EXPERIMENTATION ENVIRONMENT FOR MARINE VEHICLES

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ABSTRACT

This paper describes an experimentation environment for the various trials and manoeuvres performed to verify the stability and steerability of marine vehicles using autonomous in-scale physical models. The model has an Industrial PC which communicates through a wireless network with the laptop on land, which can in turn be connected to other PCs through Internet using 3 generation Universal Mobile Telephone System (3G UMTS) technology. To do this, a software support developed in LabVIEW is used. It is possible from a distance, via the web and via DataSocket, to view data and modify the parameters of all of the instruments of the platform using the wireless network with Wireless Fidelity (WiFi) technology and also the Internet network with 3G UMTS technology. The software accepts different protocols of communication with the platform and is appropriate for performing the sea trials most widely used at present for determining the characteristics of steering and manoeuvring of marine vehicles, such as: turning circle, zig-zag manoeuvre, pull-out manoeuvre and spiral manoeuvre.

Key words: Experimentation environment, marine vehicles, full-scale trials, Wi-Fi, wireless.

INTRODUCTION

The first step in the building of a new vessel is to design an in-scale model of the vessel and to carry out trials in a hydrodynamic testing tonk in order to obtain

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the mathematical model of the vessel. With this model, by means of simulation, several sea trials are performed to determine the vessel's manoeuvring characteristics (Fossen, 1994 and Lopez et al, 2004): turning circle, zig-zag manoeuvre, pull-out manoeuvre and spiral manoeuvre. With these trials, the characteristics of the dynamic behaviour of the vessel can be measured, an indication of its stability in a straight-line trajectory can be obtained, its robustness and the limitations of the control system can be assessed and the behaviour of the vessel in emergency situations can be evaluated. Once the vessel is built, the sea trials are repeated in the open sea in order to verify whether the same results are obtained as in the simulation.

In the MCYT Project DPI2003-09745-C04-03 and in the MEC projec DPI2006-11835, the remote experimentation environment for marine vehicles described in this paper was built. It has an in-scale physical model of a high-speed vessel, TF-120 (Figure 1). This model is autonomous and is controlled remotely from a laptop computer using a software support developed in LabVIEW (LabVIEW 7, 2003 and Bishop, 2004) and by means of a Wi-Fi connection. All of the elements which make up the system and which will be described below are industrial. The main reason for selecting this type of elements is their robustness and reliability. In this experimentation environment, the installation of a vessel is successfully emulated.
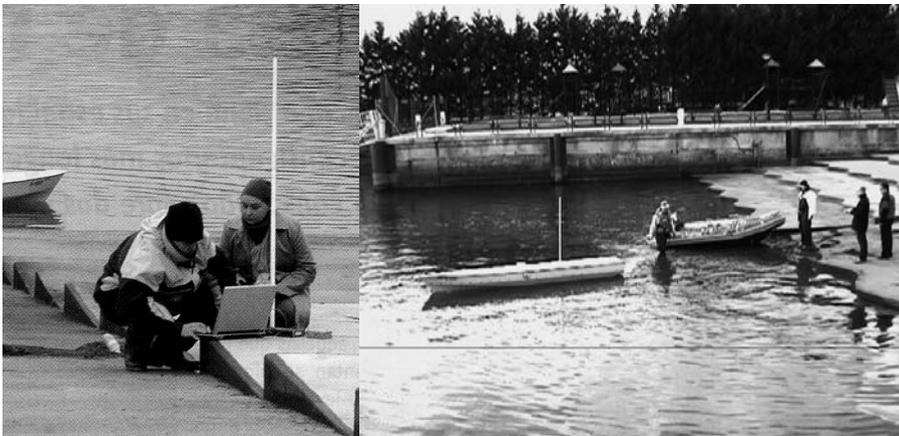

Figure 1. In-scale model of the TF-120 vessel

The experimentation environment developed enables data-gathering and the steering of the model of the TF-120 vessel, for the Guidance, Navigation and Control (GNC). With this model, it is possible to perform the various sea trials required to determine the steering and manoeuvring characteristics of the in-scale model of the TF-120 vessel or of any other vessel. This will complement the trials which can only be carried out through simulation in a hydrodynamic testing tenk. Moreover, with this experimentation environment, it is also possible to perform manoeuvres for

actions in cooperation with other vessels, such as assistance to a damaged vessel, towing manoeuvre and joint operations between ships or sailing in proximity. The various experiments are performed in an uncontrolled environment, in this case, The Bay of Santander.

