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Escuela Técnica Superior de Náutica
c/ Gamazo nº1, 39004 SANTANDER
Telfno (942) 201362; Fax (942) 201303
e-mail: info.jmr@unican.es
http://www.jmr.unican.es

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EXPERIMENTATION ENVIRONMENT FOR MARINE VEHICLES

F. J. Velasco[1], T. M. Rueda[1], E. Revestido[1], E. López[2], E. Moyano[1] and L. A. Esquibel[3]

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

[1] Grupo de Informática y Automática, U. Cantabria. [2] UPV/EHU. [3] Universidad de León

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.

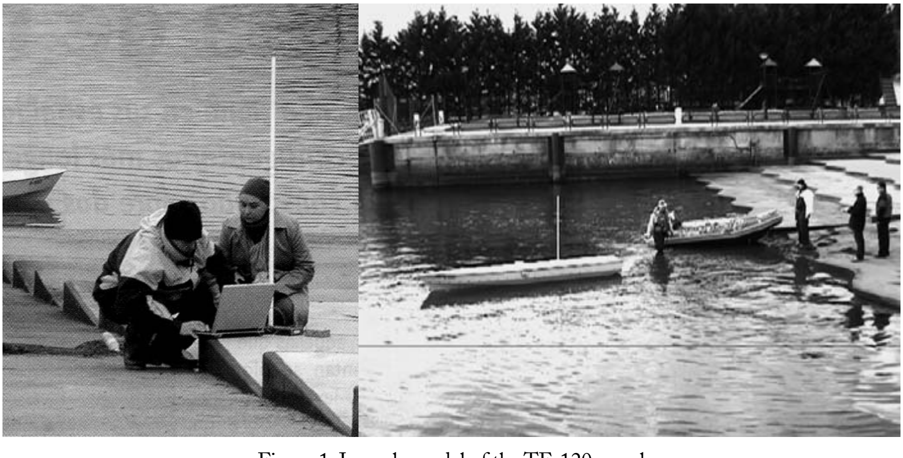

Figure 1. In-scale model of the TF-120 vessel

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 δ^o 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

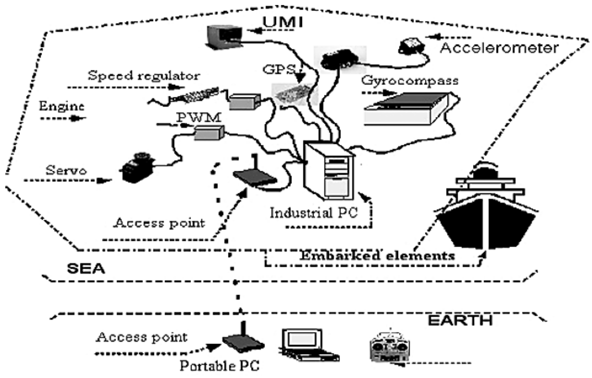

Figure 2. Elements necessary for the monitoring of a trajectory.

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

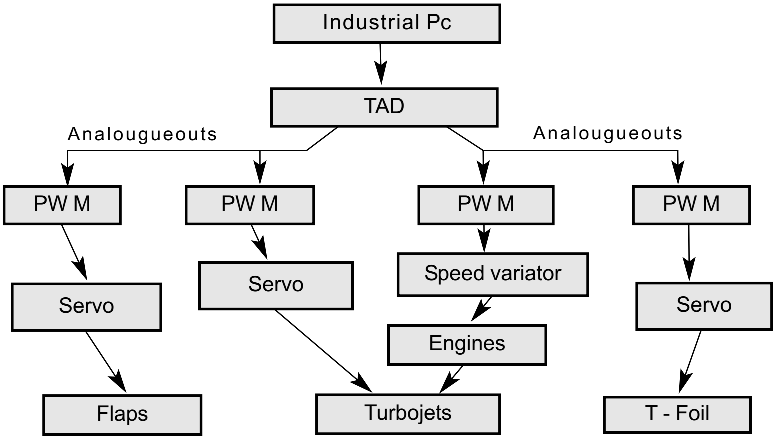

Figure 3. Control of propulsion.

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 encryptation 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.

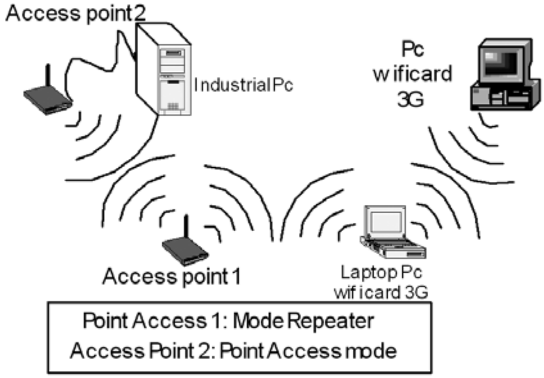

Figure 4. Elements which make up the wireless network

Publication of Vis in DataSocket Server 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 interfaces with the same appearance: once called SCADA_Industrial.vi which is run on the Industrial PC and another called SCADA_Laptop.vi which is run on the laptop. These two applications interchange information bidirectionally through the LabVIEW DataSocket server in the laptop. Any control modified by the use in the remote application of the laptop will automatically 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 application 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.

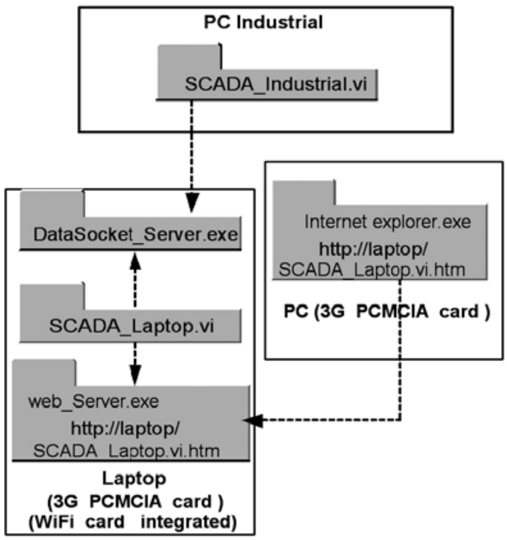

Figure 5. Software System Applications

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.

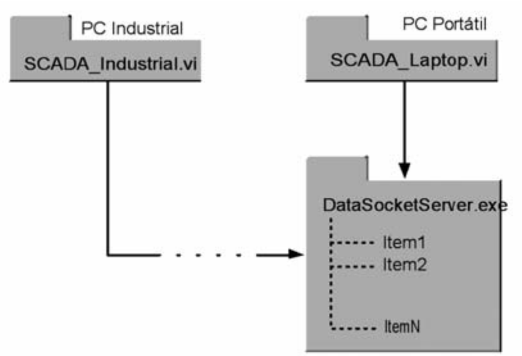

Figure 6. DataSocket communication

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.

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.

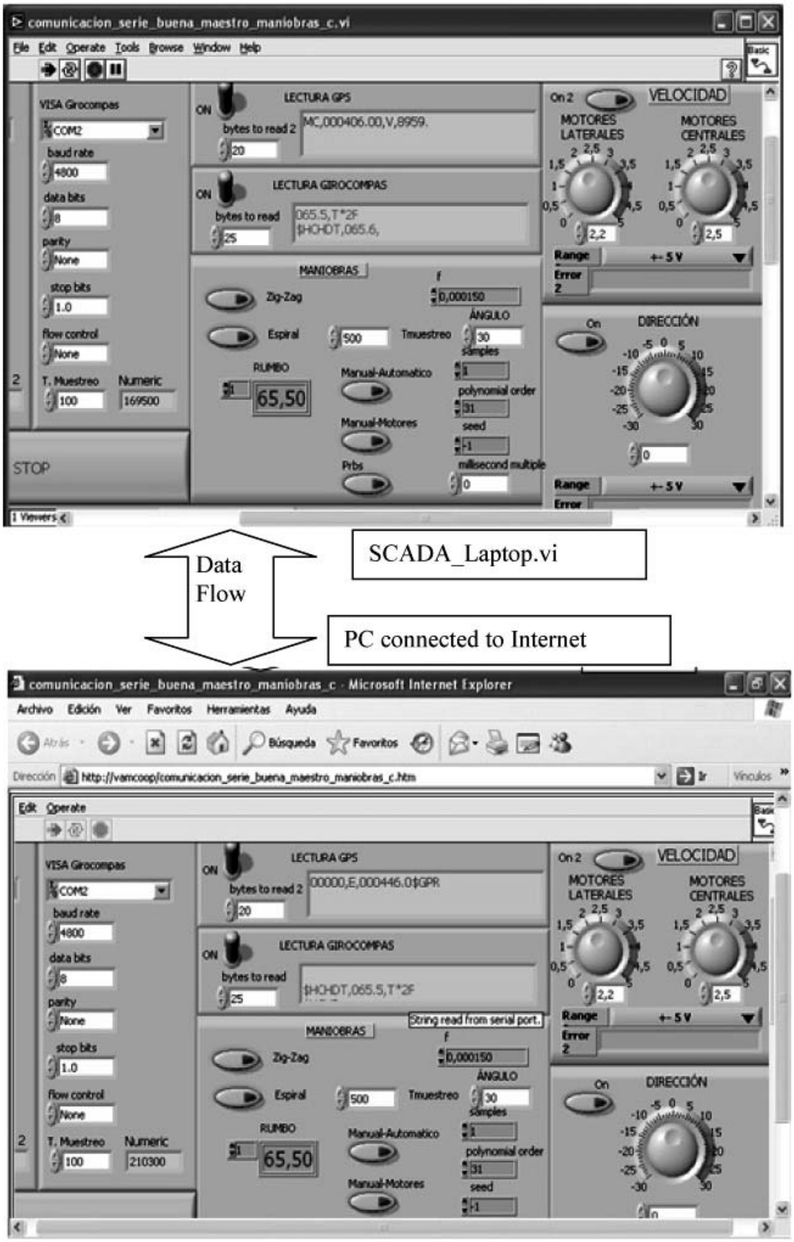

Figure 7. Communication via web between the Industrial PC and the laptop .

