The 8th IEEE International Conference on Intelligent Data Acquisition and Advanced Computing Systems: Technology and Applications
24-26 September 2015, Warsaw, Poland

A Speed Control Strategy for an Autonomous Ship Model for Towing Tank Testing

F. López Peña, A. Deibe, B. Priego, M. Míguez González
Integrated Group for Engineering Research, University of A Coruña, Mendizabal s.n., 15403 Ferrol, Spain
flop@udc.es adeibe@udc.es blanca.priego@udc.es marcos.miguez@udc.es www.gii.udc.es

Abstract—**This paper presents the strategies used to develop a speed control system for a ship model. This speed control is a part of a larger control and data acquisition system on board of an autonomous ship model that is being specifically developed to perform towing tank testing.**

Taking into account the requirements for this speed control system, and that the speeds to be measured are about one meter per second, a Laser Rangefinder is used as mean for measuring the speed of the model. This is quite unusual because these devices are just intended to measure distances between motionless objects. Various approaches used for setting up the controller are also presented.

Keywords—towing tank; autonomous systems; speed control

I. Introduction

The development of a system to measure and control the speed of self-propelled scale ship models is presented. This system is a part of an autopilot that is able to maintain a constant speed value as specified for a given test and is also able of maintaining the model course straight while keeping it centered in the tank. An Inertial Measurement Unit (IMU) with three axis accelerometers, three axis rate-gyroscopes, and three axis magnetometers is at the core of the autopilot. In addition, this autopilot is part of a larger acquisition and control system that, once installed on-board a ship model, allows it to perform ship seakeeping and resistance tests without having any material link between the ship model and a towing device; a preliminary description of the whole system has been presented elsewhere [1]. The main characteristic of this larger system is that it should have the capability of being repeatedly used in different ship models and on different towing tanks with a minimum installation work. The deployment of the whole system on a ship model can be seen on figure 1.

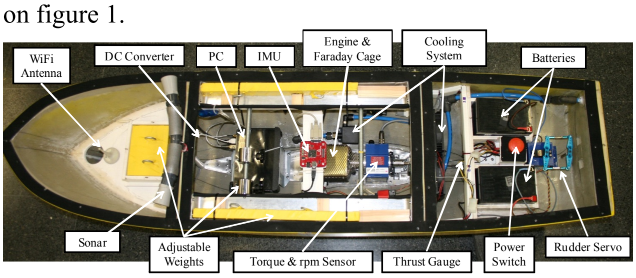

Figure 1. Autonomous ship scale model general disposition

The speed of the ship model is the most important control parameter when performing towing tank testing [2]. In any standard towing tank test, a carriage that moves on rails placed at both sides all along the tank is used for towing the ship model. Therefore, this towing device imposes its motion and speed on the model. A requisite for the present application is that the ship model cannot be towed and, consequently, it should include a system able to measure its speed and maintain it at a prescribed value by acting on the ship propulsion module. The main requirements for this speed system are that it cannot introduce any disturbance neither on the water flowing around the boat hull nor in the motion of the ship model itself. Another fundamental characteristic of the speed measurement and control system is that the speed to be measured has an order of magnitude of 1 m/s. All these requirements, and particularly this last one, lead us to decide for a laser range finder (LRF) as a main source of data for this system. The particular laser rangefinder model employed is based on light phase shift comparison measurement principles [3] and is intended to measure distances up to 150 m with an accuracy of 3 mm. The value of the velocity is obtained indirectly as a time derivative of the distance values measured by the LRF.

One of the goals of the present work has been to prove that this rangefinder was able to precisely determine the model speed. This is important because the range finder is intended to measure distances between fixed objects and not velocities; thus it needs to be validated as a speedometer. For this purpose several tests have been made to check its behavior when measuring velocities in real conditions. These tests have been performed by taking measurements on a moving target placed on a gimbal on top of a radio controlled wheeled platform that replicates the ship motion in extreme conditions, at a low cost and in a controlled way. The description of the system, the validation tests, the controller and the conclusions and future work are presented in the next sections.