The data obtained from the zig-zag and turning circle trials can be used for the identification of a mathematical model relating the heading of the vessel with the rudder angle of the propulsion turbojets. Using this mathematical model, controllers can be designed for the control of the manoeuvres mentioned above and for the monitoring of the planned trajectories (Ollero, 2001), and these can then be validated in the experimentation platform as a prior step to their real implementation.

FULL-SCALE MANEUVERING TRIALS

In order to verify the ship's maneuvering characteristics, some standard ship manoeuvres can be performed allowing the ship's dynamic behaviour characteristics to be measured and the robustness and the limitations of the ship control system to be evaluated. The manoeuvring characteristics can be obtained by holding or changing a predetermined course and speed in a systematic way.

In accordance with the recommendations of the 14th ITTC (1975) and other resolutions of the International Maritime Organization (IMO) (Haro, 2004), tests have to provide owners and builders with information on the operating characteristics of the ship. These must address the course-keeping, course changing and emergency manoeuvre characteristics. In order to determine the efficiency of the vessel in course-keeping, the tests methods proposed are: the direct or reverse spiral test and the zigzag manoeuvre test with small rudder angle. To determine the quality in the course changing behaviour, the zigzag manoeuvre test and the 15 degrees helm turning test and change of heading test are recommended.

A small description is given below of some of the standard ship manoeuvres. A detailed description one can see in López et al. (2004).

Turning Circle

This manoeuvre is used to determine the ship's steady turning radius and to verify the behaviour of the steering gear and rudder control during course-changing manoeuvres. It should be performed to both port and starboard at maximum speed, with a maximum rudder angle and with a rudder angle of 15º. It is necessary to do a turning circle of 540º at least to determine the main parameters of this trial.

Pull-Out Manoeuvre

The pull-out manoeuvre is a simple test used to obtain a rapid indication of the stability of a straight-line course held by a ship.

A rudder angle of approximately 20º is applied and time is allowed to pass until the ship reaches a constant change of heading rate. At that instant, the rudder is returned to neutral position. If the ship is stable, the speed will drop to zero both for port and starboard rudder changes. If the ship is unstable, the change of heading rate will drop to some residual speed rate.

Kempf's Zig-Zag Manoeuvre

The zig-zag manoeuvre is obtained by inverting the rudder alternatively by δº to both sides, with a shift of ψ from the initial course. The normal course changing value ψ is 10º. A modified trial can also be taken into account with a course changing of 20º. The 14th ITTC conference recommends executing the manoeuvres at maximum approach speed and, if possible, also at medium speed.

The results of this manoeuvre are indicators of the capacity of the rudder to control the ship's heading. They can also be used to compare different ship manoeuvring capacities. The normal zig-zag manoeuvre begins with the application of the rudder angle to starboard.

Direct and reverse spiral tests

These manoeuvres provide a qualitative measure of the directional stability of the ship in a straight line. For ships which show stable characteristics, the Dieudonné direct or Bech inverse spiral tests can be used to obtain the response to small rudder angles. For unstable ships, the 14th ITTC recommends the Bech inverse spiral test within the limits indicated by the results of the pull-out manoeuvres.

REMOTE EXPERIMENTATION

The experimentation environment is made up of the set of components shown in Figure 2.

The graph shows both those elements which remain on land and those which are lodged on the marine vehicle. The communication between the two is made through a wireless system with two access points, one on land connected via wireless to the laptop PC and another on the sea vessel connected to the industrial PC by
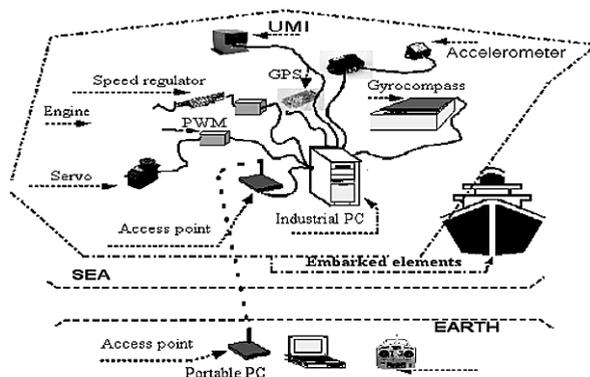

Figure 2. Elements necessary for the monitoring of a trajectory.

means of a network cable. The laptop also has a 3G UMTS card, which allows another PC or PCs to connect through Internet to the laptop. The propulsion is made up of a series of engines, which make the turbine of their corresponding turbojets rotate. Each engine is regulated by a speed variator, which is commanded by a Pulse Width Modulation (PWM) control circuit.