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

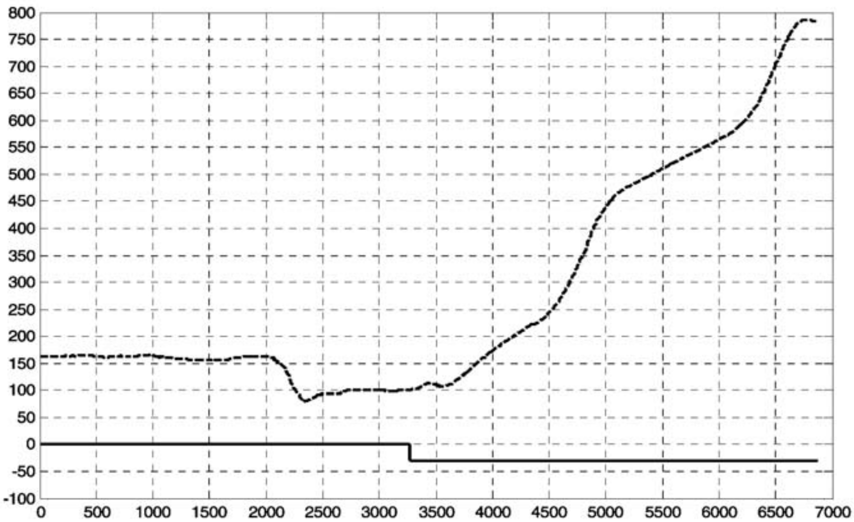

Figure 8. Evolution towards port curve

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.

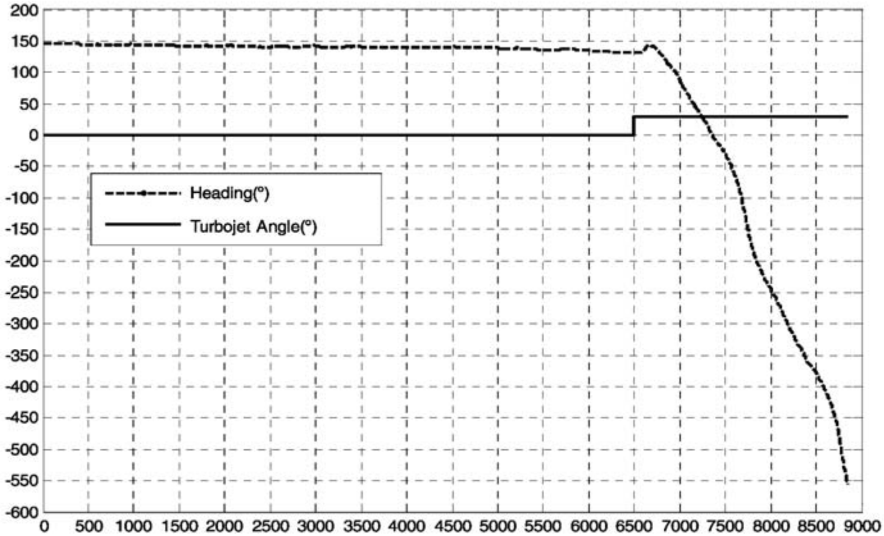

Figure 9. Evolution towards starboard curve

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.

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STUDY IN APPLICATION OF NATURAL LANGUAGE PROCESSING IN MARITIME COMMUNICATIONS

Rosa de la Campa Portela[1], Benigno A. Rodríguez Gómez[2], Mª Carmen Meizoso López[3] and Begoña Rivero Martínez[1]

ABSTRACT

Recent research on maritime accidents done at the School of Nautical Studies at the University of A Coruña (Spain) shows that nearly 20 per cent of accidents in maritime settings have been due to, among other causes, communication problems derived from the lack or misuse of a common language.

Moreover, automatic speech translation, a technology that combines speech recognition and automatic translation, has been for more than a decade the focus of research as a tool for improving communication in different settings.

Similarly, this technology can be applied, to a greater or lesser extent, in communicative processes that take place in the maritime workplace so as to minimise problems stemming from multilingual environments, especially those in which communication takes place via the use of radio devices, in which the inclusion of an automatic translator could enable two people of different nationalities, for example, to communicate with each other in their own native languages. This article describes a system of this type whose feasibility is being studied at the Universidad de A Coruña, under the auspices of a university-financed project called "Language Industries Applied in the Maritime Sector".

What this project seeks, therefore, is to study the legal and technical possibilities, as well as the commercial suitability of developing an automatic translator for oral communications in the maritime sector, and in such a case, to

[1] Departamento de Ciencias de la Navegación y la Tierra. ETS Náutica y Máquinas. Universidad de A Coruña (rosamary@udc.es). [2] Departamento de Ingeniería Industrial. Escuela Universitaria Politécnica. Universidad de A Coruña, Ferrol (benigno@udc.es). [3] Departamento de Ingeniería Industrial. Escuela Universitaria Politécnica. Universidad de A Coruña, Ferrol (mmeizoso@cdf.udc.es)

establish the foundations for such a development, as well as to study the implications that the use of a device with such features would have on maritime safety. Likewise, this project seeks to develop the simulator for learning and using maritime phrases and for the creation of the corresponding curricular material.

Key words: maritime communications, human language technologies, automatic translation, comunicaciones marítimas, tecnologías del lenguaje, traducción automática.

INTRODUCTION

Recently, at the School of Nautical Studies at the University of A Coruña, a statistical study has been conducted on the subject of maritime accidents between 1994 and 2001 (de la Campa, 2003) with the aim of determining a possible relation between communication problems stemming from the lack of or misuse of a common language, and these accidents.

The study's results show that communication problems that stemmed from the language were a leading factor in approximately 20% of maritime accidents.

However, using different risk evaluation techniques and based on the data in the maritime accidents reports, it was determined that the risk of a maritime accident happening due to communication problems stemming from language is at a tolerable level. Hence it seems advisable to establish corrective means that lead to lowering this risk to the lowest possible level. Hence, the School of Nautical Studies at the University of A Coruña has proposed a series of corrective measures that mainly focus on the following points:

— The improvement of the quality of the process of teaching/learning maritime English;

— The use of new technologies, mainly the so-called language industries, in order to improve the communication process in the maritime sector;

— Heightening the awareness of the responsibility of maritime managers in relation to training, contracting and education of multilingual crews, as well as establishing and maintaining an adequate security policy.

This article focuses on the second point mentioned above and endeavours to offer an overall view of the various possibilities that the so-called language industries can offer the maritime industry with the aim of improving security in this sector.

LANGUAGE INDUSTRIES: GENERALALITIES

Computational linguistics is the study of computer systems that are useful for the understanding and generation of natural languages, which based on the language processes enable computers to undertake activities of a linguistic nature (such as translating), process textual data, or make personal access to stored data easier (Grishman, 1986).

Those products, techniques, services or activities which require an automatic treatment of natural language, that is, which use computational linguistics as a resource, but whose aim is not the description of the language, are what is known nowadays as language industries (Cabré, 1993). These language industries mainly proceed from the combination of two fields of study: linguistics and computer science, along with the contribution of other sciences such as engineering, psychology, logic and documentation.

These linguistic products contribute to perfecting the interaction and use of computer systems, to improving the effectiveness of the assimilation, analysis, selection, use and presentation of information, and to making means of generation and translation of natural language available (Oficina del Español en la Sociedad de la Información, 2000).

The products that are most directly useful for the maritime industry are those that are related to automatic translation, teaching, natural language interfaces and speech recognition and reproduction systems.

AUTOMATIC TRANSLATION

According to Hutchins (1986), there have been and are numerous reasons for attempting to achieve automation of the translation process. Perhaps the most important reason is the need to improve univocal communication between specialists from different nationalities, in order to decrease the amount of time it takes to translate technical documents and to increase the number of translations of this type into several languages.

The translation process can be done on any type of text, but automatic translation is more useful when it deals with technical texts, since they usually do not use rhetorical and literary tropes and are limited to well-defined spheres of language, and are characterised by a style that is limited to a series of determined structures.

However, and despite the wide range of methods, all of the automatic translation processes pose problems that are not associated with the technology, but rather with the language. Linguistic problems related to translation are those that deal with lexical ambiguity, syntactic complexity, the difference of vocabulary between languages, and elliptical or incorrect grammar constructions.

These problems can be reduced by implementing certain restrictions on the original text, such as the use of controlled languages by adapting the original texts with constructions and vocabulary that the programme can translate, or by restricting the types of texts by designing programmes for a specific and well defined variety of texts.

With regards to this point, and within the maritime sector, there is the possibility of studying the viability and usefulness of the automatic translation of communication processes based on the use of the Standard Marine Communication Phrases of the IMO, with the aim of avoiding misunderstandings due to, for example, differences in the pronunciation of the English language or to the limited knowledge of these phrases in said language.

NATURAL LANGUAGE PROCESSING

The technology of natural language processing "covers a broad range of activities with the eventual goal of enabling people to communicate with machines using natural communication skills" (Cole, 1997), and includes systems that are able to do speech synthesis processes (automatic generation of speech from a symbolic representation) and speech recognition (speech conversion into a symbolic representation). The latter process, that is, speech recognition, can take place on three different levels: recognition of the language that is being spoken, recognition of the content or meaning of what is being spoken, and recognition of the speaker (Mariani, 1991).

All of these processes could be applied in the medium term to improve activities in the maritime sector. Hence for example, many of the activities that require, during the operation of a ship, man-machine communication processes, could be controlled by voice recognition and/or speaker recognition devices so that they can assure that the orders that are given are understood and executed correctly. Likewise, a device that incorporates automatic translation to speech recognition and synthesis could act as the "interpreter" in operations that require very controlled language and take place in a multilingual environment.

THE PROJECT OF THE SCHOOL OF NAUTICAL STUDIES AT THE UNIVERSITY OF A CORUÑA

Introduction

As we stated before, all of these processes can be applied to a greater or lesser extent in maritime communications, with the goal of minimising the problems that arise from a multilingual environment, especially in those communications that take place via radio devices, in which the inclusion of an automatic translator would enable two people of different nationalities, for example, to communicate with each other in their native tongues. The viability of a system of this type is being studied at the School of Nautical Studies at the University of A Coruña in a project financed by this university, called "Language industries applied to the maritime sector".

This system could be of great value when the messages that are sent have been standardised. Consequently a quality translation and a perfect comprehension are guaranteed.

The development of a translator that can be used commercially requires a high level of "maturity" of the utilised technologies, as well as a state of legality that does not prevent its use. Even if these conditions are not fulfilled, the present state of the technology enables, following the same steps, the development of simulator systems for the learning and use of the standard phrases.

What this project intends, therefore, is to study the legal and technical possibilities, as well as the commercial suitability of developing an automatic translator for oral communication in the maritime sector, and to establish the bases for this development. At the same time we seek to study the implications that the use of a device of such characteristics would have on maritime security. Likewise we wish to pursue the development of the simulator for learning and using maritime phrases and the preparation of the corresponding curricular material. In order to lay the foundation for this study, as well as for the development, it is necessary to make up a list in the form of a database of standard phrases that are commonly used in the marine sector.

