Underwater robotic cooperation

INTERNATIONAL PROJECT **GREX is an innovative technology for coordination, control and cooperation of underwater and surface robots**

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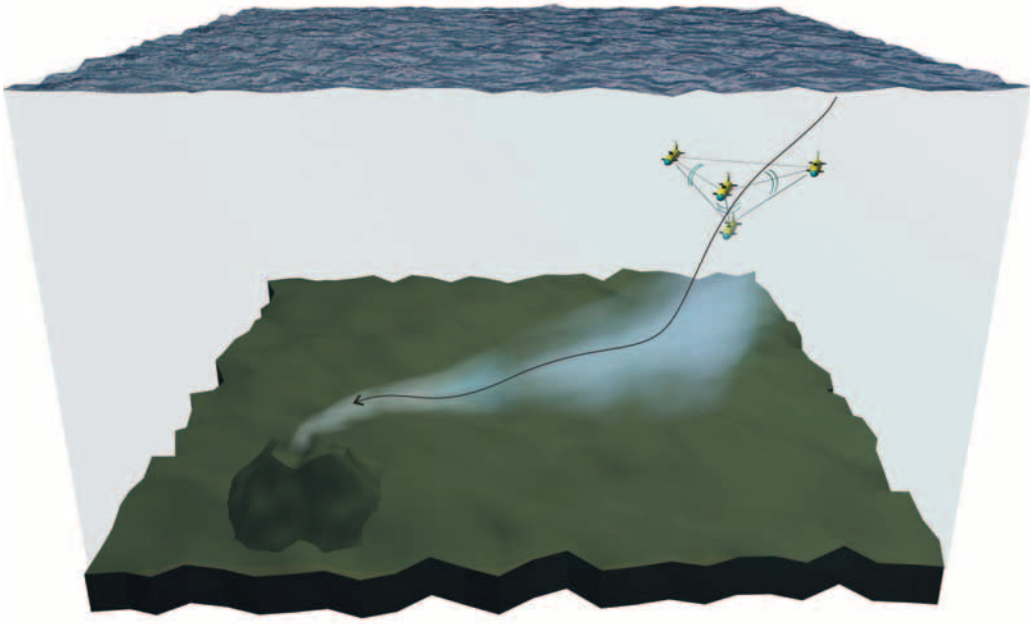
Today, due to the current state-of the art of robotics, energy storage and hydrodynamics, underwater research vehicles are limited in both, their autonomy and capabilities. It would be a leap ahead, if the user community could build on a multiple vehicle approach, whereby each vehicle plays the role of a sophisticated node (with sensor, processing, and communication capabilities) in a network.



Scenario – The quest for hydrothermal vents

GREX permits combining pre-existing vehicles into a team. It makes research more effective. It will even lead to completely new applications. The motivations behind a multiple-vehicles mission are obvious. Multiple vehicles allow surveying wider areas in less time while simultaneously obtaining time and space resolutions that are otherwise unachievable. Systems intended for searching operations could re-direct vehicles equipped with manipulators in order to refine research results. Some systems could watch other systems at work to record the operations using video or they could serve as navigation aids or communication relay stations.

In this respect a group of leading European users and manufacturers of autonomous marine vehicles as well as marine biologists and consulting companies started the GREX Project, co-funded by the European Union within the 6th framework. "Grex" – the Latin word for a group or flock – stands for the main goal: for the first time ever a team of heterogeneous, preexisting unmanned vehicles shall perform a coordinated, cooperative mission. The project started in June 2006 and faces its final evaluation in October 2009.

The key thrust of the research and development effort is to create and evaluate a conceptual framework for cooperation. Activities within the project span from the intuitive planning of a multiple-vehicle mission to its properly controlled execution in the real world. It contained the creation of theoretical and practical tools for multiple vehicle cooperation, bridging the gap between concept and practice. The problems coupled to the overall goal are numerous, e.g.:

- The planning of a cooperative mission needs to be sufficiently intuitive without loosing too much detail of fine planning.
- The generated mission language must be understandable by vehicles from various manufacturers (heterogeneous vehicles).
- Once on a mission, vehicles need to perceive themselves in order to avoid collisions or drifting apart.
- The execution of the coordinated-mission needs to take into account the different inaccuracies of navigation systems and dynamics of the vehicles. Moreover, the acoustic communication between the vehicles is limited, typically heavily delayed, and faulty – which presents strong constraints to control algorithms.