II. Speed Measurement System Deployment and Validation

The LRF is the only part of the whole measurement system that is not installed on-board the ship model. In fact the rangefinder is installed on-shore at one of the ends of the tank and transmits data via a radio-modem to the on board measurement and control system, as it is shown in figure 2. Then the speed measurement system designed for the present application takes data from the LRF and obtains the speed by making its time derivative after some filtering.

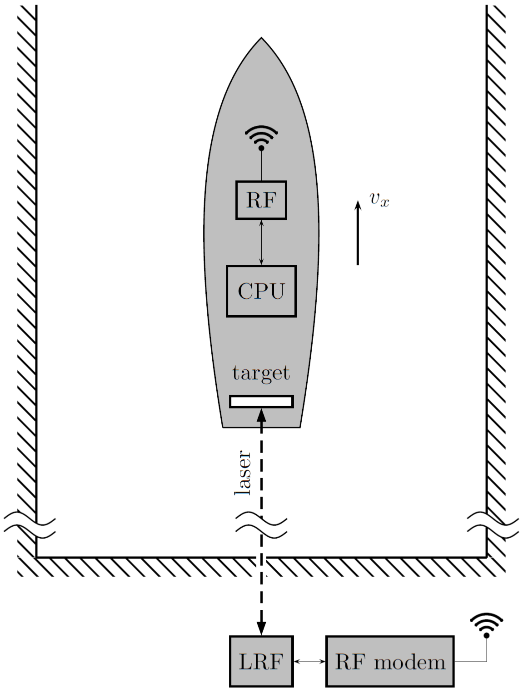

Figure 2. Laser Rangefinder disposition in the towing tank

The LRF used in the present application has different modes of operation [4]. For our purposes a mode in which it can measure up to 150 m of distance at 50 Hz sampling rate has been selected. The fixed time period of 0.02 s corresponding to this 50 Hz sampling rate is used later on to perform on-board the time derivative needed for the speed calculation. In addition, the specifications of the LRF stand that, when operating in this particular mode, it can measure distances to targets moving at speeds up to 4 m/s, so at first it appears that the LRF can be used to perform speeds up to this value in the way proposed here. It must be noted that the LRF measures the distance and from this the speed of a point in a target placed high in the ship's stern. Thus this speed is that of the ship composed with an alternating one due to the ship swaying in tested waves. However, as the LRF is not intended to measure speeds, so it was compulsory to perform some validation tests to check firstly the performance of the method and subsequently if it can effectively measure speeds up to 3 m/s, considered high enough for usual towing tank testing.

As the tests in towing tanks are costly and time consuming, we have resort on making some validation measurements on a moving target placed on a gimbal on top of a radio controlled wheeled platform. The platform is moving along paths close to a straight line and within the speed ranges corresponding to standard towing tank tests while the gimbal replicates all the rotational movements of the ship model. This way the ship model motion when sailing on heavy wavy seas is replicated at low cost in a controlled way. Figure 3 represents the moving target when performing one of the tests.

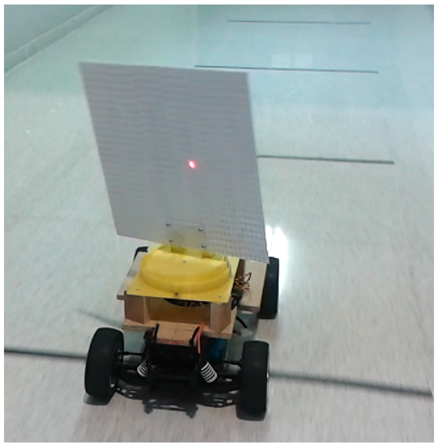

Figure 3. Set-up for validation tests on a mobile target.