The Project's Objectives

The aim of this project is to open up a line of research on the use of ICT [Information and Communication Technologies] in order to improve oral communication processes that use the standard phrases in the maritime sector.

These are the main objectives that have been established:

1. The creation of a digital sound database of standard phrases for maritime communication.
2. The development of a learning support system, as well as of a system of the usage of standard phrases.
3. The study of:
   a) the legal and technical possibilities,
   b) the commercial suitability of the development of an automatic translator for oral communication in the maritime sector,
   c) (if it is fitting) the establishment of the bases of said development, and the implications that the use of a device of such characteristics would have on maritime security.

All of these objectives share stages of development and interact among each other, and thus mutually reinforce each other. The attainment of these objectives would be the result of working on the following specific points:

1. Establish the univocal communication needs in the maritime sector and the implications of these communications on maritime security.
2. Study the International Maritime Organisation's provisions on the establishment of a common language for maritime communications as well as the use of standard vocabulary in such communications.
3. Study the suitability of the development of an automatic translator for maritime communications, taking into account the following:
   a) The legal implications of implementing this system.
   b) The implications on maritime security of the use of this system.

4. Establish the linguistic needs for the development of an automatic translator for maritime communications on the basis of:
   a) The attainment and analysis of genuine spoken samples of ship-to-ship and ship-to-land maritime communications.
   b) The study of genuine standard vocabulary in maritime communication on the basis of collected samples.
   c) The recognition and association between standard and non-standard phrases through the comparative study of collected samples and the standard glossaries issued by the International Maritime Organisation.
5. The development of a system of assessment (simulator) that enables the studying of the technological needs for the development of an automatic translator for maritime communications. This automatic translator will be readapted as a learning support system and as a system of the usage of standard phrases. An analysis of the features will focus on:
   a) The transformation of standard voice-to-text phrases and vice-versa, based on genuine samples, that should determine the rate of accuracy and reliability of the system.
   b) The study of disturbances and possibilities of elimination based on genuine samples.
6. Adaptation as a learning-assistance system and usage of the standard phrases. Preparation of the course
7. The establishment of the equipment needs in order to develop an automatic translator for maritime communications: physical characteristics of the equipment, composition and cost.
8. The study of the commercial prospects of developing such a translator.

Methodology

The current project bases a large part of its content and development on collecting and analysing genuine samples of communications in the maritime sector. These samples should be obtained on site, that is, on board the merchant ships in order to register the genuine ship-to-ship and ship-to-land communications, and in maritime traffic control towers or in other locations for genuine ship-to-land communications.

The presence on board of several members of the research team will be essential. They will be responsible for taking these samples and for beginning to process them.

Then these samples will be immediately analysed linguistically in the laboratory, and used to run different tests on language processing and to eliminate noise.

The conclusions of this analysis, and its comparison with the availability of speech processing technologies, translation, voice synthesis, all of them in real time will enable one to establish the equipment needs for the development of an automatic translator for maritime communications: characteristics of the equipment, composition and cost.

The positive assessment of the technical and legal aspects for the development of the translator, leads to the study of commercial prospects, through the search for companies in the telecommunications sector that are interested in prototyping and undertaking the complete development of the system.

On the other hand, the negative assessment of the technical and/or legal aspects, does not permit a commercial translator in the short term, but it does not impede the development of the learning-assistance simulator system and of the system of usage of standard maritime phrases, developed on a PC and which consists of readapting the translator-assessment system that is complemented by the preparation of curricular materials.

The following is a summary of the work that has been done until now on each point:

1. Establish the univocal communication needs in the maritime sector and the implications of these communications on maritime safety.

The international character of maritime commerce entails getting people from very different nationalities, languages and cultures in contact, who will work efficiently in a complex setting.

The most common way people interact is, without a doubt, through oral communication, which in this environment becomes hindered by the aforementioned coexistence of different nationalities.

Communication on board a ship can take place in the crew members' native tongue, as long as they come from the same country or share a common mother tongue. However, multinational and multilingual crews are more and more usual each time, a factor that obliges ships to establish a common work language for the safe operation of the ship. Knowledge and the ability to use said language must be shared by the entire crew. It is with this aim in mind that English is the language that is chosen in the majority of the cases.

As for the interaction between ships or between these and shore services, English has become the means of communication at sea. As a result, the entire operation of the international maritime industry, safety at sea and the protection of the sea environment, depend in many aspects on the level of knowledge and use of this language. According to Loginovsky (2002), the globalisation of the maritime industry requires sailors to be more highly qualified and to have a higher level of training and certification than previously required. Communication is closely linked to safety nowadays, and communication problems have negative effects not only on the operability of the ship, but also on the social life on board.

We are aware, according to the bibliography consulted, that these communication problems can have several origins, among which the following stand out:

— The crew members' linguistic incompetence, as a result of a low level of English;
— Differences in the level of knowledge of English among the crew members;
— Difficulty to assimilate different accents and understand new and particular forms of English;
— Environmental difficulties that are inherent to this sector, such as voice distortions via VHF, or the high noise level that hinders communication in the engine room.

2. Study the International Maritime Organisation's provisions on the establishment of a common language for maritime communications as well as the use of standard vocabulary in such communications

Despite technological advances in means and procedures to facilitate the exchange of information between ships and between ships and shore services, such advances cannot have the desired positive effect if attention is not paid to the development of the crew members' linguistic skills: "linguistically under qualified officers, either on deck or in the engine room, create a danger to their ships, crews and passengers, to other vessels and to the marine environment" (Trenkner, 1996: 125)

The International Maritime Organisation is, obviously, aware of this situation, and recognising its responsibility with regards to maintaining safe navigation and maritime commerce, they have attempted for many years to improve verbal communication in this sector by championing the standardisation of use at the international level firstly with the approval of the Standard Marine Navigation Vocabulary (SMNV) in 1973, and currently with the renewal and expansion of this vocabulary as a result of the approval in 2001 of Standard Maritime Communication Phrases.

Moreover, with regards to the use of natural language recognition, it is necessary to keep in mind that the positive achievements of this technology are due to, among other things, the use of the so-called "controlled languages" among interlocutors.

These languages stand out mainly because of their simplicity based on the use of a limited vocabulary and the simplification of grammar rules.

In the maritime sector, Standard Maritime Communication Phrases, created by the International Maritime Organisation, fulfil the necessary conditions to be considered a controlled language, and are thus suitable for use in an automatic speech translation system.

3. Study the suitability of the development of an automatic translator for maritime communications.

One of the main objectives of this project is to study the feasibility of the application of new computer technologies and communication in maritime communications, with the aim of improving its effectiveness as well as to highlight the aspects of maritime safety related to these technologies. In this sense we have summarised in this section the findings of a Delphi study undertaken to establish the legal, commercial and technical feasibility of the use of this type of resources, by consulting maritime experts who mainly work professionally in an international communication environment.

From among all the conclusions gathered in this study it is interesting to highlight the following points:

— A large majority of experts agree that oral communication between people of different nationalities can entail a safety problem in the maritime workplace; they also consider that the most problematic communications are those that take place with the exterior: ship-to-ship and ship-to-shore.

— Moreover, general knowledge of English is considered the most problematic area in exterior communications, as differences in pronunciation and accent and knowledge of standardised vocabulary are considered to be factors that are also very problematic in the development of such communications.

— To improve these exterior communications experts insist on the need, above all, to attach greater importance to the teaching of maritime English; they also indicate the need to involve maritime administrators and the appropriate authorities so that they insist upon a minimum level of English from those involved in such communications. The use of a standard international maritime language is highlighted as the third best solution to these communication problems.

— Once a possible design for equipment that would use speech recognition and automatic translation as an aid to exterior oral communications is proposed, almost 70% of the experts would recommend the development of equipment with these features, and 85% would offer to try out the equipment in case such equipment were developed and in a trial period.

— Almost 80% of the experts surveyed would select equipment that is independent of VHF, which in any case could be adapted to it whenever it were necessary.

— As for the more problematic areas that would have to be kept for the proper running of the equipment, the reliability of the voice recognition system and the time taken up for translations are underlined as the most problematic and difficult technical and linguistic impediments to overcome.

— Finally, according to the experts who were surveyed, user friendliness, price and reliability are, in this order, the most important features that are to be kept in mind when deciding on the possibility of acquiring equipment with such characteristics.

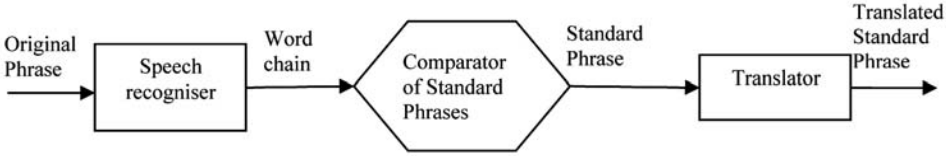
4. The attainment and analysis of genuine spoken samples of ship-to-ship and ship-to-land communications. The study of the genuine use of standard vocabulary in maritime communications based on the collected samples. The recognition and association between standard and non-standard phrases through a comparative study of the collected samples and the International Maritime Organisation's standard vocabulary.

This project bases a large part of its content and development on the gathering and analysis of real samples of communications in the maritime sector. These samples have been obtained in situ, that is to say on board merchant ships in order to register real ship-to-ship and ship-to-shore communications, and in traffic control towers or by means of other devices for real ship-to-land communications.

Up to now almost a hundred conversations have been obtained between ships, and between ships and land services. These have been transferred to a database for further analysis. Finally as well, a comparative analysis is being done of real vocabulary used in these conversations and vocabulary contained in the Standard Maritime Communication Phrases, as well as a study on the use of these phrases in real conversations.

5. The transformation of voice-to-text standard phrases, the study of disturbance and possibilities of elimination based on genuine samples. The transformation of text-to-voice standard phrases

We see our simulator as a system that links several sequential processes, in such a way that taking as the point of entry a phrase said by a speaker in his or her native tongue (Spanish in this case), it transforms it into a standardised phrase in meta(English), as shown in Graphic 1.



