On the identification and control of underwater vehicle dynamics A neural network approach

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This paper considers the trajectory control problem for Tethra, an experimental underwater inspection robot that has been developed by the Mobile & Marine Robotics Group at the University of Limerick. Tethra, shown in figure 1, must perform accurate cartography experiments on both fish farms or ship hulls, applications where precision open sea movement control is of critical importance. The measurements taken by the craft must be robust to changes in sea conditions and the need to change toolkits from mission to mission. If, for example, sonar has to be deployed, the centre of gravity of the craft changes significantly, resulting in considerable changes to the vehicle handling characteristics. Moreover, the complex nature of the underwater environment that the craft operates in, poses severe path following challenges. In water, craft experience damping and so called 'virtual mass' forces, that play only a negligible role on dry land. Currents and waves pose significant performance constraints on the accurate tracking of a desired path, or for station keeping. Due to the high number of parameters that govern these phenomena, and the nonlinear way in which these parameters act on craft dynamics there are a number of different craft control research methodologies that are being considered in the literature at the current time (Fossen, 2002). For a large group of control applications simple low order models that counteract the external influence of the underwater environment on vehicle dynamics are good enough. Control of large craft, such as oil tankers, normally focusses on a combination of crude low order trajectory tracking and optimisation of fuel consumption. The influence of exogenous disturbances, notably waves, is addressed through the prediction of dominant frequency and amplitude wave parameters and the robust control of various thrusters using output disturbance rejection techniques (Paulsen *et al.*, 1994; Torsetnes *et al.*, 2004).

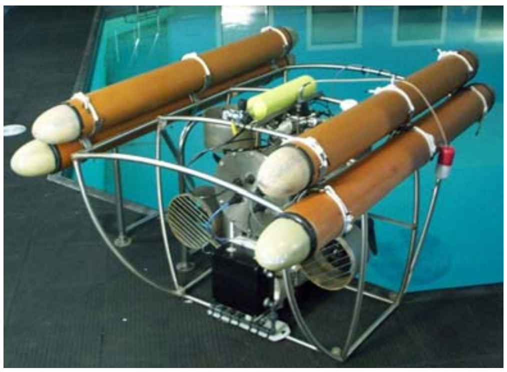

Figure 1: The University of Limerick in-house underwater robot Tethra on the side of the test pool

However, hovering craft like Tethra that require high precision tracking of a prescribed path need more detailed models of the environment to be identified and explicitly coupled to the vehicle control system. An online algorithm implementing recursive Levenberg-Marquardt back propagation (Ngia and Sjoberg, 2000) as a starting point, is considered in this paper and the stability of such algorithms is investigated. The approach is based on formulating a suitable back propagation error function used as an energy function in a Lyapunov type approach to the verification of stability. The error function is generally of the following form:

$$E(n) = \frac{1}{2}\sum_k e_k(\mathbf{w}(n)) + f(\mathbf{w}(n)) \qquad (1)$$

where $e_k(\mathbf{w})$ is the error of neural network output k, as a function of the neural network weight parameter set, $\mathbf{w}(n)$ at time n. Stability of the learning algorithm is ensured if the function $f(\mathbf{w})(n)$ can be chosen such that $E(n) \geq 0$ and the weight update yields a decreasing error function:

$$\frac{\delta E(n)}{\delta \mathbf{w}(n)} < 0 \qquad (2)$$

This paper extends the neural network methodology proposed in Van de Ven *et al.* (2004), and a comparison is carried out with a more conventional gain scheduling approach.

The paper highlights the ability of the neural network tuned vehicle controller to learn, or adapt online, and to satisfy path following requirements in the presence of a wider range of external noise conditions. The network actively identifies individual parameters in the model, a key advantage over a conventional linear approach.

The paper concludes with a consideration of some of the open questions in this field, in particular how robust stability and performance for the uncertain system at hand can be addressed. The authors are currently engaged in work that investigates how families of uncertain systems can be "covered" using circle theorem or value set type results.

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