A Novel Approach to Measure under Water Vehicle Disturbance Force for Station Keeping Control

J. Manecius Selvakumar and T. Asokan
Department of Engineering Design, Indian Institute of Technology, Chennai, 600 036, India

Keywords: Under Water Vehicles, Sensor Beam, Strain Gauge, Feedback Mechanism, Disturbance Force, Station Keeping.

Abstract: Maintenance of target position and/or orientation is essential for underwater vehicles (UWV) to successfully complete a mission. However, in the case of work class vehicles, station keeping becomes an important issue due to the presence of disturbance forces and requires effective feedback mechanism to maintain the pose. Conventionally, the changes in position due to disturbance force is monitored and fed back to the station keeping controller to make necessary corrections. This introduces unnecessary delay in response and continuous variations in vehicle position. In this paper, an attempt has been made to develop a disturbance force measurement setup using strain gauges which will directly measure the disturbance forces which can be used for predicting the vehicle pose disturbance and make necessary corrections even before the vehicle starts responding to the disturbance forces. The methodology adopted for force measurement is presented and experimental analysis has shown promising results. This approach can be used as an alternative feedback mechanism for station keeping control of underwater Vehicles.

1 INTRODUCTION

Station keeping is the process by which an underwater vehicle (UWV) is held in its desired position resisting the external forces acting on it. Ocean medium is subjected to deep sea currents arising due to the changes in temperature and other factors and hence it becomes difficult to control the undesired movements of vehicles (Eric Conrado and Maruyama, 2007).

For station keeping control of underwater vehicles, the feedback information about the disturbance acting on them is very essential (Woods, et al., 1998). However, the delay in vehicle response and feedback cause undesired movement of vehicle before it is controlled (Antonelli, et. al., 2001). One way to reduce this pose disturbance is to predict the UWV motion from the disturbance forces acting and then generate necessary control forces to nullify the effects of the disturbance. This will facilitate an UWV with faster position keeping capability. In this paper, we propose a feed-forward station keeping control using direct measurement of disturbance forces. Since strain gauges are widely used in underwater applications for force measurements (McLain and Rocky, 1992), specially designed measurement beams with strain-gauge sensors are proposed here for the force measurement. The design, analysis, and experimental details of the force sensing system are presented in this paper. The paper is organised in the following way. The station keeping control strategy and its simulation results are briefly described in section 2. Section 3 and 4 describes the disturbance velocity measurement setup. Experimentations details are covered in section 5. The results of the sensor beam testing are discussed in section 6.

2 CONTROL STRATEGY

The proposed control strategy is to equip the UWV with sensors to measure the disturbance forces acting on it and predict the resultant velocity to use this as a feed-forward data for control. Assuming that the disturbance forces due to underwater current are negligible in the vertical direction, a planar station keeping strategy is proposed. Force sensors are attached to the UWV on all four sides and the disturbance force is measured and sent to the controller. Using the dynamic model of the vehicle, the resulting velocity of the vehicle due to the

Manecius Selvakumar J. and Asokan T..
A Novel Approach to Measure under Water Vehicle Disturbance Force for Station Keeping Control.
DOI: 10.5220/0004036704600463
In *Proceedings of the 9th International Conference on Informatics in Control, Automation and Robotics* (ICINCO-2012), pages 460-463
ISBN: 978-989-8565-22-8

disturbance is predicted and fed to the controller as a feed forward data. Control action is initiated by the controller to overcome the effects of vehicle velocity resulting from the disturbance force. Figure 1 shows the flow chart for the above strategy. If needed, in addition to the predicted response of the vehicle, actual pose of the vehicle can also be used for generating the control forces.