Graphic 1: sequential processes of simulator

Our aim is to assess current technologies in order to verify the reliability of the entire process. To this end we initially assessed each one of the stages in an independent manner:

a) Speech recogniser; even though our problem is limited to a controlled language, we selected a commercial application for continuous language recognition with an extensive vocabulary, Dragon Naturally Speaking version 8. This processor requires the speaker to receive training. In order for the application to run under optimum conditions after the initial training period, the speaker was given the specific vocabulary of standard phrases, and the group of phrases as a model of the language. Under these conditions the rate of accuracy in the recognition of phrases in continuous flow was approximately 97%. It must be noted that the processor shows a preference for a particular type of speaker during the training phase, and the required signal/noise ratio is very high.

b) Comparator with standard phrases; this module takes the word chain provided by the Recogniser, and establishes the similarity with the group of standard phrases, choosing from among these the one that is closest to the word chain. This module is in the development stage; until now the frequency of each word of the vocabulary has been established as well as the concordance between groups of words; these parameters allow for the reconstruction of a standard phrase starting from some of its elements, and thus they make it unnecessary for the word chain to be exactly the same as a particular standard phrase. What remains to be done for the complete development of the module is to add the work on the groups of real conversations, which are already at our disposal but have not yet been sufficiently processed.

c) Translator; this element is not difficult to develop since the translation is not real, but rather once the comparator identifies a standard phrase in any language, its translation into any other language is basically a matter of a consultation or a group of consultations (if the phrase contains variables) of a database.

The assessment of the state of the technology in order to undertake the proposed development is the following: The voice recognition system that is dependent upon the speaker in low noise conditions is sufficiently developed in order to undertake the recognition of standard maritime communication phrases.

It is now necessary to continue the study on the following points:

— Noise conditions
— The sturdiness of the recognition in the presence of noise
— The strategies of noise filtration (conventional or adapted)
— The similarity between used and standard phrases

We have assumed as significant sources of error the following: the speaker's use of non-standard phrases, and the errors made by the speech recogniser module, due either to surrounding noise that cannot be eliminated or to other causes.

The elimination of the aforementioned errors should take place in two ways: a technological solution involving the development of an efficient filtering system, and also the creation of a comparator module that would maximise the rate of accuracy in the selection of standard phrases; the second means is educational in nature as the officers who are involved in the communications should know and be able to use standard phrases correctly, according to the IMO's recommendations.

6. Adaptation as a learning-assistance system and usage of the standard phrases. Preparation of the course

With regards to the teaching of Standard Phrases, which is the area that interests us the most in terms of the objectives of this research, the IMO's own resolution (2001) indicates the following points of reference:

— The objective of Standard Phrases is not to provide a detailed study plan of maritime English.
— Part A should be an essential element of any type of curriculum designed to fulfil the requirements of training Agreement 78/95
— Standard Phrases are to be taught and learned in a selected way, according to the specific needs of the user, and not as a whole.
— Teaching should be based on common practices in the maritime sector and should be imparted in accordance with modern methods of language learning that are considered to be appropriate.

Moreover, keeping the second point in mind, in which Standard Phrases were considered to be a controlled language, suitable for use in the automatic translation process, it is important to indicate that with regards to the learning and teaching of controlled languages, as noted by Mitamura (1999), in order for the use of a controlled language to be successful, it is critical that the users be able to accept the notion of a controlled language, and that they be willing to receive training in the controlled language in question.

According to this author, it seems that the users who are trained and use the controlled language habitually attain better results and a higher level of communicative productivity.

Thus the need to establish appropriate training methodologies in the use of Standard Phrases becomes clear in order to comply with the International Maritime Organisation's regulations and also as a provision for the use of these phrases as a controlled language of maritime communications which is subject to being processed by recognition and speech translation equipment.

We have therefore dedicated this point to studying several of the methodologies that are used nowadays in the teaching of English in the maritime sector, which can be used, and in fact some of them are being used to teach the IMO's Standard Phrases, and which use, furthermore, the new information and communication technologies as a teaching tool in order to follow the Organisation's recommendation in relation to appropriate and modern teaching methods.

7. The establishment of equipment needs for the development of an automatic translator for maritime communications: equipment characteristics, composition and cost.

The type of communication that our research focuses on is done with VHF and VHF-DSC (Digital Selective Calling) equipment. The equipment that we propose as the final product must, necessarily, respect the specifications of these types of equipment, not impede their use and be activated upon the operator's request.

Given the current state of technological development, a simple solution is a PC built-in to the VHF equipment itself, while the external aspect of the system would include a feedback screen for the user so that he or she can be aware of the information that is being transmitted when using the automatic translation, or could even be informed that he or she should desist from using this mode.

This equipment will permit sending synthesised voice with the standard phrase and will also be able to emit a digital code that will enable receiving equipment of similar characteristics to recognise the phrase directly.

A more efficient solution could be the development of a processing card with a DSP as a nucleus of the same card.

Another one of the needs that has to be evaluated in terms of noise is the incorporation of a multi-microphone system that allows for an adaptable filtration in order to improve the signal/noise ratio.

8. The study of the commercial prospects of developing the translator.

During this first year of the development of this project, contact has been made with Arteixo Telecom, which after having shown interest in the development of the equipment is presently assessing the feasibility of its commercialisation. We trust their judgment, given the implementation of their equipment in the naval sector, even if until now they have focused on developments for the Fishing sector and the Navy.

At this point one might think of multiple scenarios, but we shall only consider two assuming that the rest are variations of these.

A technologically favourable scenario: If the development of this equipment is possible, this situation should be faced with the legal scenario: What bodies should approve the use of such type of equipment? We must not forget that its usage will take place in an international setting. This undoubtedly generates a significant delay between the technological availability and the possibility of using it.

A technologically unfavourable scenario: It is not possible with the current state of technology to create equipment with the appropriate characteristics. The eventual increase of features will make this scenario evolve towards the aforementioned situation. In this case the technological and legal delays can overlap, if we begin to work immediately on the latter aspect. In any case it is foreseeable that the delay due to legal restrictions will always be greater than due to technological reasons, because while the product is not available one cannot assess its effect on maritime security, which is the ultimate objective.

Either of the two scenarios leads to a similar situation, that is, the fact that the product will not be ready immediately; however given the fact that the possibility of creation has been proven, the development depends on the industrial's sector involvement. Thus, in the last part of the project and once the results of the prior stages have been evaluated, telecommunication companies will be contacted, especially those that are involved, or wish to be involved, in the maritime sector, to assess the possibility of collaboration and development.

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APLICACIÓN PARA PROCESAR EL LENGUAJE NATURAL EN LAS COMUNICACIONES MARÍTIMAS

RESUMEN

Un reciente estudio sobre accidentes marítimos llevado a cabo desde la Escuela Técnica Superior de Náutica y Máquinas de la Universidad de A Coruña, muestra que cerca de un 20% de los accidentes en el ámbito marítimo han sido debidos, entre otras causas, a problemas de comunicación derivados de la falta o mal uso de una lengua común.

Por otro lado, hace más de una década que la traducción automática del habla, tecnología que combina el reconocimiento del habla y la traducción automática, es objeto de investigación como herramienta para la mejora de las comunicaciones en diversos ámbitos.

Esta tecnología puede ser aplicada, de igual forma, en mayor o menor medida en los procesos comunicativos que tienen lugar en el ámbito marítimo con el fin de minimizar los problemas derivados de los ambientes multilingües, especialmente aquellos en que las comunicaciones tienen lugar mediante el uso de aparatos de radio, donde la inclusión de un traductor automático podría permitir a dos personas de diferente nacionalidad, por ejemplo, comunicarse entre ellos en sus lenguas nativas. El siguiente artículo nos describe un sistema de este tipo cuya viabilidad está siendo estudiada en la Universidad de A Coruña, al amparo de un proyecto financiado por dicha universidad denominado "Las industrias de la lengua aplicadas al ámbito marítimo".

Lo que el mencionado proyecto pretende, por lo tanto, es estudiar las posibilidades legales y técnicas, así como la conveniencia comercial del desarrollo de un traductor automático para las comunicaciones orales en el ámbito marítimo, y en su caso, establecer las bases de dicho desarrollo, a la vez que estudiar las implicaciones que sobre la seguridad marítima tiene el uso de un dispositivo de tales características. Igualmente se persigue el desarrollo del simulador para el aprendizaje y uso de las frases marítimas y la elaboración del material curricular correspondiente.

INTRODUCCIÓN

Recientemente, en la Escuela Técnica Superior de Náutica y Máquinas de la Universidad de A Coruña, se ha llevado a cabo un estudio estadístico sobre accidentes marítimos acaecidos entre los años 1994 y 2001 con el fin de determinar una posible relación entre los problemas comunicativos derivados de la falta o mal uso de una lengua común y dichos accidentes.

Los resultados obtenidos de tal estudio indican que, en aproximadamente un 20% de los accidentes marítimos, los problemas comunicativos derivados del lenguaje fueron un factor desencadenante.

Por otro lado, mediante el uso de diversas técnicas de evaluación de riesgos y basándose en los datos obtenidos de los informes sobre accidentes marítimos mencionados, se determinó que el riesgo de ocurrencia de un accidente marítimo debido a problemas comunicativos derivados de la lengua se encuentra en un nivel tolerable, por lo que parece recomendable el establecimiento de medidas correctoras que conlleven la disminución de dicho riesgo al mínimo nivel posible.

Así pues, y desde la propia Universidad de A Coruña, se han propuesto una serie de acciones correctoras centradas principalmente en los siguientes puntos:

- La mejora en la calidad del proceso enseñanza/aprendizaje de inglés marítimo.
- La utilización de las nuevas tecnologías, principalmente aquellas denominadas industrias de la lengua, para la mejora del proceso comunicativo en el ámbito marítimo.
- La exaltación y concienciación sobre la responsabilidad de los gestores marítimos en cuanto a la formación, contratación y educación de tripulaciones multilingües, así como sobre el establecimiento y mantenimiento de una adecuada política de seguridad.

El presente artículo se centra en el segundo de los puntos arriba indicados y pretende presentar una visión global de las varias posibilidades que las llamadas industrias de la lengua pueden ofrecer a la industria marítima con el fin de mejorar la seguridad en este ámbito.

OBJETIVOS

La tecnología del procesamiento del lenguaje natural cubre un amplio rango de actividades cuyo propósito es permitir a las personas comunicarse con las máquinas usando las habilidades propias de la comunicación natural, e incluye los sistemas capaces de realizar los procesos de síntesis del habla (generación automática del habla a partir de una representación simbólica) y reconocimiento del habla (conversión del habla en una representación simbólica). Este último proceso, el reconocimiento del habla, puede llevarse a cabo en tres niveles diferentes: reconocimiento de la lengua en la que se habla, reconocimiento del contenido o significado de lo que se habla, y reconocimiento del hablante.

