

Internet of Things, Ad Hoc and Sensor Networks Technical Committee Newsletter

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B. Predictive Control

The fast-time prediction is constructed using the Euler method to solve the dynamics equations (4) for each DOF. The delayed state measurement is extrapolated to the current simulation time using the history of commands issued by the operator. To derive the Euler prediction, first let $y_1 = \xi$ and $y_2 = \dot{\xi}$. Then (4) can be expanded into two ordinary differential equations:

$$\begin{cases} \dot{y}_1 = y_2 \\ \dot{y}_2 = \frac{1}{M} \left(-k_{\xi} (\dot{\xi}) - k_{\xi|\dot{\xi}} |\dot{\xi}| \dot{\xi} + u(t) \right) \end{cases} \quad (5)$$

The resulting fast-time prediction is used to produce a real-time simulation of the vehicle and environment. The simulated environment is overlaid on actual video received at the operator station [5]. When a delayed state measurement is received from the actual vehicle it is used to update the simulated state. The operator controls the simulated or "ghost" vehicle directly and the commands are either sent to the remote vehicle as-is or augmented by the controller. Using this method, the operator is effectively isolated from the time delay while still remaining in the control loop.

C. Semiautonomous Region

The prediction cannot be perfect, so the predicted state does not always match the actual state. In cases where the prediction error is relatively large, the controller starts augmenting the commands. Instead of direct thruster commands, the operator's inputs are transformed into waypoints/tasks and sent to the vehicle [2].

In this semiautonomous region, the robot uses a blend of autopilot and operator commands until the error is once again acceptable for direct thruster commands. The mixing factor, is determined by analyzing the error between the current simulated pose, and the pose extrapolated from the delayed state measurement.

D. Supervisory Control

As the prediction error continues to grow, the controller will eventually resort to waypoint commands only. At this point, the controller is in supervisory control mode wherein the operator has no direct control of the vehicle and it is almost completely autonomous. [7].

V. PROOF OF CONCEPT TESTING

The first tests performed were to verify that the Euler method is sufficient for state predictions and to test the range limits. Fig. 2 (a) shows the path taken by the vehicle using the 1-DOF dynamics model as in (4), as well as the supplied thruster forces. A "ghost" vehicle was added with model parameter mismatches as well as a constant, unmodeled ocean current. The goal of the predictor-corrector system is to reduce the uncorrected ghost error in Fig. 2(b) to allow the operator to accurately control the vehicle.

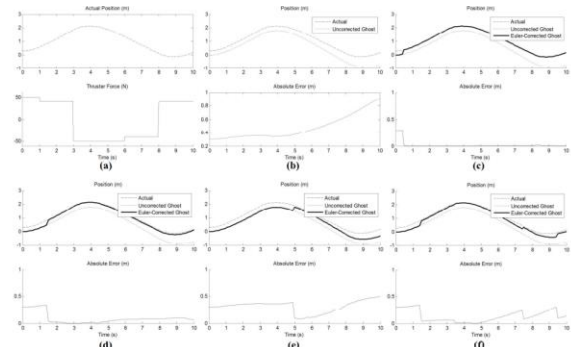


Fig. 2 1-DOF test of Euler prediction method

Fig. 2(c)-(e) show the Euler correction at various control delays/ranges (0.5s (400m), 1.5s (1000m), and 5s (4000m), respectively) with state measurements every 10ms. The state measurements are delayed by the given TD for each plot. Fig. 2(f) shows a time delay of 1.5s but less frequent state updates every 2s.

These preliminary tests verify that the linear predictor-corrector system is feasible and performs well. Improvements could include estimation of the ocean current through a Kalman filter [5], and further improvement to the vehicle model.

VI. CONCLUSION

The proposed controller represents a paradigm shift in the use and control of underwater robots. The work presented here shows that predictor systems, coupled with semiautonomous autopilot, is both feasible and effective for controlling TUVs through a wide range of time delays.

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REFERENCES

- [1] P.J. Ballou, An acoustically controlled tetherless underwater vehicle for installation and maintenance of neutrino detectors in the deep ocean, San Leandro, CA: 1997.
- [2] J. Funda and R.P. Paul, "Efficient control of a robotic system for time-delayed environments," *Advanced Robotics*, IEEE, 1991, p. 219-224.
- [3] C.C. Cheng, "Predictor displays: Theory development and application to towed submersibles," Massachusetts Institute of Technology, 1991.
- [4] C.P. Sayers, R.P. Paul, L.L. Whitcomb, and D.R. Yoerger, "Teleprogramming for subsea teleoperation using acoustic communication," *IEEE Journal of Oceanic Engineering*, vol. 23, 1998, pp. 60-71.
- [5] D.M. Steinke and B.J. Buckham, "A Kalman Filter for the Navigation of Remotely Operated Vehicles," *Proceedings of OCEANS 2005 MTS/IEEE*, pp. 1-8.
- [6] M. Caccia, G. Indiveri, and G. Veruggio, "Modeling and identification of open-frame variable configuration unmanned underwater vehicles," *IEEE Journal of Oceanic Engineering*, vol. 25, Apr. 2000, pp. 227-240.
- [7] Graham LeBlanc, Peter Gregson and Jason Gu, "A control continuum for tetherless underwater vehicles", 2011 24th Canadian Conference on Electrical and Computer Engineering (CCECE).