By means of the GPS electronic gyrocompass (KVH, 1997), the current heading, position, time etc. is obtained. These data are sent to the PC using the National Marine Electronics Association (NMEA) 0813 communications protocol through the series gate RS232.

Thanks to the GPS RCB-LJ receiver incorporated in the TIM-LF chip (TIM, 2004), fairly accurate data on the position and speed of the vessel, as well as other parameters, are obtained. This chip accepts the protocols UBX, NMEA and RTCM.

In order to obtain data on the movement of the physical model, two triaxial accelerometers are used, one located at stern and the other at bow. The inertial measurement unit (UMI) also provides values for the six degrees of freedom of movement of the model.

An application called SCADA_Industrial.vi installed in the Industrial PC will be in charge of presenting on screen and storing all the data measured by the instruments on board. It is also possible to modify the control parameters to follow a given trajectory. LabVIEW (Bishop, 2004) allows communication between the SCADA_Laptop.vi application being run on the laptop PC and its corresponding application in the Industrial PC (SCADA_Industrial.vi) using different communication protocols. The exchange of data between the various PCs is possible thanks to the publication of data with a DataSocket server or a web server.

The SCADA_Laptop.vi application publishes data on the DataSocket server to be able to exchange data with the corresponding application on the Industrial PC (SCADA_Industrial.vi) and also publishes data on the web servers that data can be exchanged with another or other computers. That is, from a computer connected to Internet, the application of the laptop PC can be accessed with the right address and this application of the laptop can access the application of the industrial PC thanks to the DataSocket server.

Trial Platform Manoeuvres

The various manoeuvres described above can be performed in the experimentation platform developed.

In order to perform the change of heading required in each of the manoeuvres, the rotation angle of the in-scale TF-120 vessel model's turbojets is modified. Next, the data from the various instruments of the platform such as the electronic gyrocompass and the GPS are gathered and stored.

It should be noted that for the turning circle, the platform allows maximum rotation angles of around 30º to port and to starboard.

The zig-zag manoeuvre is performed as follows: assuming that the physical model starts from an initial heading of 0º, the software support makes a change in the turbojet angle of 0º to 20º. Thus, until the platform exceeds 10º of heading, measured with the electronic gyrocompass, the platform does not surpass from 20º to -20º of angle of the turbojet. In the same way, until the platform exceeds -10º of heading, the platform does not change from -20º to 20º of angle of the turbojet. A minimum of five cycles are required to perform the full manoeuvre. The platform is prepared to modify the angle of comparison of the actual heading from 10º to 20º and the rotation angle of the turbojet from 20 to 10º, so that various combinations of the zig-zag manoeuvre can be performed.

In order to carry out the spiral manoeuvre trial in the remote laboratory, the marine vehicle must initially sail in a straight line. The rotation angle of the turbojets is then changed 25º to starboard and is kept thus until the system establishes itself. Then, the rotation angle is successively reduced by 5º each time until it reaches 25º to port. In the rotation angle range near 0º, the angle is decreased to values lower than 5º in order to obtain more accurate data.

The remote laboratory is capable of capturing the data on the heading of the vessel using a gyrocompass, of making a numerical derivation and thus obtaining the change of heading rate. This allows the pull-out manoeuvre to be performed. If the marine vehicle is stable for the straight line navigation, the change of heading rate when the angle is modified from 20º to 0º, should drop by the same value to starboard as to port. If not, the vessel is instable.

DEVELOPMENT OF SOFTWARE SUPPORT OF ENVIRONMENT

For the development of the software support, version 7.1 of LabVIEW has been selected as the graphic programming environment, since this is a Standard and because it allows graphic interfaces to be developed simply and in real time. Another important characteristic of LabVIEW is that it allows the testing of different types of controllers to be carried out fairly simply. Figure 3 shows the different control signals of the system actuators which may be: the signal of the propulsion speed, the signal of the propulsion direction and the signals of the stabiliser flaps. Each engine is controlled by a speed variator, a servomotor and a PWM control circuit, but the analogue control signal of the data acquisition card may be the same for the different engines or not. In this way, the turbojet rotation angle and the speed of rotation of the engine are practically the same.