Todos estos procesos podrían aplicarse, en un plazo de tiempo medio, en la mejora de las actividades en el ámbito marítimo. Así por ejemplo, muchas de las actividades que requieren, durante la operación del buque, procesos comunicativos hombre-máquina, podrían ser controladas mediante dispositivos de reconocimiento de la voz y/o reconocimiento del hablante, de manera que aseguren que las órdenes dictadas son correctamente entendidas y ejecutadas.

De la misma forma, un dispositivo que incorpore la traducción automática al reconocimiento y síntesis del habla podría realizar la función de "intérprete" en operaciones que requieran un lenguaje muy controlado y se desarrollen en un ambiente multilingüe.

Así mismo la aplicación de estos procesos a las comunicaciones marítimas permitirían minimizar los problemas surgidos por la multilingualidad del ámbito, sobre todo en aquellas comunicaciones que se realizan a través de aparatos de radio, en los que la inclusión de un traductor automático permitiría, por ejemplo, que dos personas de nacionalidades diferentes se comunicasen en sus lenguas nativas. La viabilidad de un sistema de este tipo está siendo estudiada desde la Escuela Técnica Superior de Náutica y Máquinas de la Universidad de A Coruña, a través de la realización de un proyecto financiado por dicha Universidad, denominado "Las industrias de la legua aplicadas al ámbito marítimo".

Este sistema podría ser de gran utilidad cuando los mensajes que se emiten se encuentran normalizados. De esta forma se garantiza una traducción de calidad y un entendimiento perfecto.

El desarrollo de un traductor utilizable comercialmente requiere un grado elevado de "madurez" de las tecnologías empleadas, así cómo un estado de legalidad que no imposibilite su uso. Aún cuando estas condiciones no se cumpliesen, el estado actual de la tecnología permite, siguiendo los mismos pasos, el desarrollo de sistemas simuladores para el aprendizaje y uso de las frases normalizadas

Lo que dicho proyecto pretende, por lo tanto, es estudiar las posibilidades legales y técnicas, así como la conveniencia comercial del desarrollo de un traductor automático para las comunicaciones orales en el ámbito marítimo, y en su caso, establecer las bases de dicho desarrollo, a la vez que estudiar las implicaciones que sobre la seguridad marítima tendría el uso de un dispositivo de tales características. Igualmente se persigue el desarrollo del simulador para el aprendizaje y uso de las frases marítimas y la elaboración del material curricular correspondiente. Para sentar la base tanto del estudio, como del desarrollo es necesario efectuar el registro, en una base de datos, de frases normalizadas en su forma habitual de uso en el medio marino.

METODOLOGÍA

El mencionado proyecto basa gran parte de su contenido y desarrollo en la toma y análisis de muestras reales sobre comunicaciones en el ámbito marítimo. Estas muestras deberán ser obtenidas in situ, es decir a bordo de buques mercantes para el registro de comunicaciones reales buque-buque y buque-tierra, y en torres de control de tráfico marítimo u otros dispositivos para las comunicaciones reales buque-tierra.

Será imprescindible la presencia a bordo de varios miembros del equipo investigador, que se encargarán de tomar dichas muestras y realizar un primer tratamiento informático de las mismas.

Seguidamente estas muestras serán analizadas lingüísticamente en el laboratorio, y utilizadas para realizar las diversas pruebas sobre procesamiento del lenguaje y supresión de perturbaciones.

Las conclusiones de este análisis, y su comparación con la disponibilidad de tecnologías de procesamiento del habla, traducción y síntesis de voz, todas ellas en tiempo real permitirán establecer las necesidades de equipamiento para el desarrollo de un traductor automático para las comunicaciones marítimas: características del equipo, composición y coste.

La evaluación positiva de los aspectos técnicos y legales para el desarrollo del traductor, conduce al estudio de las perspectivas comerciales, a través de la búsqueda de empresas del sector de las telecomunicaciones interesadas en prototipar y llevar a cabo el desarrollo completo del sistema.

Por el contrario la evaluación negativa de los aspectos técnicos y/o legales, no permite el desarrollo a corto plazo de un traductor comercial, pero no impide el desarrollo del sistema simulador de ayuda al aprendizaje y uso de las frases marítimas normalizadas, desarrollado sobre un entorno PC y consistente en la readaptación del sistema de evaluación del traductor que se complementa con la elaboración de materiales curriculares.

ESTADO ACTUAL DE PROYECTO

En el momento de redacción de este artículo el proyecto se encontraba en la siguiente fase:

Han sido completados un estudio sobre las particularidades de las comunicaciones externas en el ámbito marítimo y la realización de un cuestionario Delphi o panel de expertos, para determinar las opiniones y sugerencias de los destinatarios finales de esta tecnología, sobre la viabilidad de su desarrollo y posterior utilización, así como sobre las implicaciones en la seguridad marítima que el uso de tal equipo conllevaría.

Se ha realizado un estudio de las Frases Normalizadas de la OMI para las comunicaciones marítimas. Este estudio refleja las posibilidades de uso de estas frases como "lenguaje controlado" válido para la facilitación de la traducción automática. Así mismo se realiza un análisis probabilística exhaustivo de estas frases con ayuda de la herramienta WordSmith Tools, que nos ha permitido, entre otras cosas, conocer la probabilidad de uso de los términos contenidos en dichas frases.

Muestras reales están siendo obtenidas en distintos puntos y analizadas simultáneamente. En este punto se está realizando el entrenamiento del software de reconocimiento de voz "Dragon Naturally Speaking".

El desarrollo de un sistema de evaluación(simulador) que permita el estudio de las necesidades tecnológicas para el diseño de un traductor automático para las comunicaciones marítimas se encuentra igualmente en fase de desarrollo, para lo cual se está utilizando la herramienta de ayuda al aprendizaje "Lingus".

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A CONTROLLER DESIGN BY QFT METHODOLOGY FOR DYNAMIC POSITIONING OF A MOORED PLATFORM

R. Muñoz Mansilla[1], J. Aranda Almansa[1], J. M. Díaz Martínez[1], S. Dormido Canto[1] and D. Chaos[1]

Abstract

An analysis and design of a dynamic positioning system for a moored floating platform has been carried out. The model of the platform is a single degree of freedom SIMO system. The goal is to minimize the drift resulting from the wave action by appropriate thrusters control. An interesting question is that the plant has less degree of freedom for actuation and is more difficult to control. The multivariable QFT robust control technique for underactuated systems is employed. The problem is solved by an iterative multi-stage sequential procedure. It is shown that the control achieves the positioning system.

Key words: positioning system, robust control, multivariable control, stability, Nichols chart.

INTRODUCTION

Control of underactuated systems is a typical problem in marine systems. So, problems of tracking, point stabilization or path following for some kind of marine vehicles or dynamic positioning for offshore systems are examples of these types of problems.

In this work we analyse the use of a multivariable QFT design method for underactuated systems. The method is applied to a moored floating platform model. The model is a single-input/multi-output (SIMO) linear time invariant (LTI) system with a single degree of freedom.

1 Universidad Nacional Española a Distancia (UNED).

This system has been examined and analysed in the specialized literature, in which is possible to find several robust control methods. For example, (Scherer, *et al.*, 1997) presents an overview of a linear matrix inequality (LMI) approach to the multiobjective synthesis of linear output-feedback controllers. A multiobjective H_2/H_∞ is proposed to specify the closed-loop objectives in terms of a common Lyapunov function.

In Revilla (2005), this system is used to validate the results obtained in the study about synthesis of reduced-order controllers based on LMI optimization.

In Nakamura, *et al.* (2001) the problem was formulated in the framework of a multimodel-based design of the H_∞ control law with pole region constraints. Methodology based on LMI was used to solve the problem.

QFT (Quantitative Feedback Theory) (Horowitz, 1992, Yaniv, 1999, Borguesani, *et al.*, 1995, Houpis *et al.*, 2006) is a frequency domain design methodology that has not been very common in naval systems. Our group has applied this technique in the fast ferries stabilization problem (Aranda, *et al.*, 2005) with successful experimental results, and in addition it has been developed an interactive computer-aided control tool (Díaz, *et al.*, 2005a, b).

The objective of this work is to verify that this technique can be extended to underactuated systems, and to show the results obtained in the application of a typical dynamic positioning problem.

MODEL OF THE PLATFORM SYSTEM

The system consists of a floating platform that is anchored to the bottom of the ocean and equipped with two thrusters, as it is showed in Fig. 1 (the model of a replica of this system and previous control is described in Kajiwara, *et al.* (1995). The objective is achieving an appropriate thrusters control in order to minimize the drift *Y* resulting from the wave action.

The action from the wave is considered as a force F and a torque M. The force F consists of two components $F = F_1 + F_2$ with the following characteristics:

— F_1 is a high-frequency high-amplitude excitation with small drifting effects. Due to its large magnitude, it can not be countered by the thrusters. The spectral energy of F_1 is beyond 5 rad/s.

— F_2 is a low-frequency low-amplitude excitation that can cause a large drift. This drifting action has to be eliminated by thrusters control. The spectral energy of F_2 is concentrated between 0 and 1 rad/s.

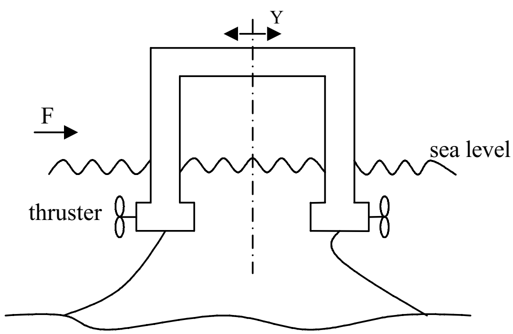

Fig.1. Moored floating platform.

The model of the system has two outputs y (the horizontal drift Y and angular deviation from the vertical axis ϕ), one control input u (the force delivered by the thrusters F_u) and two disturbance inputs d (the force F and the torque M from the wave action). Therefore a single degree of freedom (DOF) SIMO system is presented, with one single input F_u and two outputs (Y,ϕ).

The platform dynamics are described by state-space equations (1).

$$\dot{x} = Ax + B\begin{pmatrix} F \\ M \\ F_u \end{pmatrix} \quad \begin{pmatrix} Y \\ \phi \end{pmatrix} = Cx \tag{1}$$

where A, B, C are:

$$A = \begin{pmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ -0.1010 & -0.1681 & -0.04564 & -0.01075 \\ 0.06082 & -2.1407 & -0.05578 & -0.1273 \end{pmatrix};$$
$$B = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0.1179 & 0.1441 & 0.1476 \\ 0.1441 & 1.7057 & -0.7557 \end{pmatrix}; C = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{pmatrix} \tag{2}$$

In addition, the dynamic of the thrusters are modelled by the first-order transfer function $G_{act}(s)$:

$$F_u = G_{act}(s)u \qquad G_{act}(s) = \frac{1}{0.7s+1} \tag{3}$$

where u is the control input and F_u the actual force delivered by the thrusters.