Figure 4 presents an example of data obtained by the RFD speed measurement system. The upper part of this figure corresponds to a case where de target mimics the movement of the autonomous model ship in a standard towing tank test with smooth oscillations, the second case corresponds to a tough acceleration in a wavy sea, and the bottom one to a moderate acceleration with large oscillations. The situations corresponding to the last two tests are extreme and the one of the mid case could never happened in a current self propelled ship model test as it will be not able to accelerate that fast. This shows another advantage of using a rolling platform as a proxy of the ship model for validation purposes, as it can achieve extreme performances severer than the real ones, and thus it guarantees the correct function of the system once installed on-board a ship model and working in any standard tests conditions.

Each of the images on figure 4 presents two sets of data, one is the raw velocity as it is obtained by direct time differentiation of the distances measured by the LRF, and the other is the same set but filtered such to neglect spurious measurements. The filter used is a simple three-sigma one that takes the average and standard deviation of the last ten valid points and eliminates the point under consideration if its value differs on more than three times the standard deviation from the average value. As it can be seen on these results, the filtered measurements for the two first cases are very good, and in the third case some intervals appear without a valid velocity value. This is due to the fact that this case represents extreme oscillating conditions and so the target not only has large rotational oscillations around three axes, but also it is moving along a track that bends and turns across the straight ideal track. This bending movement has a variable amplitude that in some occasions moves the optical target out of the laser beam during some tenths of a second and so the velocity cannot be measured during these intervals.

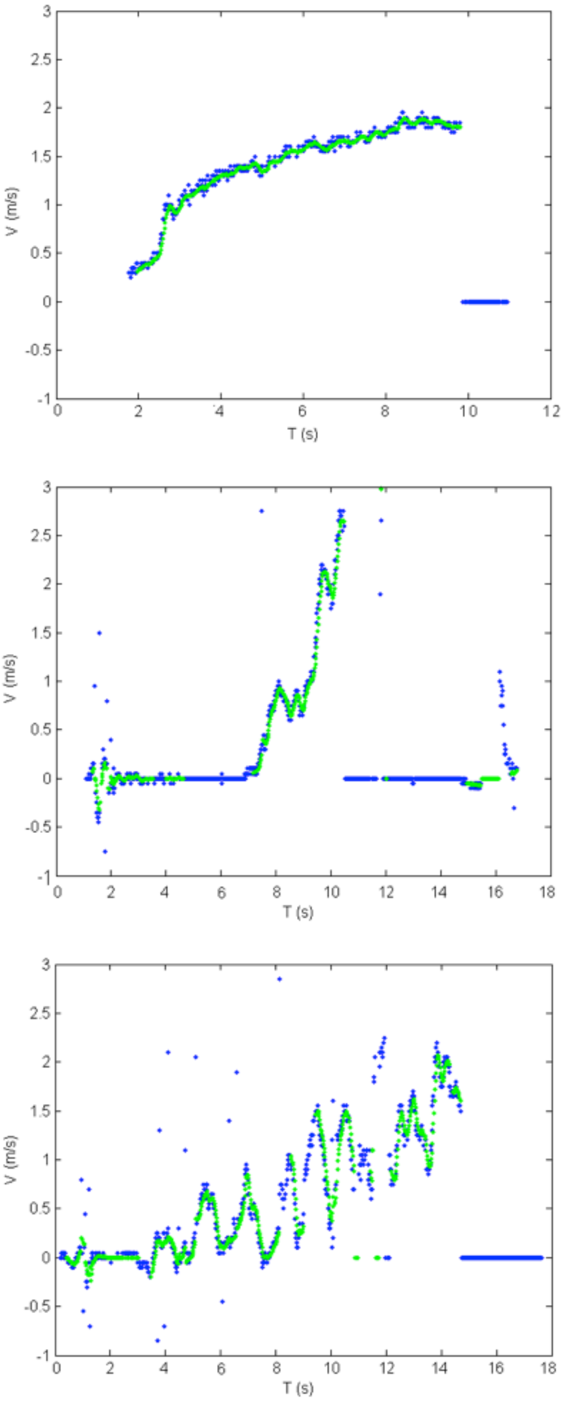

Figure 4. Three examples of velocity measurement. Blue dots represent raw data and green dots represent filtered data