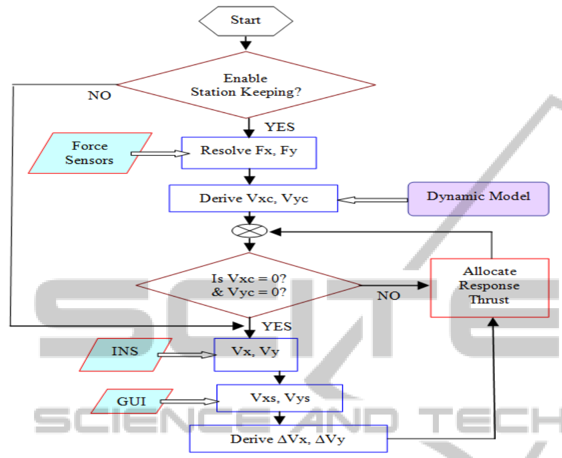

Figure 1: Control Scheme using Disturbance Force data.

Figure 2 shows the proposed station keeping control methodology using the measured force. To execute the correction in account of vehicle's dynamics, the conventional motion reference unit (MRU) data is used.

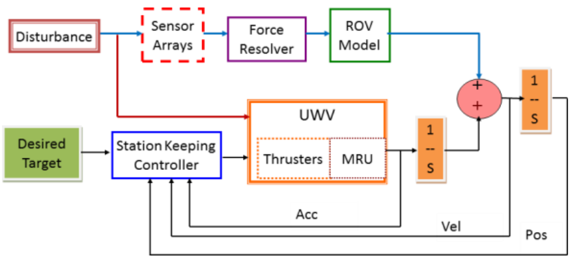

Figure 2: Proposed Control Method.

The motion control algorithm based on Inverse Dynamic Task theory (Krut'ko., 1989) is represented in figure 3. This algorithm drives the control function using the vehicle's motion parameters and is used in the station keeping control task.

The performance of the developed control method has been analyzed. The following is the sample result of the simulation. Figure 4 shows the desired position, actual position without feed forward and with feed forward controller in x-axis. The simulation was done for the disturbing current

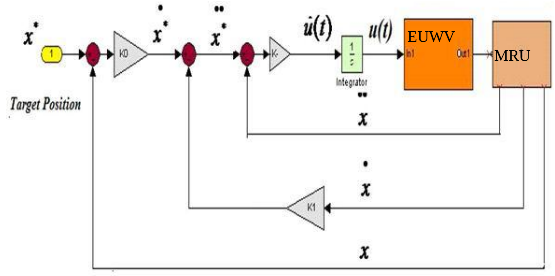

Figure 3: Vehicle motion controller.

velocity which changes its magnitude and direction at 10 sec and 40 sec. It is inferred that with the feed forward method, the deviation from desired target and the settling time are reduced to 50% than the original case of performance without feed forward loop. The simulation result reveals that the existence of feed forward loop improves the position control action.

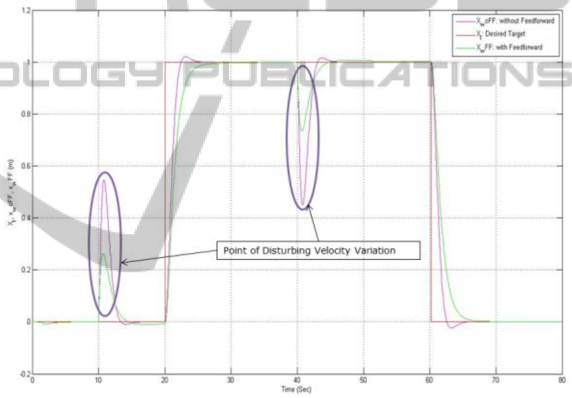

Figure 4: Controller Response.

3 DISTURBANCE VELOCITY MEASUREMENT

A prototype vehicle designed for laboratory level experimental studies is used here for verification of the strategy. Force sensors are arranged on the vehicle as shown in figure 5. As a first step, the measurement of disturbances forces arising out of the currents is measured using this setup. The solid model of the Experimental Underwater Vehicle (EUWV) with its major subcomponents is shown in figure 5.

Since measurement of disturbance force is a major consideration in this method, the optimal orientation and position of the sensor beam is essential and will be decided based on the results of the performance test of the EUWV with sensor beam.