ROBUST CONTROL PROBLEM FORMULATION

The control objectives are:

— Reduce the drifting action F_2 by using the actuators control.
— Maintain the horizontal drift $|Y| < 0.025$m.
— Maintain the angular deviation $|\phi| < 3$ degrees.
— Keep $|F_u| < 0.25$ N.
— Make sure that the thrusters have no response to the high-frequency component F_1.

For design purposes, the system transfer function can be described as:

$$y = P_{plant}(s)\cdot u + P_d(s)\cdot d$$
$$u = -G_{control}(s)\cdot y \quad (4)$$

where $P_{plant}(s)$ is a transfer functions matrix (2x1) that connects the input *u* with the output *y*, and $P_d(s)$ is a transfer functions matrix (2x2) that connects the disturbance *d* with the output *y*. The control structure is displayed schematically in Fig. 2.

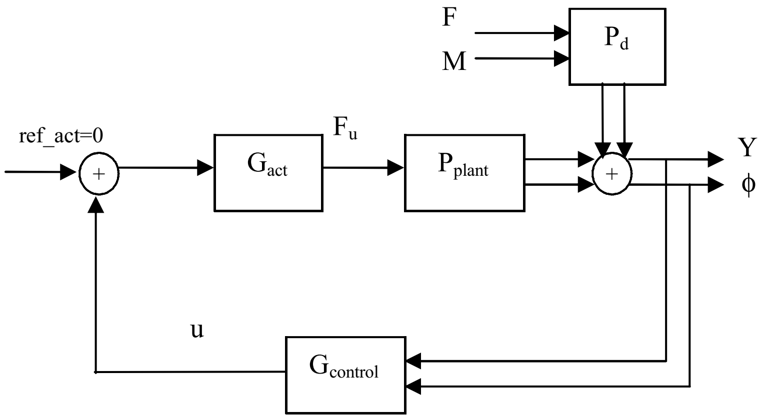

Fig. 2. Single DOF SIMO system with disturbances at the plant's output.

The equation (4) is described in explicit form in (5).

$$\begin{pmatrix} Y \\ \phi \end{pmatrix} = \begin{pmatrix} p_{13}(s)\cdot G_{act}(s) \\ p_{23}(s)\cdot G_{act}(s) \end{pmatrix}\cdot u + \begin{pmatrix} p_{11} & p_{12} \\ p_{21} & p_{22} \end{pmatrix}\begin{pmatrix} F \\ M \end{pmatrix}$$
$$u = -G_{control}\cdot\begin{pmatrix} Y \\ \phi \end{pmatrix} \quad (5)$$

Once the equations of the system are formulated the control problem is how to design the controller, $G_{control}$ such that it simultaneously

— Stabilizes the plant P_{plant} and

— Decreases the plant output due to disturbances, i.e, for all *d*, the plant output $y=[Y,\phi]^T$ is bounded by

$$\left|Y(t)\right| \le e_1(t) = 0.025m$$
$$\left|\phi(t)\right| \le e_2(t) = 3^o \quad (6)$$

An interesting question is added to the position control design because the plant has less degree of freedom for actuation, that is, it is an underactuated system, and is more difficult to control.

Taking into account all this, the challenge is to study the effectiveness of the QFT technique to accomplish the dynamic positioning of an underactuated system.

DEVELOPMENT OF THE QFT DESIGN PROBLEM

QFT is a frequency domain design methodology introduced by Horowitz (1992). The foundation of QFT is the fact that feedback is principally needed when the plant is uncertain and/or there are disturbances acting on the plant. Therefore, the feedback control of the platform is a good example for using QFT technique, because the system presents output disturbances (the seaway).

The QFT design procedure involves three basic steps:

— Computation of QFT bounds,
— Design of the controller (loop shaping), and
— Analysis of the design.

QFT converts close-loop magnitude specifications into magnitude constraints on a nominal open-loop function (QFT bounds). A nominal open-loop function is then designed to simultaneously satisfy its constraints as well as to achieve nominal closed-loop stability (loop shaping). It is defined the open-loop function $L(j\omega)$ as the product of the controller transfer function and the plant transfer function.

$$L(j\omega) = G_{control}(j\omega) \cdot P_{plant}(j\omega) \tag{7}$$

In any QFT design, it is necessary to select a frequency array for computing bounds. In the case of the platform plant, the range of frequencies that belongs to the seaway spectrum will be $\omega \in [0.1, 10]$.

When the QFT designed is completed, it is necessary an analysis of the closed-loop response at frequencies other than those used for computing bounds.

Formulating frequency domain specifications. QFT bounds.

The specifications must be given in terms of frequency response. For the particular case of the design of the dynamic positioning system for the moored platform model, the specifications (6) are given in temporal domain. Therefore, it is necessary to translate these constraints into frequency domain specifications. The QFT specifications used are: the gain and phase margins stability (8), the output disturbance rejection (9) and the control effort (10):

— Gain and phase margins stability

$$\left| \frac{G_{plant} G_{control}}{1 + G_{plant} G_{control}} \right| \leq W_{s1} \tag{8}$$

— Sensitivity reduction

$$\left| \frac{1}{1 + G_{plant} G_{control}} \right| \leq Ws_2 \tag{9}$$

— Control effort

$$\left| \frac{G_{control}}{1 + G_{plant} G_{control}} \right| \leq Ws_3 \tag{10}$$

In Nichols chart, the stability type problem results in bounds about the critical point where the loop response must remain outside the bounds. Sensivity reduction type problems result in bounds about the origin, where the loop response must remain outside the bounds. Control effort type problems result in bounds about the origin where the loop response must remain inside the bounds.

Design of the controller. Loop shaping.

The control law of the system in Fig. 2 is:

$$u = -G_{control} \cdot \begin{pmatrix} Y \\ \phi \end{pmatrix} = -\begin{pmatrix} k_1 & k_2 \end{pmatrix} \cdot \begin{pmatrix} Y \\ \phi \end{pmatrix} \tag{11}$$

Resolving equation (4)

$$\left(P_{plant}^{-1} + G_{control} \right) \cdot y = P_{plant}^{-1} \cdot P_d \cdot d \tag{12}$$

Using the notation $P_{plant}^{-1} = \begin{pmatrix} \pi_{13} & \pi_{23} \end{pmatrix}$, equation (12) is solved as

$$\begin{aligned} &(\pi_{13} + k_1) \cdot Y + (\pi_{23} + k_2) \cdot \phi = \\ &= (\pi_{13} p_{11} + \pi_{23} p_{21}) \cdot F + (\pi_{13} p_{12} + \pi_{23} p_{22}) \cdot M \end{aligned} \tag{13}$$

The design process is based on this equation which depicts the SIMO system of Fig. 2 with one input and two outputs. The equation presents two unknown quantities (the controllers k_1 and k_2). In this way, the problem of the controllers design is solved by a multi-stage procedure by transforming the problem into the design of two sequential SISO systems, as follows:

First stage. State initially k_2=0. From equation (13) and specification e_1 (6), k_1 must be designed such that

$$|Y| = \frac{|\pi_{13} p_{11} F + \pi_{23} p_{12} M| + |\pi_{23}| e_2}{|\pi_{13} + k_1|} \le e_1, \quad \forall\, \mathrm{d} = [\mathrm{F}, \mathrm{M}]^T \in \{\mathrm{d}\} \tag{14}$$

Hence, a first SISO problem is set out. The single DOF SISO system is shown in Fig. 3. The transfer function k_1 is designed such that:

— The system must be stable, and

— For all $d=[F,M]^T$ the plant output is bounded by $|Y(\omega)| \le |e_1(\omega)|$, where $|d| \le |\pi_{13} \cdot p_{11} \cdot F + \pi_{23} p_{12} \cdot M| + |\pi_{23}| e_2$.

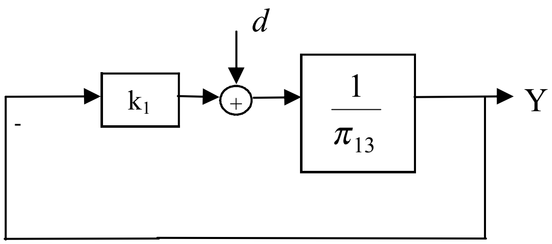

Fig. 3. The SISO feedback system to be solved in the design of k_1.

Second stage. Once k_1 is designed, again from the equation (13) and specification e_2 (6), k_2 is design to satisfy

$$|\phi| = \frac{|\pi_{13} p_{11} F + \pi_{23} p_{12} M| + |(\pi_{13} + k_1) e_1|}{|\pi_{23} + k_2|} \le e_2, \quad \forall\, \mathrm{d} = [\mathrm{F}, \mathrm{M}]^T \in \{\mathrm{d}\} \tag{15}$$

The second single DOF SISO system is set out (Fig. 4). The transfer function k_2 is designed such that:

— the system must be stable and

— for all $d=[F,M]^T$ the plant output is bounded by $|\phi(\omega)| \le |e_2(\omega)|$, where $|d| \le |\pi_{13} \cdot p_{11} \cdot F + \pi_{23} p_{12} \cdot M| + |\pi_{13} + k_1| e_1$.

Third stage. From the result of k_2, a new control k_1 is re-designed for the first SISO system, such that it satisfies

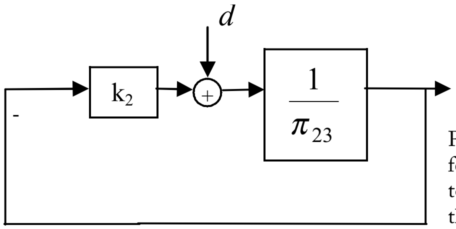

Fig. 4. The SISO feedback system to be solved in the design of k_2.

$$|Y| = \frac{|\pi_{13} p_{11} F + \pi_{23} p_{12} M| + |\pi_{23} + k_2| e_2}{|\pi_{13} + k_1|} \leq e_1, \tag{16}$$

$$\forall\, \mathrm{d} = [\mathrm{F}, \mathrm{M}]^T \in \{\mathrm{d}\}$$

i-stage. The second and third stages repeat successively up to the controllers k_1 and k_2 meet the objectives for the SIMO system in Fig. 2 and the specifications (6).

