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A TEST BED APPLIED TO MOBILE ROBOT NAVIGATION

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Abstract. *In this work, it is presented a test bed applied to studies on dynamics, control, and navigation of mobile robots. A cargo ship scale model was chosen, which can be radio-controlled or operate autonomously through an embedded control system. A control program, which manages on board mission execution, is implemented on a microcontroller.*

Navigation is based on a electronic compass, which includes automatic compensation for pitch and roll motions. Heading control loop is based on this sensor, and on a rudder positioning system. A propulsion control system is also implemented.

Typical manoeuvres as the turning test and "zig-zag", were implemented and tested. They are included on a manoeuvre library, and can be accessed independently or in combined modes.

The embedded system is also in charge of signal acquisition and storing during the missions. It is possible to analyse experiments on identification of ship dynamics, control, and navigation, through the data transfered to a PC by serial communication. Navigation is going to be improved by including inertial sensors on board, and a DGPS. Preliminary tests are aimed to ship identification, and manoeuvrability, using free model tests. Future steps include extending this system for developing other mobile robots as, ROVs, AUVs, and aerial vehicles.

Keywords: *Robot, Navigation, Ship Manoeuvring, Identification.*

1. INTRODUCTION

Mobile robotics has been deserved attention from AI researchers and engineers since the beginning of 70's. However, concerning autonomous robots, significant progress towards feasible and practical results from an engineering point of view has been achieved only recently.

Tasks related to underwater cables and pipeline survey, mining, monitoring of forests and geological activities undersea, agriculture survey, aerial and underwater reconnaissance, space projects, are applications of autonomous robots nowadays. It is recognised the educational role of the field as providing an excellent platform for developing a number of engineering topics.

The project described in this paper was initially motivated by research on unmanned underwater vehicles: autonomous underwater vehicles (AUVs) and remote operated vehicles (ROVs). The latter type of vehicle has been used particularly by the oil industry during exploration in deep seas. Other uses include underwater environment survey, and inspection of marine structures and inland water facilities. AUVs concern undersea activities that usually require a long span in space and/or time. Usual missions include survey in large areas for pipelining and cable checking, environment monitoring, oil exploitation support, rescue, and military objects reconnaissance. A preliminary test bed for both vehicles was planned to be a surface model to reduce initial costs, and to provide flexibility for other applications.

Vehicle scale models have been motivated a number of projects on autonomous vehicles (Charles, 1998; Hallberg et al., 1999). A cargo ship model was chosen in this project as the common test bed for initial tests concerning dynamics, control and navigation. While testing the embedded system (control and acquisition software/hardware, sensors, actuators, etc.) for future developments, manoeuvring trials have been also carried out and applied to the research on oceanic vehicles motion identification and control. The first mission of our vehicle was to perform two usual manoeuvres for steering dynamics identification: the turn manoeuvre, and the “zig-zag” test. Data analysis from those tests will allow us to estimate parameters related to basic manoeuvrability characteristics in calm water, and to define a control algorithm for autopilot design.

Afterwards, another application for the ship model development was decided. A project on dynamics of high-speed vessels required the implementation of free model tests. The hull is a standard for comparative tests performed by the “International Towing Tank Conference” members. The embedded vehicle control system will receive mission commands from a surface operator through a radio-control system. Manoeuvres are supposed to be performed autonomously by the control system which also manages the signal acquisition from motion sensors (DGPS, accelerometers, rate-gyro, compass, and inclinometers), pressure gauges (for local efforts), and wave meters. While dynamics is the focus of the first project, research using the model of a high-speed vessel will be also concerned with navigation systems. As example, the integration of inertial with DGPS systems will be investigated

All the instrumentation, control architecture, and navigation software inside those vehicles can be explored in the development of other unmanned vehicles (ground, aerial or underwater). This greatly widens the range of applications to be approached using results from this project.

2. SYSTEM DESCRIPTION

A hull on fibber glass is used. Main features of the vehicle are described on table 1.