All of the manoeuvres are programmed in this software support so that they can be performed automatically. To do this, the Industrial PC has a resident application, SCADA_Industrial.vi, which controls the movement of the turbojets in order

Industrial Pc

TAD

Analougueouts   Analougueouts

PW M   PW M   PW M   PW M

Servo   Servo   Speed variator   Servo

Engines

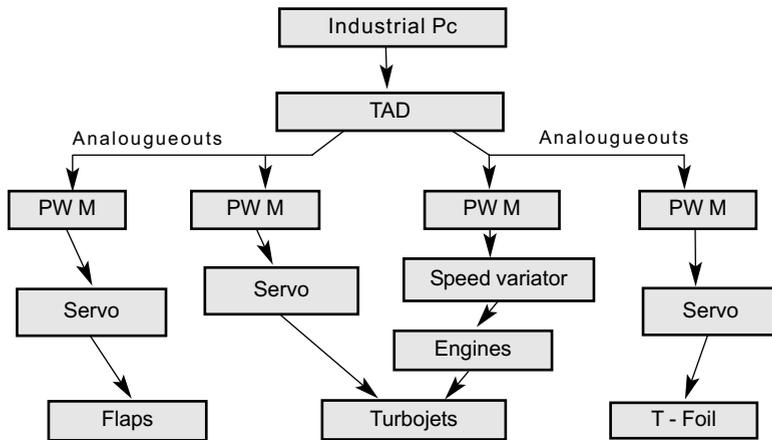Flaps   Turbojets   T - Foil

Figure 3. Control of propulsion.

to perform the manoeuvres. It also captures and stores the data from all of the instruments that make up the platform.

Software support communications system

The communication between the computer located on land and the one positioned on the sea vessel is made through a wireless network using Wi-Fi technology based on the standard 802.11g (Planet, 2004). The laptop PC can in turn communicate with one or several PCs equipped with a 3G UMTS mobile telephone card with transmission speeds of 384 Kbps.

The connection will function at the maximum speed allowed for maintaining an optimum transmission automatically. This is, for an 802.11g protocol: 54, 48, 36, 24, 18, 12, 9 or 6 Mbps. The speed will depend on the distance the client is from the point of access, on whether or not there is encrypting between the client and the point of access, on the existence of interference in the 2,4 Ghz band (mobile telephones, microwaves, …).

The laptop links with the industrial PC through the access points by means of omnidirectional antennas which allow a distance between access points of around 250 metres, the result being the same as if the two pieces of equipment had been connected to a typical local area network. By having an access point in repeater mode, the coverage is tripled, with the only drawback that the technical specification forbids WPA encrypting between two access points configured in repeater mode, so that all of the information we send can only be encrypted in Wired Equivalent Privacy (WEP) mode, an encryption which has proven to be vulnerable, even in its 128 bit version. The laptop PC also has a 3G PCMCIA card, which allows access to Internet. Once connected to Internet, it is possible to connect with any other PC or

PCs connected to Internet. These PCs may be connected to Internet via an Ethernet cable or using a 3G PCMCIA card, as can be observed in Figure 4.

Figure 4. Elements which make up the wireless network

Publication of Vis in DataSocket Ser ver and in Web Server

In order to be able to access the SCADA type application being run on the Industrial PC via the wireless network and at the same time be able to access this application from another or other PCs through Internet, it was necessary to combine DataSocket technology and the web publication of LabVIEW, in the software support, as can be seen in Figure 5.

There are two graphic inter-faces with the same appearance: once called SCADA_Industri-al.vi which is run on the Indus-trial PC and another called SCADA_Laptop.vi which is run on the laptop. These two appli-cations interchange information bidirectionally through the Lab-VIEW DataSocket server in the laptop. Any control modified by the use in the remote application of the laptop will automatically