The latter field of research has been structured by decomposing the problem into several subtasks:

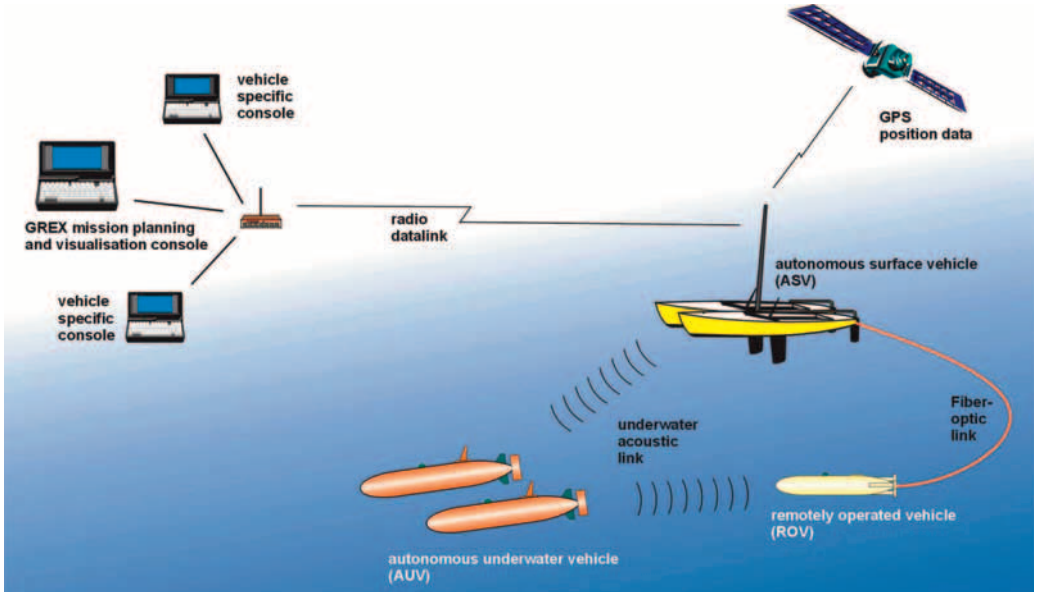
- mission-monitoring and -control,
- coordinated vehicle control,
- cooperative navigation,
- adaptive communication network.

The main task of mission-monitoring and -control is to ensure the proper execution of the mission, taking into account all vehicles involved. This means further, that certain strategies to cope with unforeseen events have been developed.

Coordinated vehicle control covers the control of a formation. In order to minimize the communication it relies on the fact that the different vehicles are able to navigate on predefined tracks. So the final task is the speed adaptation of the different vehicles.

The track-follow capabilities are dependent on the internal navigation of the vehicles. Thus, a newly developed cooperative navigation system allows a regular update of the local navigation solution, so that all vehicles involved are able to keep their relative position between them. The underlying algorithm relays on sparse exchange of local navigation estimates and range measurements. Data fusion is performed by means of Kalman-filtering.

The communication system sets up a dynamic ad-hoc network between the vehicles. It automatically switches to best connection available: radio communication at the water surface and acoustic communication in dived condition. For the first time in Europe an underwater network has been realized.



GREX system overview

A series of field trials is ongoing to assess the efficacy of the methods developed.

Trials and first results

Last summer the GREX partners met in the Azores to perform a series of tests aimed at transitioning from the „drawing board" to the real world. The first GREX mission at sea was performed flawlessly in the Pico Channel near Horta harbour at the islands of the Azores. This test confirmed the resilience of the catamaran DELFIMx and opened the way for integration with other GREX computers and the execution of cooperative missions at sea.

During these trials DELFIMx, still under the control of a GREX computer, performed a coordinated target tracking with the manned Águas Vivas (AV) vessel. In this scenario, the AV was free to roam the sea along unplanned trajectories and to broadcast its GPS positions via radio. In tune with the spirit of GREX missions, a system was developed which was able to read and process the position information in order to fit lines and arcs. DELFIMx "read" the successive path segments and followed them, thus achieving the first cooperative maneuver with real vehicles in the scope of the project, using the GREX communications module.