Table 1. Main features of the vehicle.

Item	Dimension
Length	1.340m
Breadth	0.180m
Draught	0.090m

Mass	17.377kg
Vertical Moment of Inertia	1.555kg*m^2
Longitudinal Position of the Centre of Gravity	0.675m (from stern)

A schematic view of the embedded system is presented in fig.1. The propulsion system is composed by a dc-motor coupled to a propeller through a reduction gear. Propeller speed is sensed through a tachometer at the other side of the shaft. The steering system is composed by another dc-motor coupled to the rudder's shaft. Rudder's deflection is measured by a rotary encoder coupled to the motor. Heading is measured through an electronic compass. At first, both heading and speed control, algorithms were implemented at the main board. The positioning system for the rudder is implemented at IC level that is fed by the reference angle signal from the main board. Now, both speed and positioning loops are being implemented on a secondary board, which includes also a decoder circuit for radio-based control.

In this way, when it is necessary, the model can be commanded directly by the user, bypassing the main board. Except for the data acquisition and the autopilot algorithm, only the high-level software developments, like mission management, will be left to the main board.

A radio control system can command the embedded controller, starting or aborting pre-programmed manoeuvres, and providing manual control of the model. In the last case, the system becomes a typical radio-controlled model, which can also record data during the manual operation.

2.1 Main Parts

Radio-Control System. A pulse width modulated (PWM) proportional remote control system manufactured by Futaba was chosen. The transmitter is commanded manually through levers, and the receiver on board generates a PWM signal. This signal will be interpreted at the main board for generating mission related commands.

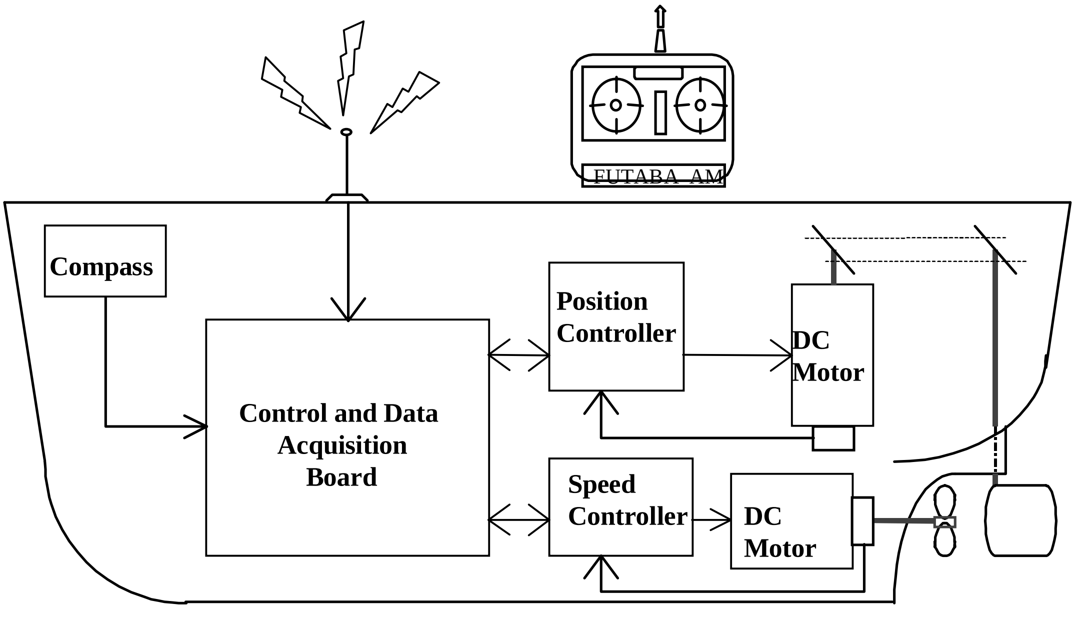

Fig. 1. Schematic view of the vehicle main systems.