Figure 5. Software System Applications

be modified in the application of the Industrial PC. At the same time, the SCADA_Laptop.vi application publishes its data on the web server which is also in the laptop. Thus, any other PC connected to Internet may have access to this applica-tion and take over the control at any moment. A PC, or more than one PC, can be connected through Internet, as can be observed in Figure 5. It must be borne in mind, however, that only one of them can assume control of the application while the others can only visualise the data.
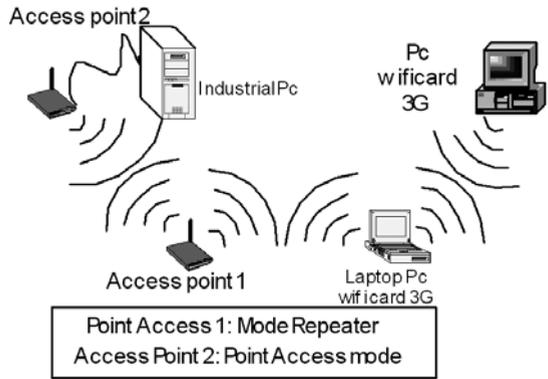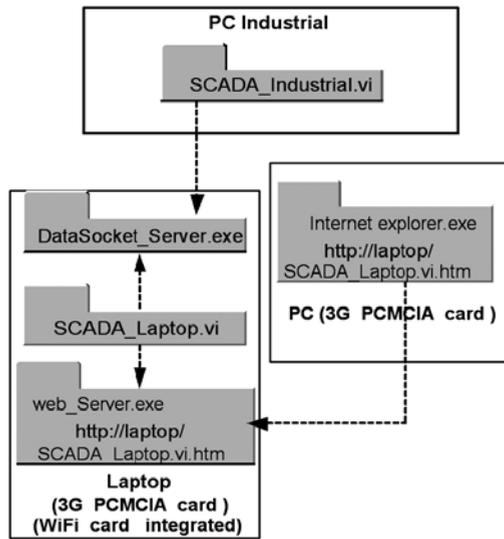
The implemention of the communications system described above might have been undertaken using only DataSocket technology (DataSocket, 2003). However, apart form the SCADA_Industrial.vi for the Industrial PC and SCADA_Laptop.vi for the laptop, it would have been necessary to design one application for each computer connected to Internet that wanted to connect to the laptop. This is why web server technology is also being used since, in this way, any computer connected to Internet can access the laptop by typing in the corresponding address in a search engine, such as Internet Explorer, without the need to create a new application for each computer that wants to connect to the laptop. For all of these reasons, the most adequate solution is to combine DataSocket technology with the LabVIEW web server technology.

When using DataSocket technology, each of the controls of the SCADA_Industrial.vi application or the SCADA_Laptop.vi application which form the user interface, such as the scroll bars, on/off buttons, text frames, etc. are the elements denominated 'items'.

These items are published through a DataSocket Server capable of publishing data so that other client processes can read them or write them. In our system, the SCADA_Laptop.vi application is connected to the DataSocket server where all of the items of this application are published, in reading and writing mode (Figure 6). In the same way, the SCADA_Industrial.vi application is connected to the DataSocket server through the wireless network to access the data published by the client application of the laptop. The Client application of the Industrial PC subscribes to the data published by the laptop and only has reading capacity, not writing.

The technology includes the DataSocket Transfer Protocol (DSTP) communication protocol used by LabVIEW, a protocol based on TCP/IP. It is possible to connect the DataSocket server using DSTP URL, as shown in the following example.

Figure 6. DataSocket communication

The URL below connects in the DataSocket server the data called Item1 which is being run in the same computer, the local computer, which may be the laptop where the SCADA_Laptop.vi. application is available.