At the end of last year the GREX project reached an important milestone in the early part of November 2008 when a series of successful sea trials took place off the Mediterranean coast around the French city of Toulon. The main objective of the trials was to gather first hand experience at operating simultaneously two AUVs, which relied on inter-vehicle acoustic communication to perform a series of simple coordination tasks. The achievement of this goal represents an important step forward for the GREX consortium because vital experience and knowledge has been gathered that will provide the multi-partner development team the elements to bring the project to a successful conclusion.

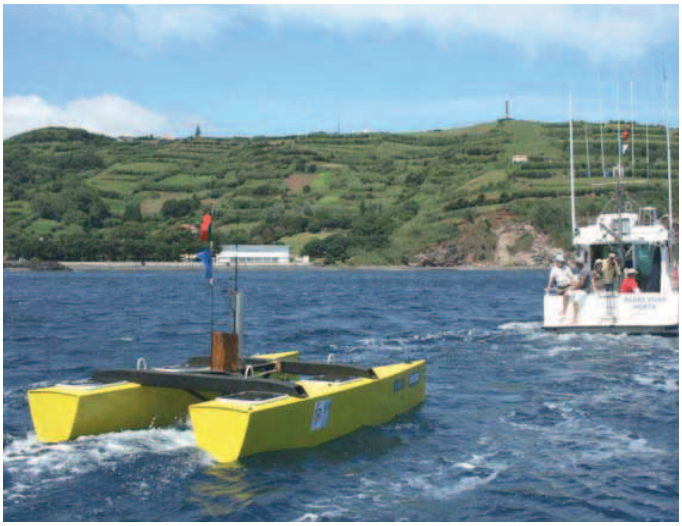
The November trials featured inter-vehicle acoustic communication as the main focus. In order to gather useful data and experience in realistic condition two AUVs owned by IFREMER were equipped with the acoustic modem chosen by the GREX consortium.

For many reasons, the two AUVs used in the tests are very radically different vehicles. The first is a survey type, 3000 m capable, operational AUV "Aster^x", a non hover torpedo shaped vehicle whose typical velocity ranges between 1.2 m/s and 3 m/s.

The second vehicle used is the experimental AUV "AUVortex", a laboratory test platform developed by IFREMER and specially fitted for the trials. Vortex is a 200 kg hover capable AUV, equipped with six thrusters and able to reach a maximum speed of 0.7 m/s. The vehicle is 50 m max depth rated.

The different scenarios that have been tested involved an increased complexity in the coordination task. The most comprehensive scenario featured the survey type AUV starting a series of wait circles at set altitude and communicating the coordinates of the centre of the circle to the slower AUV. This allows the trailing vehicle ("AUVortex") to reach the given point while the leading AUV ("Aster^x") waited and monitored the distance gap getting reduced. When confirmation of the completion of the wait task has been acknowledged by both vehicles, they were ▶

The DELFIMx Catamaran performs a first GREX mission at sea: Going-to and Following a „Lawn-Mowing" Pattern



DELFIMx and Águas Vivas performing a coordinated target tracking manoeuver

IFREMER's oceanographic vessel "l'Europe" Source: Ifremer

PROJECT PARTNERS

GREX

- ATLAS Elektronik GmbH, Bremen, Germany
- Centre of IMAR at Department of Oceanography and Fisheries at the University of the Azores, Horta, Portugal
- Ifremer, La Seyne sur Mer, France
- Innova S.p.A., Rome, Italy
- Instituto Superior Tecnico (IST), Lab: Institute for Systems and Robotics (ISR), Lisbon, Portugal
- MC Marketing Consulting, Kiel, Germany
- Orange Energy Consulting, Lisboa, Portugal
- SeeByte Ltd., Edinburgh, United Kingdom
- Technical University Ilmenau, Ilmenau, Germany

automatically released on the original paths.
The overall behaviour is fully automatic, as both vehicles are both untethered and autonomous. The performance of the task relies heavily on the acoustic communication exchange which is affected by the known issues of reduced bandwidth, packet loss due to ambient noise, absorption, multipath and doppler-effect. For this reason a specific communication module has been developed to handle packet exchange and synchronisation. This module will form the core of the GREX communication handler to be developed in the later stage of the project that will extend the capabilities to several vehicles therefore supporting a comprehensive underwater acoustic communication network (including adaptive network management, network discovery, message forwarding and retransmission).
The success of the GREX trials is further enhanced by the fact that for the first time two fully autonomous vehicles have been operated by IFREMER from an operational oceanographic vessel. A further important milestone reached is having two vehicles communicating automatically among themselves underwater.