Main Board. The control and acquisition board was manufactured by Intec Automation Inc. It is based on the Motorola's 16 bit microcontroller 68HC16, which has digital signal processing capabilities, and control specific features such as 2 pulse width modulation (PWM) outputs, pulse counting, high speed inputs and outputs, and 8 channels of 10 bit analogue to digital (A/D) conversion. HC-16 accesses memory and peripheral chips through memory mapping. Correspondence between address space and peripheral chips can be defined by the programmer by setting chip select lines. Chip select is used for accessing the rudder control system. Input capture channels can independently time stamp events (like high to low transitions, etc.). This feature was used for interpreting the pulses generated by the radio receiver. Memory space for data and code is provided by 256KB of SRAM and 256KB of Flash EEPROM. Communication to a host-PC and other boards can be done through the RS-232C and an RS-485 network. Further features include debug ports, a dedicated liquid crystal display and keypad port, 34 programmable digital I/O channels, and 8 analogue inputs to a 10 bit analogue to digital converter.

Electronic Compass. An electronic compass sensor module, "TCM2", manufactured by Precision Navigation provides the heading signal to be used by the autopilot algorithm. Besides compass heading, TCM2 outputs pitch, and roll readings. Information on environment conditions through magnet field (three-dimensional) and temperature is also provided. Instead of using universal joint or fluid bath to hold the sensor level, this module uses an inclinometer to allow a microprocessor to mathematically correct for tilt. The module particulars are presented in table 2.

Table 2. Specifications of the electronic compass module.

Information	
Heading Accuracy Resolution	 ±1.5°RMS 0.1°
Tilt Accuracy Resolution	 ±0.4°RMS 0.3°
Magnetic Field Accuracy Resolution Range	 ±0.2μT 0.01μT ±80μT
Temperature Accuracy Resolution Range	 ±0.5°C 0.5°C -20°C to 70°C
Dimensions	2.5"x2"x1.1"

3. CONTROL SOFTWARE

Control and acquisition software development has been executed by modules. Propulsion, steering system, and autopilot loops were implemented first. Afterwards, a library including typical manoeuvres started to be built. Now, it includes only the turning and the zigzag manoeuvres. Further steps can add the spiral, pulse response, harmonic response, and the pseudo random binary signal response, for example. All of them need, as embedded sensors, only the absolute encoder (for measuring the rudder angle) and the compass (for heading). Another kind of action is a manually controlled manoeuvre, like in the usual RC models, which includes the option for data recording. Complex manoeuvres can be implemented based on an obstacle detection system (for example, an acoustic one). In this case, the library may include a “wall-following” manoeuvre, for example.

Other libraries will include specific settings and commands to internal devices (like the IC responsible for the dc-motor position control). The mission control program may be easily modelled as a finite state machine, where the main events are radio transmitted signals that can start/abort manoeuvres or the whole mission, and start data uploading to a host PC.