Dstp://localhost/Item1

The URL below connects the data from the industrial PC to the Item1 in the DataSocket server which is running in the laptop connected to the wireless network.
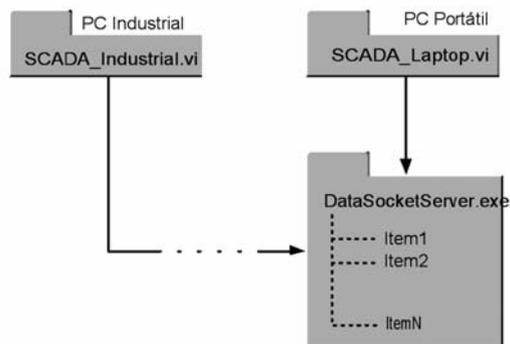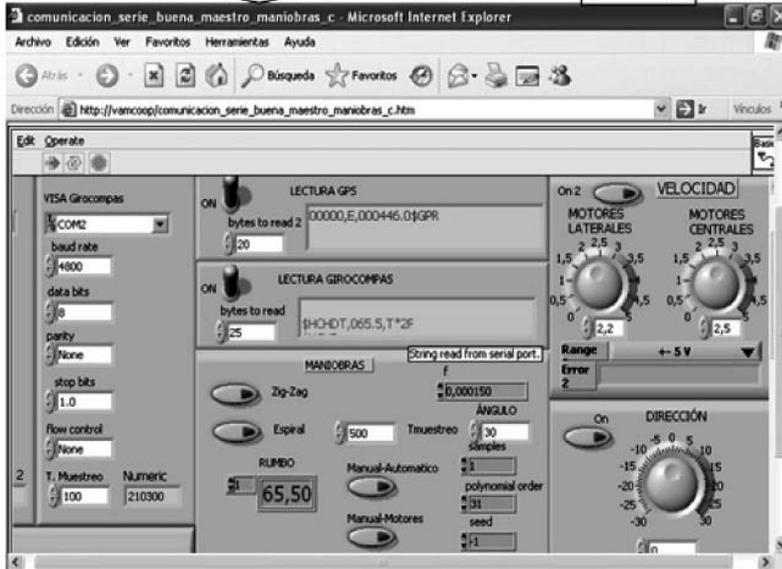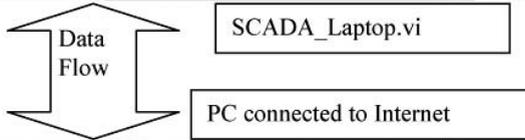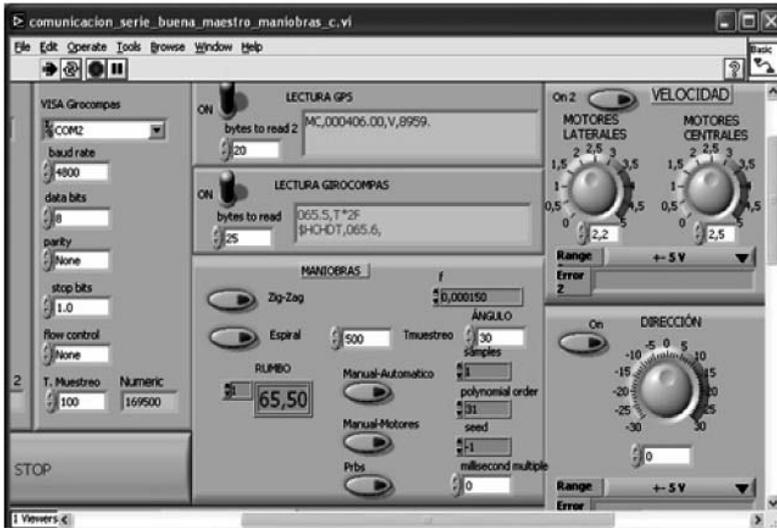
Figure 7. Communication via web between the Industrial PC and the laptop .

Dstp://Direccion_PCPortatil/Item1

In this way, data are exchanged through the wireless network between the industrial PC and the laptop with a single DataSocket server.

Once the above-mentioned applications are connected to the wireless network using DataSocket technology, the network can access from an external network, such as Internet, the SCADA_Laptop.vi application via the web server. For this, it is necessary to key in the corresponding address in a search engine such as Internet Explorer. The parameters of this URL specify on the one hand the web server address, which in this case is the address of the laptop, and on the other hand the name of the corresponding application (SCADA_Laptop.vi). The full address is given below:

http://address.server.web/nameVI.htm

The SCADA_Laptop.vi application of the laptop and the application embedded on a web page which can be seen when the corresponding address is keyed in Internet Explorer appear in Figure 7.

RESULTS OF SEA TRIALS WITH THE PLATAFORM

Figures 8 and 9 below show the results of the turning circle manoeuvre made with the platform (Velasco, 2006).

Figure 8 show the turning circle towards starboard. In the abscissa axis, the number of samples captured with a sampling period of 0.1 s. are represented. In the
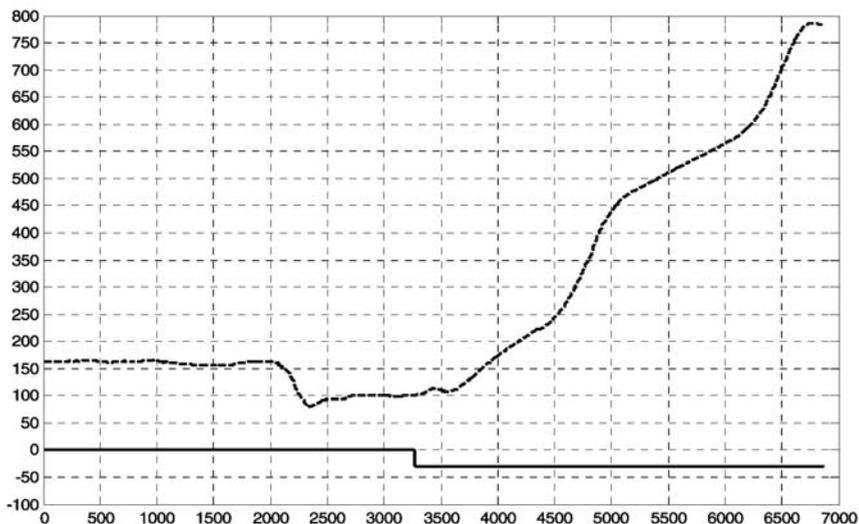

