication.

In the summer of that year the team headed to Toulon (France) and later to Sant Feliu de Guíxols (Spain), testing the suitability of all vehicles and performing first cooperative motions. There was a steep learning curve how to operate and coordinate a fleet of vehicles and an even bigger fleet of researchers in terms of logistics, accommodation and cooperation within the team. Sometimes over 30 people were cooperatively solving the problems. One of the major lessons learned was that before going to water a core software team has to meet in order to establish a common status of the software integration and freeze this status for the subsequent trials.

In 2014 the major technical hurdles were taken. A joint trial for the lower segment in Lisbon (Protugal) and a subsequent trial for the upper segment in Sant Feliu de Guíxols were successful.

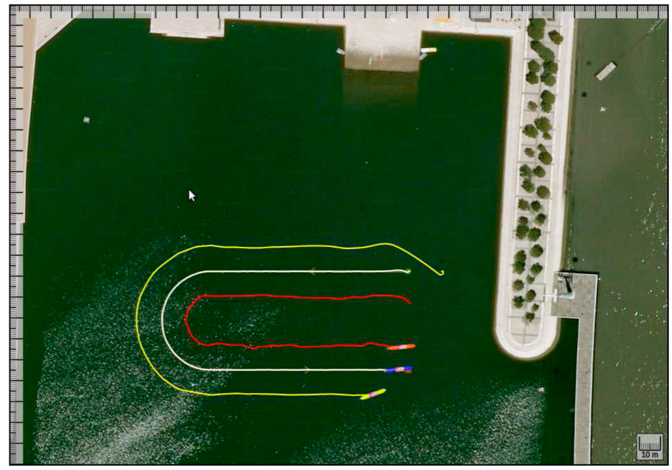

Fig. 5. Testing the bottom segment in Lisbon. The formation is kept by range information only.

At the beginning of September 2014, the project reached a significant milestone: trials have been conducted on the backside of Monte da Guia, in the ‘Porto Pim’ bay of Faial Island (Azores).

For the first time the Morph Supra Vehicle came into life, composed of a formation of five autonomous underwater vehicles. The reference point for the group was formed by a surface craft (Medusa S), the position of which had been determined accurately with the aid of GPS signals. Two submerged sonar vehicles (Medusa D and Girona 500) moved relative to this reference point in a line, which in turn provided the position reference for two camera vehicles that navigated solely by means of ranging sensors (SeaCat and Sparus). The camera platforms recorded data for a composite 3D picture of the seabed by moving a stereo camera just above the bottom. During the tracks Girona 500 performed online mapping using the Multibeam Echosounder. The data was analyzed in real time and several obstacles were detected. The information was sent to the camera vehicles which performed avoidance maneuvers.

5. SUMMARY AND FURTHER PLANS

This paper presents the state of research of the European Project MORPH as achieved by end of 2014. It has been shown that significant progress has been achieved on crucial fields of scientific research. Among these are

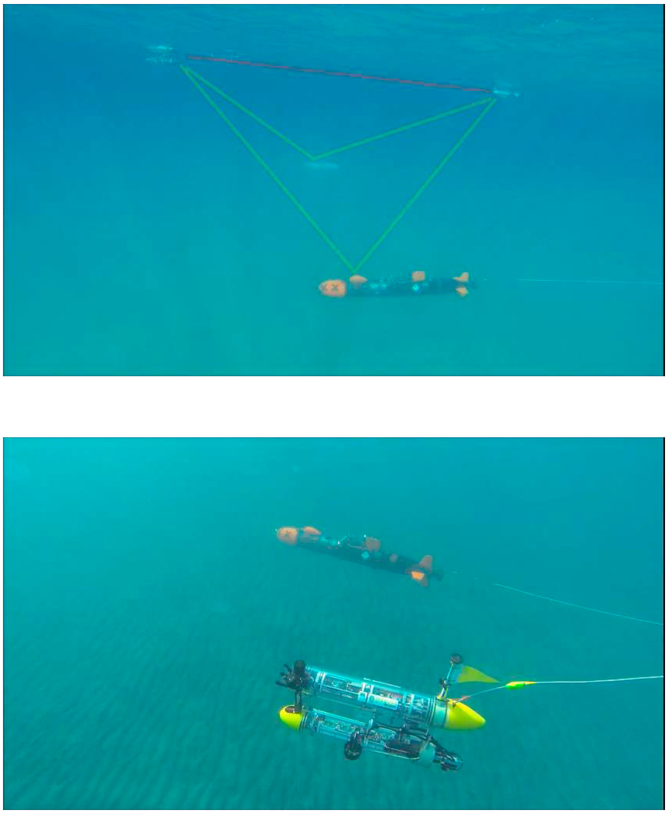

Fig. 6. The first MORPH supra vehicle in action.

- Creating a reliable acoustic underwater network as basis for communication and navigation,
- Solving basic control problems on how to keep a formation with limited hardware costs by doing range based control,
- Achieving a coarse online mapping as basis for further decisions on environmental adaptation,
- Establishing an environment for software development which supports collaborative work, which includes extensive simulation capabilities.

There are many other achievements not listed here which eventually make the system work as intended. But still there is lot of work left.

Taken into account that the project finishes in January 2016 it is expected that the final results will be achieved in 2015. Up to now the team demonstrated the basic features while mapping flat terrain, which mirrors the concept of figure 1. But the ultimate goal of MORPH is the mapping of vertical walls. This postulates an adaptation of the supra-vehicle with respect to the terrain in terms of spatial distribution and sensor placement. The open steps are:

- Detection of a wall by means of a forward looking sonar,
- Decision to “morph” and control of the transient behaviour,
- Rotation of sensors towards the objects,
- Automatic contour following and pathplanning to map an area without gaps.

The open points still present a challenging task before the final trials will be conducted. These are scheduled for September 2015. The current progress can be found in the internet. The address of the MORPH project homepage is **http://www.morph-project.eu**.

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