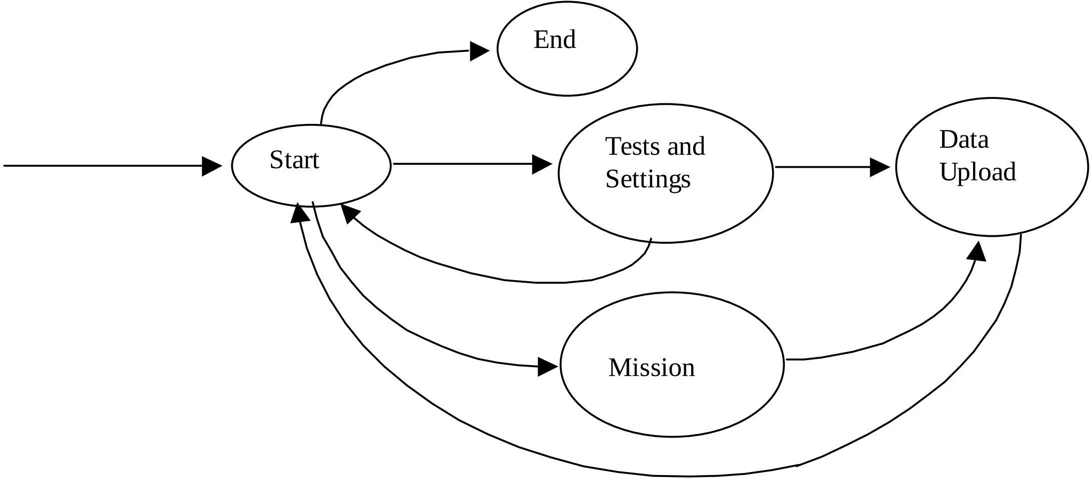

Fig. 2. Finite State Machine Representation of the Main Program.

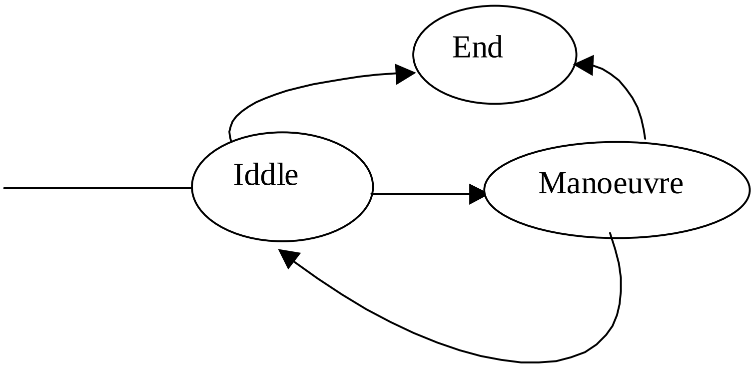

Fig. 3. Finite State Machine Representation of the Mission Management Module

4. SYSTEM IDENTIFICATION EXPERIMENTS

Simulation is a very practical tool for predicting dynamic behaviour of vehicles, investigating stability and manoeuvrability, and helping at the design stage. Mathematical modelling uses Newton’s second law for describing the equations of motion. In the case of ocean vehicles, forces involved are essentially hydrodynamic, which generally are difficult to be estimated through theoretical analysis.

Free model tests using system identification techniques have been applied to the study of ocean vehicles dynamics for more than four decades. They are used mainly for evaluating vehicle manoeuvrability and estimating parameters included in simplified linear models of ship dynamics.

Other applications include the estimation of coefficients present in more complex linear and non-linear models, which have been receiving more attention since the last decade. These involve the use of methods for modeling and analysing stochastic processes (e.g. Kalman Filtering), and usually represent nowadays what is known as system identification techniques.

For estimating hydrodynamic parameters explicitly, captive model tests are very popular among hydrodynamicists. In this class, the most complete technique is the planar motion mechanism, PMM, technique. During PMM tests, a scale model is forced to oscillate at pre-defined frequencies by an apparatus which includes a sensory base connected to the model in one extremity and actuators in the other (Clayton and Bishop, 1982). Fourier decomposition of forces and moments that are measured during the forced motion together with an assumed form for the expressions of hydrodynamic efforts provide the basis for calculating the derivatives. Main advantages of this kind of technique include the provision for data related to separate effects of hull and appendages, and the provision for numerical values of a complete set of derivatives that can be combined for simulation of a number of manoeuvres.

However, captive model tests need expensive model basin facilities, they are time consuming like the planar motion mechanism, and cumulative errors are present in their analysis.

Model test results may suffer from scale effects related to the large difference in Reynolds number between model and ship. This difference is particularly significant for full-bodied ships, and for ships operating in shallow water. This suggests that realistic form and numerical values for the hydrodynamic efforts should be based on full-scale tests. In the case of ships, full-scale testing is possible through free model trials. A number of trials have already been carried out using full-scale ships. The most famous is described by Abkowitz(1980). Simple manoeuvres can be proposed in system identification experiments, which reduce time and save costs. From the trials using full-scale ships, results can indicate whether the model structure used in simulations should be changed, and the scale effects should be considered.