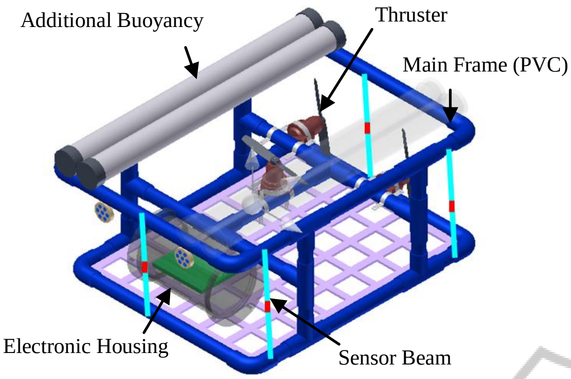

Figure 5: Solid Model of EUWV with sensor setup.

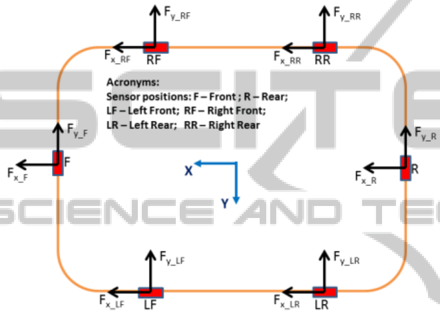

Figure 6: Sensor Beams and Forces.

Locations of sensor beams with their significant measurement axis and force components are indicated in figure 6. Since, the orientation of sensor beams F and R are perpendicular to X axis, the F_{y_F} and F_{y_R} are insignificant. Similarly, F_{x_LF}, F_{x_LR}, F_{x_RF} and F_{x_RR} are also insignificant. The resultant force in x and y axis is calculated by averaging the force measured by the number of significant sensors in the respective axis.

4 MEASUREMENT SETUP

The sensor beam of dimension: length (L) 300 mm, breadth (b) 20 mm, and thickness (t) 3 mm has been designed and used in testing.

The theoretical strain resulting from the forces acting on the UWV is calculated as follows:

Drag force on the beam due to the current velocity is given as (Blevins and Robert, 2003)

$$F_d = \frac{1}{2}\rho A V^2 C_d \text{ (N)} \qquad (1)$$

where, density of water, ρ = 1000 kg/m^3

V – Speed of the object relative to the fluid (m/s)

A – Area of the object = L x b (m^2)

C_d – Coefficient of drag = 1.28 (Source: "Shape Effect on Drag" at Glenn Research Centre, NASA)

The pressure on the beam P = F_d /A (N/m^2) and load per unit length w = P *b (N/m) is calculated and the strain is calculated using Hooks law as:

$$\varepsilon . E = \sigma_b \qquad (2)$$

where, **ε** is the strain acting on the beam, σ_b is the stress and E is young's modulus of acrylic material (Johnson and Devenport, 2007).

Confirmation of appropriate thickness, width and the strength of the acrylic sensor beam are done by analysis and analytical calculation. Two metal foil strain gauges of Gauge factor (GF) 2.09 (placed on the opposing sides and connected to half bridge circuitry) are used for measurement of the actual forces acting on the beam. (Hoffmann, 1889) (Kleckers, 2004) (Schäfer, 2004).

5 TESTING OF SENSOR BEAM

Deflection members made up of Aluminium, Stainless Steel and Acrylic were fabricated and calibrated by the laboratory standard method (William A. Lokos and Rick Stauf, 2004). Based on the results of this, acrylic was chosen as the material for sensor beam.

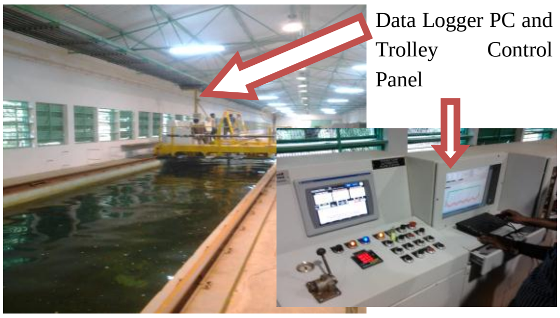

Figure 7: Towing Tank Facility.

Testing of the developed sensor beam was carried out in towing tank of Ocean Engineering Department at the Indian Institute of Technology Madras. The carriage used for the tests has dimension of 85 m x 3.2 m x 2.5 m and has variable carriage speed from 0 m/s to maximum 5 m/s. (figure 7).