Thus, the problem is solved by an iterative multi-stage sequential procedure. The idea is schematically depicted in Fig. 6.

For each stage and consequently, for each SISO system, once stability and performance bounds have been computed, the next step in a QFT procedure involves the design (loop shaping) of a nominal function that meets its bounds. The nominal loop $L(j\omega)$ has to satisfy the worst case of all bounds. The MATLAB toolbox includes an interactive design enviroment.

Analysis of the design

Once the controller parameters are designed by using QFT design, the system in closed loop dynamic (Fig. 2) is simulated in order to prove if the control meets the specifications.

RESULTS

According to the methodology explained, finally the control design procedure was completed in five stages.

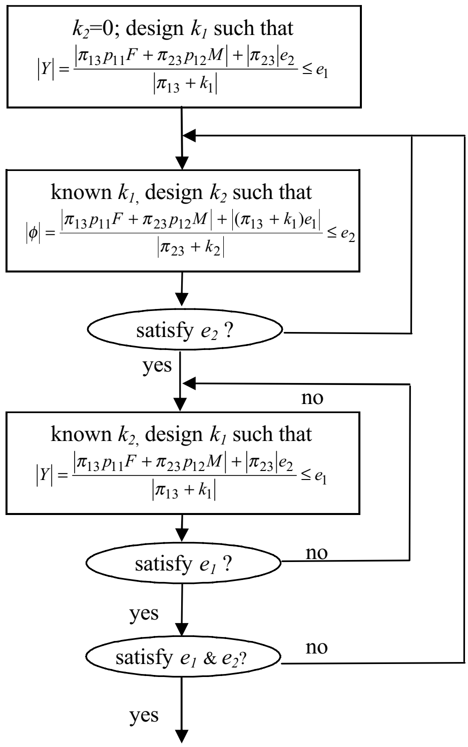

Fig. 6. Scheme of design.

In this work it is shown the results of the QFT design of the two last stages in which the definitive controller (k_1,k_2) is determined. Specifically, the fourth stage corresponds to the k_2 design, and the fifth stage to k_1 design. Finally, simulations of the system in closed loop are tried in order to examine if the positioning system is achieved. Thus, temporal responses are shown.

Design of the controller k_2. Fourth stage.

Robust Stability and Performance Bounds. The specifications fixed for QFT design for the second SISO system in Fig. 4 are:

— Gain and phase marginsW_{s1}= 2.8,
— Sensivity reduction W_{s2}= 3,
— Control effort W_{s3} = 15.

These specifications guarantee adequate gain margins, sensitivity and control effort.

Control design. The control k_2 must be designed such that open loop function $L_2(j\omega)$:

$$L_2 = G_{control} \cdot P_{plant} = k_2 \cdot 1/\pi_{23} \tag{17}$$

satisfies the worst case of all bounds (intersection). The controller designed (18) is a second order filter, with 2 poles and 2 zeros.

$$k_2(s) = \frac{\left(\frac{1}{0.26^2}s^2 + \frac{2\cdot 0.02}{0.26}s + 1\right)}{\left(\frac{1}{2.4^2}s^2 + \frac{2\cdot 0.7}{2.4}s + 1\right)} \tag{18}$$

Figure 7 shows the Nichols chart of the open-loop function $L_2(j\omega)$ with the given specifications. It is shown that this controller accomplishes the specifications.

Design of the controller k_1. Fifth stage

Robust Stability and Performance Bounds. The specifications fixed for QFT design for the first SISO system in Fig. 3 are:

— Gain and phase marginsW_{s1}= 3,
— Sensivity reduction W_{s2}= 3,
— Control effort W_{s3} = 15.

These specifications guarantee adequate gain margins, sensitivity and control effort.

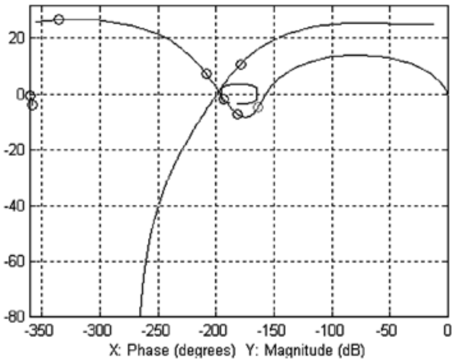

Fig. 7. Nominal open loop function *L2(jw)* and intersection of all bounds, for second SISO system.

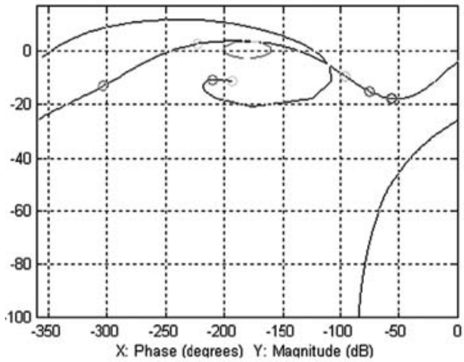

Fig. 8. Nominal open loop function *L1(jw)* and intersection of all bounds, for first SISO system.

Control design. The control k_1 must be designed such that open loop function $L_1(j\omega)$ satisfies the worst case of all bounds (intersection).

$$L_1 = G_{control} \cdot P_{plant} = k_1 \cdot 1/\pi_{13} \tag{19}$$

The controller designed (20) is a first order filter, with 1 pole and 1 zero. Figure 8 shows the Nichols chart of the open-loop function $L_1(j\omega)$ with the given specifications. It is shown that this controller meets the specifications.

$$k_1(s) = -0.28 \cdot \frac{\left(\frac{1}{0.52}s+1\right)}{\left(\frac{1}{1.95}s+1\right)} \tag{20}$$

Analysis of the design

Temporal responses of the SIMO system (Fig. 2) in closed loop dynamic are shown. Figures 9 and 10 compare both outputs *Y* and ϕ with and without control respectively. It is shown that the control achieves the positioning system.

CONCLUSIONS

In this work an analysis and design of a dynamic positioning system for a moored floating platform has been carried out. The plant model is a single degree of freedom SIMO system, therefore a notable question is that the plant is underactuated. Thus, it has been used a quantitative design technique (QFT) for synthesizing

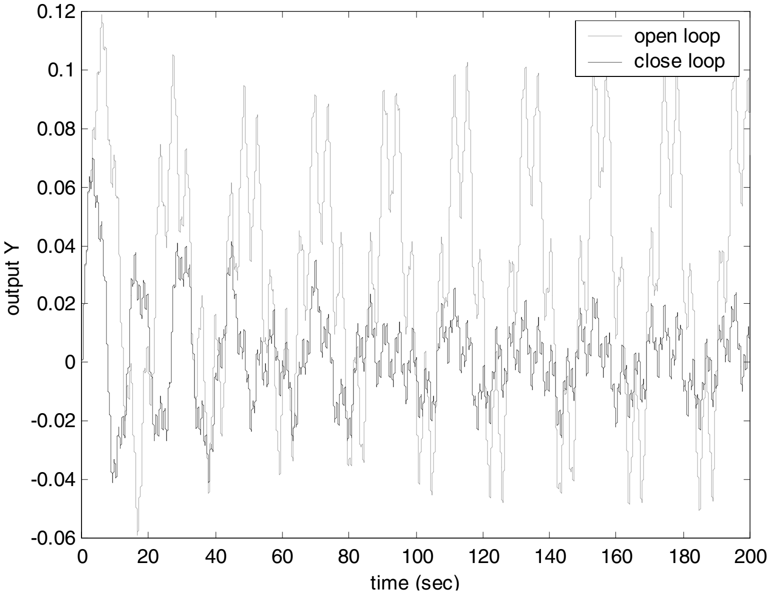

Fig. 9 Comparison of temporal response Y in open loop (dashed line) and closed loop (solid line).

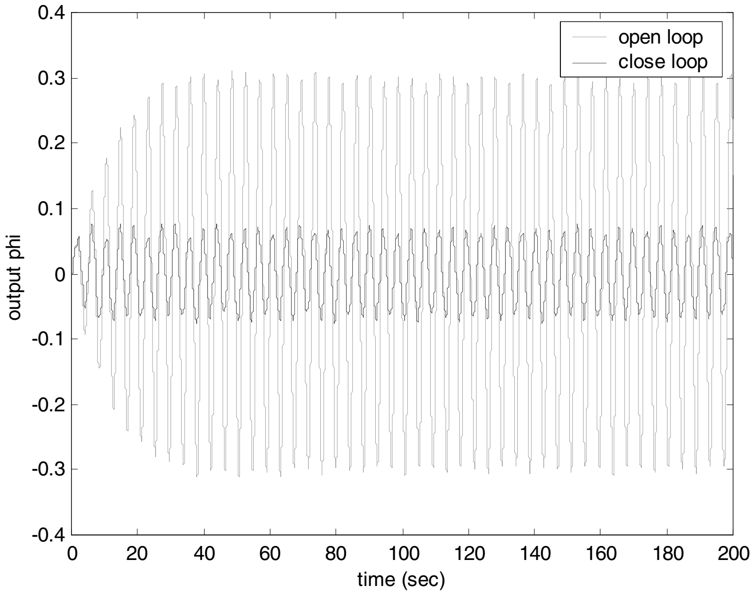

Fig. 10 Comparison of temporal response ϕ in open loop (dashed line) and closed loop (solid line).

the controller for the SIMO plant. The idea consists of transforming the problem into two sequential SISO systems and breaking the design process into a series of iterative stages, in such a way that the solution in the first system is used in the design in the second system, and vice versa. Finally it is shown that QFT design is a robust method very suitable for the implementation, and that accomplishes the objectives efficiently. We have verified that this method is an attractive alternative for robust design of these kinds of systems.

ACKNOWLEDGEMENT

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DISEÑO DE UN CONTROLADOR MEDIANTE LA TÉCNICA QFT PARA POSICIONAMIENTO DINÁMICO DE UNA PLATAFORMA AMARRADA.

RESUMEN

En este trabajo se ha llevado a cabo el análisis y diseño de un sistema de posicionamiento dinámico para una plataforma amarrada flotante. El modelo de la plataforma consiste en una planta con una entrada y dos salidas (sistema SIMO) de un grado de libertad. La finalidad del controlador es minimizar el desplazamiento provocado por el oleaje mediante un control adecuado de los propulsores. Una cuestión interesante que se plantea es que la planta tiene menos grados de libertad para la actuación y es más difícil de control. El método empleado para el control es la técnica de control robusto QFT para sistemas subactuados. El problema se resuelve mediante un proceso secuencial iterativo multi-etapa. Finalmente se comprueba que el control consigue el posicionamiento dinámico.