In the case of unmanned ocean vehicles, usually the size considered during the tests is already the full-scale. This is a reason that motivates the investment on system identification methods, avoiding the more expensive PMM trials.

Another reason is related to the sensors and infrastructure system used during the free model trials. Navigation technology has dramatically evolved recently. We intend to investigate inertial navigation systems together with differential global positioning systems (DGPS) for vehicle navigation, using data fusion techniques. Those systems can also be applied for estimating dynamical parameters of a vehicle.

Two common manoeuvres used in the identification of ship steering dynamics were already implemented on board and tested during water tank trials, the turning and the zig-zag. The turning manoeuvre helps in the evaluation of the ship manoeuvrability. After a straight trajectory at constant speed is achieved, step input is fed into rudder. A stable ship reaches a circular path in the steady state, at constant linear and angular velocities. The more stable the ship, the larger is the turning radius. The larger is the rudder area, the smaller is the turning radius. Other important parameters measured from this test are the “advance” and “transfer”. Step response analysis can also be applied for estimating a simple transfer function between rudder input and heading (Fossen, 1994).

Ship response in the transient state can be evaluated by the zig-zag manoeuvre. Nomoto’s parameters “K” and “T” can be estimated from the experiment results. They are related to the intensity of rudder influence on the ship, and the speed of response to the rudder action, respectively. These parameters are presented in the simplified yaw equation:

$$T'\dot{r}' + r' = K'\delta'_r \tag{1}$$

Where, r is the yaw velocity of the ship, and δ_r is the rudder angle. The “ ‘ “ symbol indicates that the equation is on the non-dimensional form.

Based on some yaw angle values measured from the test, and correspondent time intervals, “K” and “T” parameters can be estimated (Nomoto, 1960).

Both manoeuvres were performed during tank tests. Results are shown in figures 4, and 5.

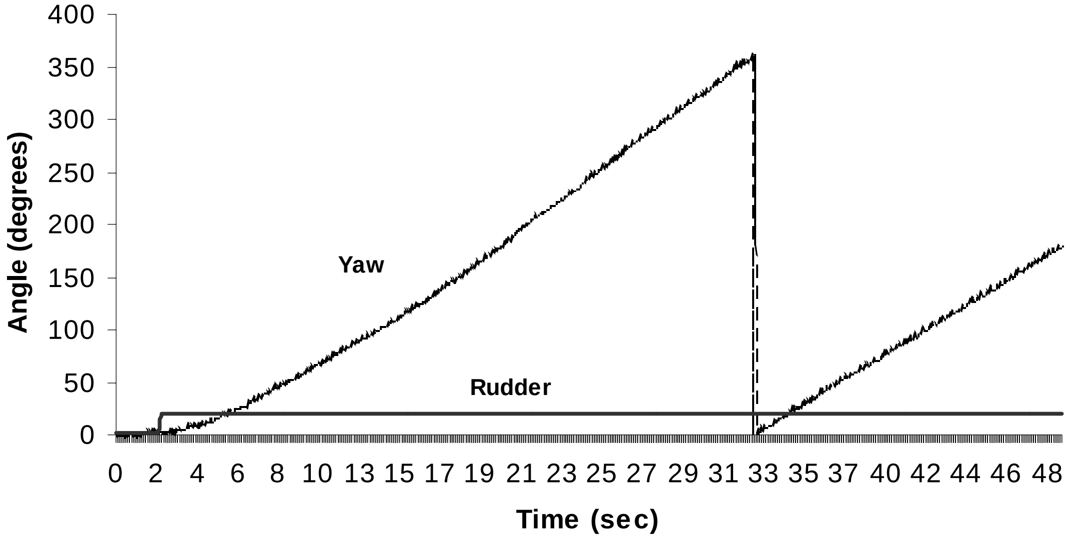

Fig. 4. Turning Test.