In the above said towing tank testing, two identical sensor beams as shown in Figure 8, were fixed on the carriage and interfaced with the instrumentation amplifier.

Figure 8: Test Setup – Three Sensor Beams.

6 RESULTS AND DISCUSSION

The experiments were carried out by varying the speed of towing trolley from 0 knot to 1 knot with the step increase of 0.5 knot (0.25 m/s).

The result for one of the tests is shown in Figure 9, which shows the comparison of theoretical strain and the measured strain on the 50 mm width beam (the graphs in this section are plotted based on the data points, however, one can easily identify the speed increase from 0.5 knot to 1 knot and then to 1.5 knots from the graphs).

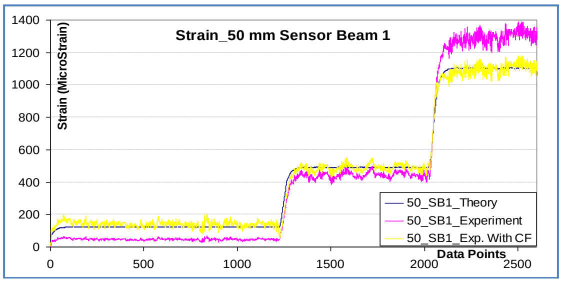

Figure 9: Results_50 mm Sensor Beam 1.

As the measured strain has constant offset from actual, we propose to use correction factors as listed in table 1 to use while using the output of sensor beam for control of the EUWV.

Table 1: Correction Factors of Sensor Beams.

Width Speed (m/s)	Correction Factor			
	20 mm	30 mm	40 mm	50 mm
0.25	2.5	2.05	2	3
0.5	1.25	1.4	1.4	1
0.75	0.625	1.025	1.125	0.825

Using the conventional relationship of force and strain, the disturbing current velocity is derived using the strain measured from the sensor beams.

7 CONCLUSIONS

Development of a disturbance velocity measurement setup using strain gauges is presented in this paper. Feed forward control strategy and simulation study showing performance of the proposed control scheme are presented. Study on the performance of developed sensor setup of varying thickness and width has been carried out. Acrylic sensor beam having 2 mm thickness is selected to use for implementation and experimental validation of proposed control scheme. Derived correction factors for the sensor beams will be used during further experiments. This method of disturbance force measurements can be effectively used for station keeping control of AUVs.

REFERENCES

André Schäfer, Dr.-Ing, 2004, Force, Strain and Pressure transducers based on foil type strain gauges, *HBM GmbH*, Darmstadt, Germany.

Antonelli G., Chiaverini S., Sarkar N. & West M., 2001, Adaptive control of an autonomous underwater vehicle: experimental results on ODIN, *In Transactions on Control Systems Technology*, IEEE, Sep 2001.

Blevins, Robert D., 2003, Applied Fluid Dynamics Handbook. *Krieger Publishing Co*.

Eric Conrado De Souza, Newton Maruyama, 2007, Intelligent UUVs: Some Issues on ROV Dynamic Positioning, *In IEEE Transactions on Aerospace and Electronic Systems*.

Eric R. Johnson and William J. Devenport, 2007, Static Response of a Beam, in experimental manual.

Hoffmann K., 1889, An introduction to measurements using strain gauges, *Hottinger Baldwin Messtechnik Publisher*.

Krut'ko. P. D., 1989, Inverse problems of control system dynamics: nonlinear models, Nauka Phys. & Math Publisher, Moscow.

McLain T. W., Rocky S. M., 1992, Experimental Measurement of ROV Tether Tension, *In Proceedings of ROV*, San Diego, CA.

Thomas Kleckers, 2004, Important characteristics of force transducers, *HBM GmbH*, Darmstadt, Germany

William A. Lokos, Rick Stauf, 2004, Strain-Gauge Loads Calibration Parametric Study, *In Technical Report of NASA Centre for Aero Space Information* (CASI).

Woods A. J., Penrose J. D., Duncan A. J., Koch R., Clark D., 1998, Improving the Operability of Remotely Operated Vehicles, *In Appea Journal*, pp 849 – 854.