The way ahead

The coming months until the end of the project are under the light of evaluation and improvement. The focus has been placed on the realization of user scenarios which will be tested in full scope in October 2009. Milestones on that way will be the application of an underwater network (Toulon, France) and the test of various coordinated control procedures in a team (Sesimbra, Portugal). At the end of the project a GREX-package will be available which turns a pre-existing vehicle into a cooperative robot. This package consists mainly of a bunch of software modules which organize communication to other GREX-systems, care for navigation updates, and control the cooperative movement of the group. There is a single interface (GIM) to the vehicle which needs to be updated. It mainly cares for translating the GREX messages into the vehicle proprietary format and vice versa. Planning of the coordinated mission requires a SeaTrack® license. Because of the fact that communication protocols are not standardized in the marine environment, there is also the need to install specific communication hardware on the vehicle, mainly a radio modem and a low cost acoustic communication module.
The status achieved by October will allow using the GREX system as a stepping stone for real multi-vehicle applications. Emphasis needs to be placed on payload data exchange in order to maximize the effect of spatially distributed measurements. Ideas to share and discuss with the GREX-consortium are very welcomed.

www.grex-project.eu

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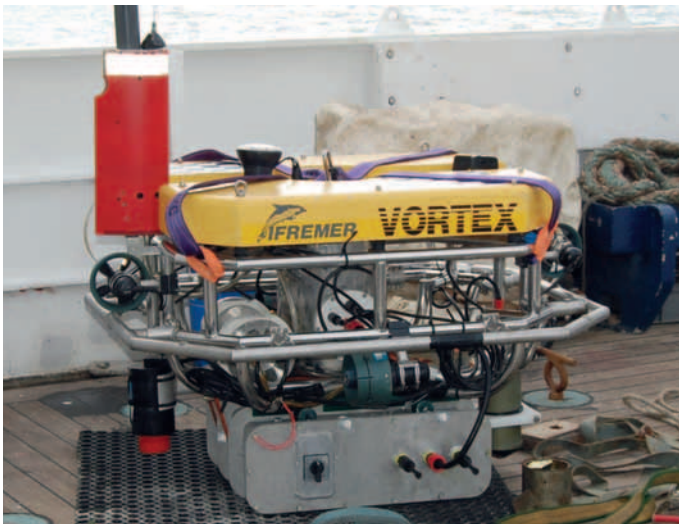

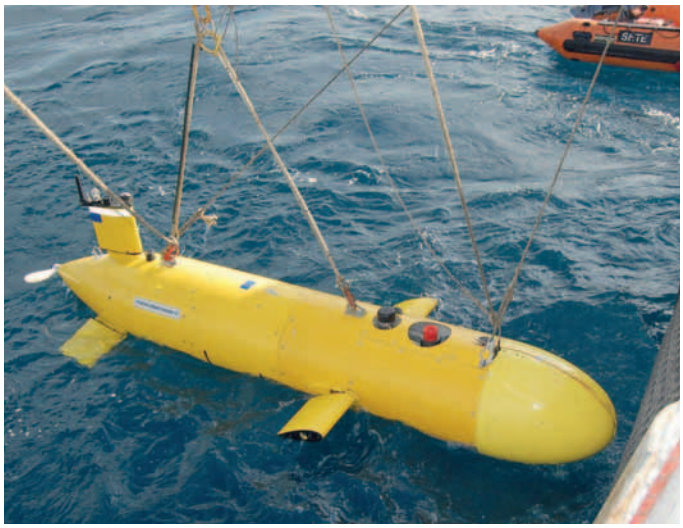

"AUVortex" (left) and "Aster^{x}" (right) the two AUVs that featured in the November trials Source: Ifremer