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Modelling and Identification of Underwater Robotic Systems

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Quel che è detto è detto.
Ma sarà poi vero? Io non ho accesso
al vero, il mio pensiero ha un andamento
incerto, è sottoposto al vento
di scirocco, ma so per certo
che questi giorni invernalprimaverili
sono un eccesso inutile di luce e a me
non è concesso che attraversare i ponti
e al rosso del semaforo guardare con invidia
qualche ossesso che tra bestemmie e insulti
a passo lento infrange l'armata compatta
delle macchine. E basta, non c'è che questo.

(*Patrizia Cavalli*,
POESIE (1974-1992)
Giulio Einaudi Editore, 1992)

ABSTRACT

Whatever is the strategy pursued to design a control system or a state estimation filter for an underwater robotic system the knowledge of its identified model is very important. As far as ROVs are concerned the results presented in this thesis suggest that low cost on board sensor based identification is feasible: the detailed analysis of the residual least square costs and of the parameter estimated variances show that a decoupled vehicle model can be successfully identified by swimming pool test provided that a suitable identification procedure is designed and implemented. A two step identification procedure has been designed on the basis of: *(i)* the vehicle model structure, which has been deeply analyzed in the first part of this work, *(ii)* the type of available sensors and *(iii)* the actuator dynamics. First the drag coefficients are evaluated by constant speed tests and afterwards with the aid of their knowledge a sub-optimal sinusoidal input thrust is designed in order to identify the inertia parameters. Extensive experimental activity on the ROMEO ROV of CNR-IAN has shown the effectiveness of such approach. Moreover it has been shown that the standard unmanned underwater vehicle models may need, as for the ROMEO ROV, to take into account propeller-propeller and propeller-hull interactions that have a most relevant influence on the system dynamics (up to 50% of efficiency loss in the applied thrust with respect to the nominal model). It has been shown that such phenomena can be correctly modelled by an efficiency parameter and experimental results concerning its identification on a real system have been extensively analyzed. The parameter estimated variances are generally relatively low, specially for the drag coefficients, confirming the effectiveness of the adopted identification scheme. The surge drag coefficients have been estimated relatively to two different vehicle payload configurations, i.e. carrying a plankton sampling device or a Doppler velocimeter (see chapter 4 for details), and the results show that in the considered surge velocity range ($|u| < 1m/s$) the drag coefficients are different, but perhaps less then expected. Moreover it has been shown that in the usual operating yaw rate range ($|\dot{\psi}| < 10 \deg /s$) drag is better modeled by a simple linear term rather then both a linear and a quadratic one. This is interesting as it suggests that the control system of the yaw axis of slow motion open frame ROV can be realized by standard linear control techniques. For a detailed description of the identification procedure and of the identification results of the ROMEO ROV consult chapter 4.

In the last part of this thesis the issue of planar motion control of a nonholonomic vehicle has been addressed. Inspired by the previous works of Casalino et al.[1] and Aicardi et al.[2] regarding a unicycle like kinematic model, a novel globally asymptotically convergent smooth feedback control law for the point stabilization of a car-like robot has been developed. The resulting linear velocity does not change sign, curvature is bounded and the target is asymptotically approached on a straight line. Applications to the control of underwater vehicles are discussed and extensive simulations are performed in order to analyze the algorithms behaviour with respect to actuator saturation. It is analytically shown that convergence is achieved also in presence of actuator satu-

ration and simulations are performed to evaluate the control law performance with and without actuator saturation. Moreover the generation of smooth paths having minimum square curvature, integrated over length, is addressed and solved with variational calculus in $3D$ for an arbitrary curve parametrization. The plane projection of such paths are shown to be least yaw drag energy paths for the $2D$ underwater motion of rigid bodies.