III. Speed Estimation

On the view of the speed measurement system validation results, at first sight it appears that a simple PID controller that takes the measured velocity as input could be enough to control the velocity of the ship model. This sort of controllers performs correctly when the ship is sailing in calm waters or across not very rough waves. As a mater of fact, in cases where the tests are performed in steady water, for a given configuration of a self-propelled ship model it exist a direct relationship between its steady state velocity and its propeller rotational speed. Therefore, in these cases it is possible to perform the tests without using any speed controller but just imposing the rotational speed corresponding to the test prescribed velocity and letting the ship run for a large enough time interval. When using this procedure the speed measurement system presented here could serve to obtain a more accurate actual value of the velocity. Nevertheless, when performing tests on wavy seas, the waves induce a drag term on the ship movement that makes it very difficult to use a similar procedure, and that would become just impossible in case of irregular waves tests, thus making necessary the use of a speed controller.

Having this into account, a double PID speed control has been at first implemented [1]. Latter on, a speed control algorithm based in a complementary filter has been realized [5]. This filter, shown in Figure 5, estimates the ship speed from two different speed measures having diverse and complementary frequency components.

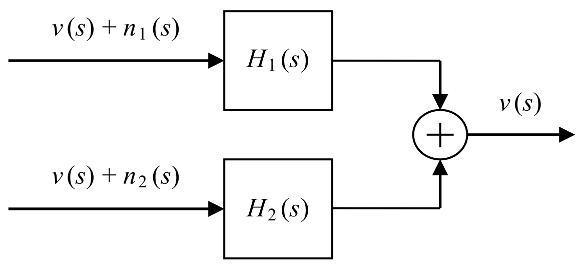

Figure 5. Complementary filter speed estimation

A complementary filter is based upon the use and availability of two independent noisy measurements of the same physical magnitudes [6]. In this particular case this magnitude is the ship speed, $v(s)$. A first measurement signal $v(s)+n_1(s)$ is coming from the derivative of the LRF position estimation in the way that has been previously described, and the second one $v(s)+n_2(s)$ is coming from the integration of the acceleration measured by the IMU. Each one of these signals is a measure of the ship speed $v(s)$, but they have different noise signals embedded, $n_1(s)$ and $n_2(s)$. If both signals have complementary spectral characteristics, the transfer functions $H_1(s)$ and $H_2(s)$ may be chosen in such a way as to minimize speed estimation error. The general requirement is that one of the transfer functions complements the other. Thus, for both measurements of the speed signal [7]:

$$H_1(s) + H_2(s) = 1 \qquad (1)$$

This will allow the signal component to pass through the system undistorted since the output of the system will always sum to one. In this case, n_1 is predominantly high-frequency noise and n_2 is low frequency noise; these two noise sources have complementary spectral characteristics. Choosing $H_1(s)$ to be a low-pass filter, and $H_2(s)$ a high-pass filter, both with the same, suitably cut frequency, the output $v(s)$ will not suffer from any delay in dynamic response due to low-pass filtering, and will be free of both high and low frequency noises.

IV. Speed Control

The speed estimated with this complementary filter is used to close the loop in the speed control algorithm. As stated earlier, at first a double PID control algorithm was implemented [1], as shown in Figure 6. The upper section of the controller tries to match the ship speed with a set point selected by the user, c_v. This portion of the controller uses the derivative of the ship position along the tank, x, coming from the LRF, as an estimation of the ship speed, v_x. The bottom section uses the integral of the ship acceleration in its local x-axis from the onboard IMU as an estimation of the ship speed, v_a. Each branch has its own PID controller, and the sum of both outputs is used to command the motor, c_m.

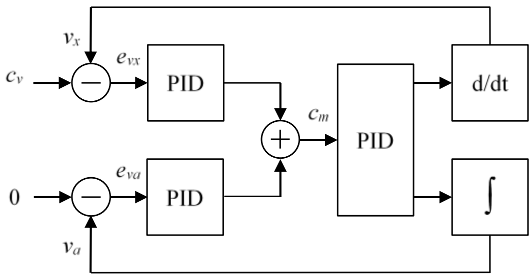

Figure 6. First, double PID, controller algoritm

Coming from different sensors, the speed measurements of both branches have different noise perturbations. The derivative and integral parts of both branches of the controller increase this differences further more. Thus, both PID parts act on less than optimal speed estimates, and the controller behavior, though proved valid, has margin enough to be improved.