Figure 8. Evolution towards port curve

ordinates axis, the data on the heading measured with the electronic gyrocompass are shown as well as the turning angle of the turbojets. In the case of the evolution towards port, a turbojet angle of 30º has been set. This figure shows a first phase of approximation, typical of the manoeuvre, in which the heading of the physical model remains constant with a turbojet angle of 0º. Then, the turbojet angle is modified to 30º, which is when the physical model begins to rotate towards port, and this turbojet angle is maintained until the model passes 360º twice to perform the full manoeuvre (Bech, 1968).

Figure 9 shows the evolution towards starboard curve, following the same philosophy as for the port manoeuvre. For this curve, a turbojet rotation of -30º has been set.
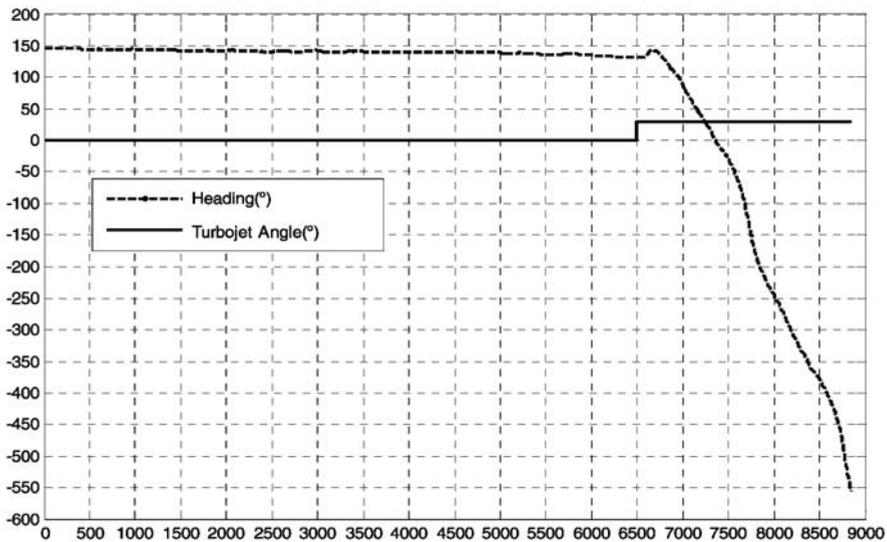

Figure 9. Evolution towards starboard curve

In the development of these trials, a constant position of 0º degrees has been set for the bow flaps and 7,5º for the stern T-foil.

CONCLUSIONS

A remote experimentation environment for marine vehicles for in-scale models of vessels has been designed, with all of the instrumentation required to emulate the installations of a real ship. A software system has been designed for this platform, capable of communicating via the web, capturing data and controlling the manoeuvres and steering of the physical in-scale model of a high-speed TF-120 vessel.

The correct functioning of the model has been verified in the manual/automatic/manual operating modes.

It has been verified that the establishment of communications through the wireless network is correct. To do this, the communication between each PC and their access point and also the bidirectional communication between each PC and its point of access are verified. Once these checks have been made, the data published on the web server of the Industrial PC can be accessed from the laptop without any problem. Communication between the 3G PCMCIA of the laptop and Internet is also verified as well as the correct communication between another or other PCs to Internet, whether it be using Ethernet cable or other 3G PCMCIA cards. LabVIEW allows the connection to the web server of up to a maximum of 5 PCs. The software support design is intended to make an efficient use of the CPU memory and resources.

ACKNOWLEDGMENT

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ENTORNO DE EXPERIMENTACIÓN DE VEHÍCULOS MARINOS

RESUMEN

En este artículo se describe un entorno de experimentación para los distintos ensayos y maniobras para comprobar la estabilidad y gobernabilidad de vehículos marinos con modelos físicos a escala autónomos. El modelo tiene un PC Industrial que se comunica a través de una red inalámbrica con el PC portátil en tierra, el cual se puede conectar a otro u otros PCs a través de internet mediante tecnología 3G UMTS. Se ha implementado un soporte software en el PC Industrial, que es capaz de adquirir y almacenar datos de todos los instrumentos de la plataforma de ensayos de forma remota.

