Thesis abstract

First EURON PhD Award
Gianluca Antonelli

September 30, 2001

Underwater Robotics have known in the last years an increasing interest from research and industry. Currently, it is common the use of manned underwater robotics systems to accomplish missions such as sea bottom and pipeline survey, cable maintenance, off-shore structures' monitoring and maintenance, collect/release of biological surveys. The strong limit of the use of manned vehicles is the enormous cost and risk in working in such an hostile environment. The aim of the research is to progressively make it possible to perform those type of missions in a completely autonomous way.

This objective is challenging from the technological as well as from the theoretical aspects since it implies a wide range of technical and research topics. Sending an autonomous vehicle in an unknown and unstructured environments, with limited on-line communications, requires some on board *intelligence* and the ability of the vehicle to react in a reliable way to unexpected situations. Techniques as artificial intelligence, neural network, discrete events, fuzzy logic can be useful in this ***high*** level mission control. The sensory system of the vehicle must deal with a noisy and unstructured environment; moreover, technologies as GPS are not applicable due to the impossibility to underwater electromagnetic transmission, vision based systems are not fully reliable due to the generally poor visibility. The actuating system is usually composed by thrusters and control surfaces, both of them have a non-linear dynamics and are strongly affected by the hydrodynamic effects.

In this framework, of course, the use of a manipulator mounted on a autonomous vehicle plays an important role. From the control point of view, underwater robotics is much more challenging with respect to ground robotics since the former deal with unstructured environments, mobile base, significant external disturbance, low bandwidth of sensory and actuating systems, difficulty in the estimation of the dynamic parameters, highly non-linear dynamics.

The current technology in control of underwater manipulation is limited to the use of a master/slave approach in which a skilled operator has to move a master manipulator that works as *joystick* for the slave manipulator that is performing the task. The limitations of such a technique are evident: the operator must be well trained, underwater communications are hard and a significant delay in the control is experienced. Moreover, if the task must be realized in deep water, a manned underwater vehicle close to the unmanned vehicle with the manipulator must be considered to overcome the communications problems thus leading to enormous cost increasing.

The thesis deals with the main control aspects in underwater manipulation tasks:

- First, the mathematical model is discussed, the aspects having significant impact on the control strategy have been remarked.

- Kinematic control for underwater manipulation is then presented. Kinematic control plays a significant role in unstructured robotics where off-line trajectory planning is not a reliable approach; moreover, the vehicle-manipulator system is often kinematically redundant with respect to the most common tasks and redundancy resolution algorithms can then be applied to exploit such characteristic. Along the thesis, the implementation of Inverse Kinematics (IK) algorithms known in industrial robotics are firstly discussed, then, the integration of fuzzy techniques in such IK algorithms is proposed and successfully achieved in numerical simulations.

- Dynamic control is then discussed; several motion control schemes have been analyzed and presented in this thesis. The common aspect of these controllers is that they have been designed in order to be easily implemented in a future experimental set-up; in detail, the poor knowledge of the dynamic parameters and the complexity of the mathematical model are of concern. With this is mind, the Virtual Decomposition Approach seems to be a very promising control strategy.

- Experimental results with the autonomous vehicle *ODIN*, without manipulator and in 6 degrees of freedom are presented. Two main groups of experiments have been performed: in the first an adaptive control law is implemented, in the second a fault tolerant control strategy is proven to be effective.

- The interaction with the environment is discussed. Such kind of operation is critical in underwater manipulation for several reasons that do not allow direct implementation of the force control strategies developed for ground robotics. Hence, an external and an explicit force control schemes are proposed. Numerical simulations have been performed in which all the topics developed run at the same time, the kinematic control coordinates the motion between vehicle and manipulator, the law level dynamic control is performed via a virtual decomposition approach and the outer loop is in charge of achieving the force control task.

⊙ Finally, a simulation tool for multi-body systems is presented. Due to memory reason, the current software packages can not create complex symbolic models of underwater manipulator structures with high degrees of freedom (dofs). An algorithm based on the Netwon-Euler equation of motions has been then implemented that was the core of all the thesis' simulations. In all the simulations the model of a 6 dofs carrying a manipulator of 6 dofs is used with hundreds of dynamic parameters while the control design is performed with the inaccurate knowledge of the main inertial parameters.