Being the nature of both speed noises complementary, as been said, the use of the proposed complementary filter (CF) uses the best part of both speed measurements, and discard the worst. The speed estimation coming from this filter is suitable to close the loop of a more traditional single stage PID filter, used in the second iteration of the controller, as seen in Figure 7. This controller is easier to tune, and has better behavior in both ends of the speed envelope, where each of the estimates has problems.

The noisy nature of both speed measures can be characterized and its first and second statistics (mean and standard deviation) obtained. Also the dynamic ship behavior in tested waves can be modeled. Taking advantage of this knowledge, a third approach to the controller is being developed based on a Kalman Filter speed estimator. The speed estimation obtained from this filter is expected to be more robust, and optimal if the Kalman Filter can remain linear. This kind of filter yields better speed estimation because it uses knowledge from both speed measures, the nature of its noises and the dynamic behavior of the ship.

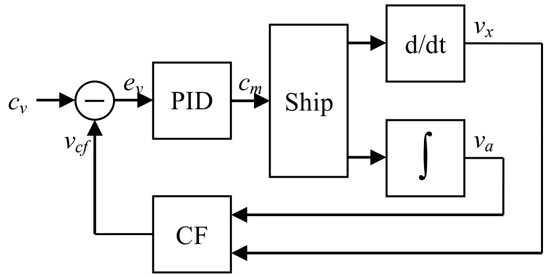

Figure 7. Second, single PID with complementary filter, controller algorithm

V. Conclusions and Future Work

The automatic speed measurement and control system presented in this paper is part of an autopilot for an autonomous ship model that has been developed for towing tank testing. The speed measurement system determines the velocity by differentiating the data coming from an onshore LRF, while the control is based on a complementary filter controller that makes use of the LRF signal as well as of the acceleration signal coming from the IMU of the ship. The use of an LRF to measure the speed is quite unusual and has been tested and validated on a moving target that mimics the ship movements but is able to perform extreme maneuvers with amplitudes and accelerations larger than the real ones.

A new ANN controller is being developed in order to improve the performance of the speed controller in cases that the test is made on irregular waves.

Acknowledgment

This work has been founded by the Xunta de Galicia and European Regional Development Funds under grant GRC 2013-050.

References

[1] F. Lopez Peña, M. Miguez Gonzalez, A. Deibe, D. Pena, F. Orjales, "An autonomous scale ship model for towing tank testing." *Proceedings of the 7th IEEE International Conference on Intelligent Data Acquisition and Advanced Computing Systems: Technology and Applications*. Berlin, Germany. September, 2013.

[2] A. F. Molland, S. R. Turnock, D. A. Hudson. *Ship Resistance and Propulsion: Practical Estimation of Propulsive Power*. Cambridge University Press. New York, USA. 2011.

[3] R. R. Clark. *Scanning rangefinder with range to frequency conversion*. US Patent 5,309,212, 1994.

[4] Acuity Research Inc. *AccuRange AR1000 Laser Distance Sensor user's manual*, rev. 1.7. 2010

[5] M. Míguez González, A. Deibe, F. Orjales, B. Priego, & F. López Peña. "An Autonomous Scale Ship Model for Parametric Rolling Towing Tank Testing" in *Some Advances in Intelligent Robotics and Collaborative Automation*. River Publishers. 2015.

[6] R. Brown, P. Hwang, *Introduction to Random Signals and Applied Kalman Filtering, Second Edition*, John Wiley and Sons Inc. 1992

[7] E. R. Bachmann, *Inertial and Magnetic Tracking of Limb Segment Orientation for Inserting Humans into Synthetic Environments*, PhD Thesis, Naval Posgraduate School, USA. 2000