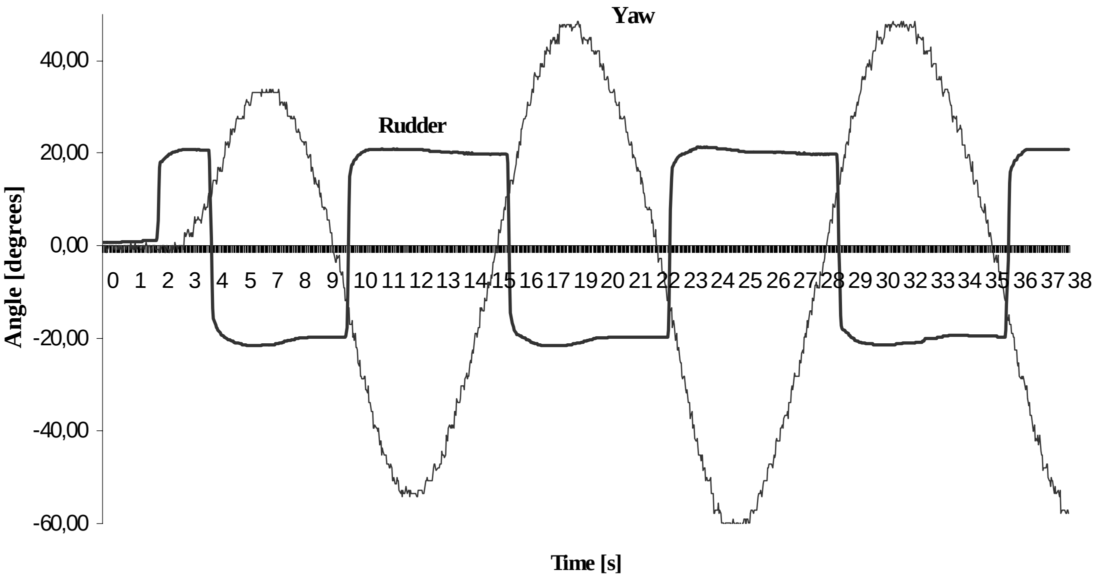

Fig. 5. Results from the zig-zag test.

In fig. 4 , it is possible to observe that the yaw rate converges to a constant value, as expected from a stable ship whose linear model fits well.

Fig.5 indicates a clear configuration of the zig-zag response. During this test, the rudder angle is at first displaced from amidship position, and kept to a constant value, e.g. 20 degrees starboard, until a specified value of the yaw angle starboard is reached. Then, the rudder is reversed to the opposite side by the same value, and kept in this position until the yaw angle reaches the same angle to port. From this point, the rudder angle is reversed again to starboard. Fig. 5 corresponds to a rudder absolute displacement equal to 20° at a 10° yaw angle that is called “20/10” test. Other usual cases are the “20/20” and the “10/10” (Fossen, 1994).

5. CONCLUSIONS

A preliminary version of a test bed was completed. A number of experiments on ship dynamics, and control are already feasible. System identification experiments will be used to estimate transfer functions relating rudder and yaw angles, and validating prediction methods from theoretical and semi-empirical basis.

There are a number of expressions proposed for estimating hydrodynamic derivatives based on hull and rudder geometric properties. It is possible to use these estimations on manoeuvre simulators, and compare the results to the experimental data from tank tests. Thus, from data collected during the trials, it is possible to validate estimation methods, and improve them for using on future vehicle projects.

Concerning software, further developments include improving the mission management system, and implementing new manoeuvres and autopilot algorithms. Inertial sensors (accelerometers, rate gyros, and gyrocompasses) will be added on board, for improving identification and navigation. In parallel, another control and acquisition system based on the PC-104 compact system of larger capability is being investigated for extending this project to missions that are more complex.

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