Palabras clave: Entorno de experimentación, vehículos marinos, pruebas de mar, wifi, inalámbrico

INTRODUCCIÓN

El entorno de experimentación de vehículos marinos, tiene todos los elementos necesarios para emular la instalación de un buque real y es capaz de realizar todas las maniobras necesarias para comprobar la estabilidad y gobernabilidad de vehículos marinos como paso previo a la implementación real. Tiene un modelo físico a escala de un buque de gran velocidad, TF-120. Este modelo es autónomo y se controla remotamente desde un PC Portátil mediante comunicaciones inalámbricas tipo WiFi. Además, el PC portátil se puede conectar a otro u otros PCs a través de internet mediante tecnología 3G UMTS y de esta forma se puede controlar y visualizar la plataforma desde otro PCs.

METODOLOGÍA: PRUEBAS DE MAR

Las pruebas de mar que se utilizan principalmente para verificar las características de maniobra del buque, también permiten medir las características del comportamiento dinámico del buque así como la robustez y las limitaciones del sistema de control y proporcionan información sobre las características de funcionamiento del buque en el mantenimiento y cambio de rumbo y en las maniobras de emergencia.

Para determinar la eficacia del comportamiento del buque para el mantenimiento de rumbo se utilizan la prueba en espiral directa e inversa y la maniobra de zig-zag con ángulos del timón pequeños. Para determinar la calidad del comportamiento en la maniobra de cambio de rumbo se recomiendan la maniobra de zig-zag, la prueba de evolución de 15º de timón y la maniobra de cambio del rumbo.

Para determinar la capacidad del buque ante situaciones de emergencia, las pruebas de mar más convenientes propuestas son: prueba de evolución con el máximo timón y maniobra de parada de emergencia o "crash-stop".

En este artículo se realiza una pequeña descripción de algunas de las maniobras más habituales y se han obtenido los datos de diversas curvas de evolución con el modelo físico a escala.

SOPORTE SOFTWARE

En este soporte software están programadas todas las maniobras para que puedan ser realizadas de forma automática. Para ello se dispone de una aplicación residente en el PC Industrial embarcado en la plataforma, llamada SCADA_Industrial.vi, que aparte de realizar las maniobras, se dedica a la captura y el almacenamiento de los datos de todos los instrumentos que integran la plataforma.

Para poder acceder a la aplicación de tipo SCADA que se esta ejecutando en el PC Industrial a través de la red inalámbrica y al mismo tiempo poder acceder a esta aplicación desde otro u otros PCs a través de Internet ha sido necesaria la combinación, en el soporte software, de la tecnología DataSocket y publicación web de LabVIEW. La comunicación entre el PC Industrial y el PC Portátil se realiza a través de una red inalámbrica de tipo WiFi y la conexión entre el PC Portátil y otro u otros PCs se realiza a través de Internet.

Como se ha dicho, la comunicación entre el ordenador situado en tierra y el situado en el vehículo marino se realiza a través la tecnología WiFi basada en el estándar 802.11g. El PC portátil se puede comunicar a su vez con uno o varios PCs que dispongan de tarjeta de telefonía móvil 3G UMTS o que estén conectados a Internet de cualquier otra forma, con velocidades de transmisión de 384 Kbps.

CONCLUSIONES

Se ha desarrollado una plataforma de ensayos de vehículos marinos en la que se ha diseñado y montado una instalación con los actuadores y la instrumentación necesaria para realizar la captura de datos y control de la plataforma, de tal manera que, se pueda realizar maniobras típicas para determinar características de maniobrabilidad de vehículos marinos. Se ha diseñado un sistema software para esta plataforma, que dispone de una red inalámbrica para comunicar el vehiculo con el PC portátil en tierra y además, existe la posibilidad de acceder a esta red mediante Internet. La aplicación diseñada se encarga de capturar datos y controlar el modelo físico del Turbo-Ferry TF-120.

Se ha verificado que el establecimiento de las comunicaciones y el funcionamiento de la instalación en los modos de actuación manual/automático/manual es correcto. Se ha comprobado el correcto funcionamiento del girocompás electrónico descartando cualquier posibilidad de incompatibilidad electromagnética.