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

(IoT-AHSN TCN)

Volume 1, No. 18

June, 2023

CONTENTS

PREFACE

The IEEE ComSoc Ad Hoc and Sensor Networks Technical Committee (IoT-AHSN TC) sponsors papers, discussions, and standards on all aspects of IoT, ad hoc and sensor networks. It provides a forum for members to exchange ideas, techniques, and applications, and share experience among researchers. Its areas of interest include systems and algorithmic aspects of sensor and ad hoc networks, networking protocols and architecture, embedded systems, middle-ware and information management, novel applications, flow control and admission control algorithms, network security, reliability, and management. In an attempt to make all the TC members as well as the IoT-AHSN worldwide community aware of what is going on within our main areas of concerns, this newsletter had been set up. The newsletter aims at inviting the authors of successful research projects and experts from all around the world with large vision about IoT-AHSN-related research activities to share their experience and knowledge by contributing in short news.

The eighteenth issue of the IoT-AHSN TC Newsletter focuses on the theme “Internet of Underwater Things”. Specifically, this issue includes 1 news article: A Control Continuum for Tetherless Underwater Vehicles. We thank the contributors for their efforts to help make the IoT-AHSN TC Newsletter a success. We hope that the methods/approaches presented in this issue could significantly benefit researchers and application developers who are interested in IoT and ad hoc/sensor networks.

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A Control Continuum for Tether less Underwater Vehicles

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Abstract: This research presents a new class of controller for TUVs that isolates the operator from the time-varying lag. This isolation is accomplished through various means such as predictive control and automatic waypoint creation and tracking. A continuum of control is formed with these various paradigms and a smooth evolution through the continuum is formulated, based on the measured time delay.

Keywords- TUV controller, Euler predictor-corrector.

I. INTRODUCTION

A Tetherless Underwater Vehicle (TUV) replaces the tether with an acoustic data link. Removal of the tether not only greatly reduces operating costs, but also increases vehicle agility and reduces risks such as tether entanglement [1].

This letter introduces a new control continuum allowing a human operator to control the TUV through a wide range of operating distances. The research focuses on a simulation/prediction system.

II. CONTROL LOOP PROBLEM

One issue with TUVs is the time-varying delay element in the loop. Although the actual delay would be approximately split in half between the forward and backward paths, from the operator's perspective, the delay can be represented as one lumped delay. As the distance from the acoustic transmitter increases, the total time delay increases accordingly. The control delay alone does not greatly burden the human operator; however, when coupled with the dynamics of underwater vehicles the time delay can present a serious control problem and destabilize the loop. When the delay exceeds 1s, direct human control is nearly impossible [2].

1.1. Operator Isolation

Humans can plan and predict the motion of a complex system by constructing an internal dynamic model of themselves and their environment [3]. The efficiency and accuracy of the internal human prediction is greatly reduced when the system is nonlinear and relatively high order. In this case, an external model is used to aid the human operator, referred to as a predictor display.

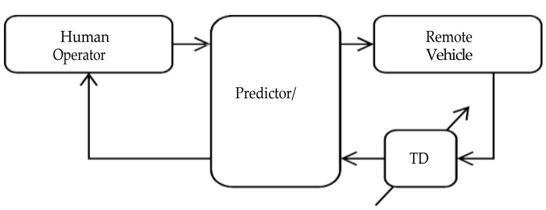

Fig. 1. Control loop with predictor

The main objective of the control paradigm Fig. 1 is to isolate the human operator from the time delay, in part, by using a predictor display. Fig. 1 illustrates how the original control loop is modified to achieve this. From [3], the advantages of isolation are as follows: 1) The mental load of the operator is reduced; 2) The learning period is shortened; 3) The human operator can achieve better control performance.

III. VEHICLE DYNAMICS MODEL

From Steinke's approach [5], a second-order, nonlinear dynamics model of the TUV in 6 DOFs is written as:

$$\left(M + M_A\right)\ddot{\xi} = F_B\left(\eta\right) + F_D\left(\dot{\xi}\right) + F_C\left(\dot{\xi}\right) + u\left(t\right) \quad (1)$$

Where F_B, F_D, F_C are the buoyancy, drag and Coriolis forces, respectively; $M \text{ and } M_A$ are the mass and added mass matrices; $\dot{\xi}$ is the velocity in the vehicle's reference frame; η is the vehicle's pose in an Earth-fixed framed; and $u\left(t\right)$ is a vector of external forces. The mass matrix can be considered diagonal and is comprised of surge $\left(u\right)$, sway $\left(v\right)$, heave $\left(w\right)$, roll $\left(\rho\right)$, pitch $\left(q\right)$, and yaw $\left(r\right)$ inertial terms:

$$M = diag\left(M_u, M_v, M_w, I_p, I_q, I_r\right) \quad (2)$$

The simplified model is written as :

$$M\ddot{\xi} = F_D\left(\dot{\xi}\right) + u\left(t\right) \quad (3)$$

And expanded in one DOF:

$$M\ddot{\xi} = -k_{\dot{\xi}}\left(\dot{\xi}\right) - k_{\dot{\xi}|\dot{\xi}|}\dot{\xi}\left|\dot{\xi}\right| + u\left(t\right) \quad (4)$$

Where M is the inertial term for the given DOF; and $k_{\dot{\xi}}$ and $k_{\dot{\xi}|\dot{\xi}|}$ are the linear and quadratic hydrodynamic damping coefficients, respectively. These coefficients must be identified experimentally for each DOF of a specific vehicle configuration.

IV. TUV CONTROL PARADIGM

A. Close Control

Close control is the lowest level of control in the continuum. In this mode, the operator has direct and almost instantaneous control of the remote vehicle. This is equivalent to tethered ROV operation, so existing ROV pilots would require little to no additional training.

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:

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

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.

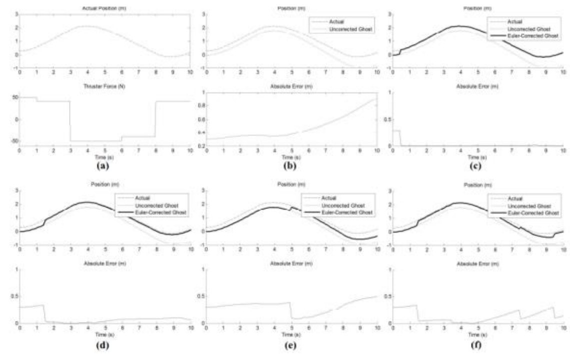

Fig. 2 1-DOF test of Euler prediction method

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.

ACKNOWLEDGEMENT

Thanks to the work done by former graduate students Graham LeBlanc and Late Professor Peter Gregson. The content of this letter is abstracted from the conference paper CCECE 2011 [7].

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