INTRODUCCIÓN

El control de sistemas subactuados es un problema típico en los sistemas navales. Ejemplos de este tipo de problemas son el diseño de controladores para seguimiento de trayectoria, estabilización, y posicionamiento dinámico.

En este trabajo se analiza el uso del método de diseño QFT (del inglés Quantitative Feedback Theory) multivariable para sistemas subactuados, aplicado al modelo de una plataforma amarrada flotante. El modelo es un sistema lineal invariante en el tiempo (LTI) con una entrada y dos salidas (SIMO) con un grado de libertad.

Este tipo de sistemas ha sido examinado y resuelto mediante diferentes métodos de control robusto (Scherer, *et at.*, 1997; Revilla, 2005; Nakamura, *et al.*, 2001).

La técnica QFT (Horowitz, 1992; Yaniv, 1999; Borguesani, et al., 1995; Houpis, et al., 2006) es una metodología de diseño en el dominio de la frecuencia que no es muy común en los sistemas navales. Nuestro grupo de trabajo ha aplicada esta técnica en el problema de estabilización de barcos de alta velocidad (Aranda, et al., 2005) con excelentes resultados.

El objetivo de este trabajo es verificar que esta técnica puede extenderse para sistemas subactuados y mostrar los resultados obtenidos en la aplicación de un problema de posicionamiento dinámico típico.

METODOLOGÍA

El sistema consiste en una plataforma flotante amarrada al fondo del océano, y equipada con dos propulsores. El objetivo es conseguir un control de los propulsores adecuado de manera que minimice el desplazamiento derivado de la acción de las olas. El modelo presenta dos salidas y (el desplazamiento horizontal Y, y el ángulo de desviación del eje vertical ϕ), una entrada de control u (la fuerza F_u producida por los propulsores), y dos entradas de perturbación (la fuerza F y el momento M debido al oleaje). Por tanto se presenta un sistema de un grado de libertad SIMO, con una entrada y dos salidas.

Los objetivos del control son: reducir la fuerza de desplazamiento mediante el control de los actuadores, mantener el desplazamiento horizontal Y por debajo de los 0.025 m, y la desviación angular ϕ por debajo de los 3 grados, conseguir que la fuerza de los propulsores F_u no supere los 25 N, y asegurarse que los propulsores no tienen componente en alta frecuencia.

El fundamento de QFT es el hecho de que la realimentación se necesita principalmente cuando la planta tiene incertidumbres y/o hay perturbaciones, por lo que el sistema de la plataforma es un buen ejemplo de aplicación.

El proceso de diseño QFT contempla tres pasos básicos: *i*) cálculo de fronteras, *ii*) diseño del control, *iii*) análisis del diseño. QFT convierte las especificaciones de magnitud en lazo cerrado en restricciones de magnitud de una función en lazo abierto nominal (fronteras). Así, se diseña una función en lazo abierto $L(j\omega)$, que se define como el producto de las funciones de transferencia del control y de la planta, de manera que satisfaga simultáneamente tanto sus restricciones como la estabilidad en lazo cerrado (*loop shaping*).

En cualquier diseño QFT, es necesario seleccionar un rango de frecuencias para calcular las fronteras. En el caso de la planta de la plataforma, se emplea un rango de frecuencias que pertenece al espectro del oleaje, $\omega \in [0.1, 10]$ rad/s.

Finalmente, a partir de la ley de control, se obtiene una ecuación con dos incógnitas k_1, k_2, correspondientes a los dos términos de la matriz de funciones de transferencia del control. El diseño del controlador se basa en este ecuación, que ayuda a transformar el problema SIMO en el diseño de dos sistemas SISO secuenciales. Así, se resuelve mediante un proceso secuencial iterativo, de tal forma que la solución del control k_1 en el primer sistema SISO se emplea para el diseño de k_2 en el segundo sistema, y viceversa. Las etapas se repiten sucesivamente hasta que los controladores k_1 y k_2 cumplen los objetivos del sistema SIMO original.

RESULTADOS

Siguiendo el procedimiento planteado, el proceso de diseño del controlador (k_1, k_2) se completa en cinco etapas. El controlador k_1 final es un filtro de primer orden, con un polo y un cero, y el control k_2 es un filtro de segundo orden, con dos polos y dos ceros. Finalmente, se obtienen simulaciones de las respuestas temporales del sistema en lazo cerrado y se comparan las salidas con y sin control. Se demuestra que el control consigue el sistema de posicionamiento.

CONCLUSIONES

En este trabajo se ha llevado a cabo el análisis y diseño de un sistema de posicionamiento dinámico para una plataforma amarrada flotante. El modelo de la planta es un sistema SIMO con un grado de libertad, por tanto una notable característica es que la planta es subactuada. Para resolver el problema de posicionamiento, se emplea la teoría cuantitativa realimentada (QFT). Finalmente se demuestra que el diseño QFT es un método robusto que resulta adecuado para la implementación del controlador, y que consigue los objetivos de forma efectiva. Así, hemos verificado que este método es una alternativa atractiva para el diseño de control robusto de sistemas navales.

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AIRFOIL SECTION OPTIMIZATION FOR USE IN SAILBOAT FOILS

A. Fernández[1] and M. R. Chakkor[2]

ABSTRACT

In recent years we have been witnesses of an extraordinary development in sailing technology. All aspects of the sport have benefited from the advancement of computational tools. Computational fluid dynamics, finite element analysis of structures, and optimization tools can increasingly be found in the bag of tricks of designers. In this article we will present a methodology and a tool to treat the design of sailboat foils. The methodology is grounded in the adequate use of current technologies, scaling them when deemed necessary. The construction of a model that includes the treatment of geometrical and structural constrains at the same time using currently available tools will be described.

PRECISION MODELS

For years, the most used tools for foil design were based on panel codes. Those have the advantage of relative short running times with the computing power available today. Recent developments in CFD (computational fluid dynamics) technology have brought more precise predictive capacity. The downside is computational expense.

Today, it is possible to analyze a certain foil configuration or even several of them with CFD tools (RANS codes). If we want the added precision of more advance codes we would have to upgrade to LES (Large Edy Simulation) codes. These are still expensive from the computational time perspective. In terms of using them for an optimization that may involve tens or hundreds of evaluations is still prohibitive for most projects.

[1] Cognit Design, Arquitecto Sert 31 (info@cognitdesign.com), Barcelona, Spain. [2] Facultad de Náutica, Universidad Politécnica de Cataluña, (mohammed.reda.chakkor@upc.edu), Barcelona, Spain.

The alternative is to use older models. A middle ground can be found though. Using a variety of technologies, namely neural networks and genetic algorithms it is possible to generate a model that mixes different models for use in optimization.

NEURAL NETWORKS

In general, the area of neural networks is based on our understanding of the workings of the human brain. NN (neural networks) work in a similar way to our brain, by learning. This is, in fact, their most significant property.

Neural computing concepts are mainly based on attempts to mimic the way our brain processes information in order to solve different kinds of problems. NN, obviously, have not even get close to model the complexity of the human brain but they have proven to be very efficient at problems that are easy for the human brain but difficult for traditional computers, such as pattern recognition.

The way to visualize the working of an ANN (artificial neural network) is to think of mathematical models of a biological neuron linked together on a network. This forms an information processing structure that has the ability to learn to perform certain tasks.

There are different kinds of neuron, different kinds of networks and different kinds of associated performance functions and learning algorithms.

Neuron models are mathematical models of the behaviour of a single neuron in a biological nervous system. These models receive information in the form of a set of numerical input signals. This information is then integrated with a set of free parameters to produce a message in the form of a single numerical output signal.

The kind of NN comes conditioned by the way its neurons are arranged to form a particular architecture. The architecture is defined by the number of neurons, their arrangement and their connectivity.

The performance function is in charge of defining the task the neural network is required to carry out and provides a measure of the quality of the representation that the network is required to learn. Each particular application requires a different performance function.

The missing piece in this puzzle is the learning algorithm. This is the procedure used to carry out the learning process. The learning (or training) algorithm is applied to the network in order to obtain a desired performance. There are different types of learning that are defined by the way the adjustment of the free parameters in the NN takes place.

In our case, we have used a neural network composed of perceptrons. This neuron model has been combined in what is known as a multilayer perceptron. The network is composed of an input layer for six inputs, sigmoid hidden layers, and an output layer.

GENETIC ALGORITHMS

According to [Heitkoetter, 1994]: *"Evolutionary algorithm is an umbrella term used to describe computer-based problem solving systems which use computational models of evolutionary processes as key elements in their design and implementation"*.

Genetic algorithms are based on an analogy with the laws of natural selection proposed by Darwin and its most famous principle of survival of the fittest. Genetic algorithms are multiple solution algorithms. They work on a *population* of solutions called *individuals*. Each individual is represented by its *genome*. A genome defines unequivocally a solution of the problem. The individuals strive for survival and for continuity of their genome (*reproduction*). The time is divided into discrete steps called generations. Depending on the type of genetic algorithm every individual (simple genetic algorithm) or some individuals (steady-state genetic algorithm) are born (created) each generation.

The analogy of the environment for a genetic algorithm is the evaluation function. This function assigns a fitness value to each individual. The goal of the algorithm is to find the individual best fitted to the environment, thus maximizing the evaluation function.

GAs (Genetic Algorithms) differ from classical optimization strategies in several respects:

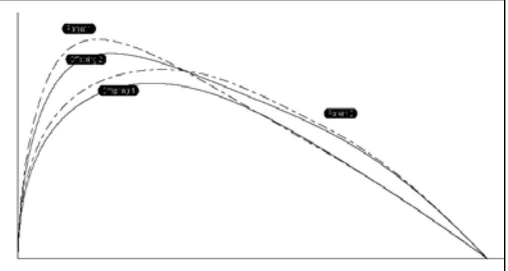
— GAs operate simultaneously on a population of potential solutions not on a single instance that gets iterated to find the optimum.

— GAs use directly the objective function and do not need to calculate derivatives or other auxiliary knowledge.

— GAs are stochastic methods, not deterministic. They are frequently found more robust in some cases. This is especially true in the case of non differentiable, multi-modal or convex functions.

— GAs have a greater potential to explore the whole search space.

The way a genetic algorithm works is by evolving the population to find the best individual (best solution to the problem). To accomplish that, three genetic operators are applied to the population: selection, crossover and mutation. Each individual can either survive, reproduce or die according to their fitness value which is related to the value of the cost functional.



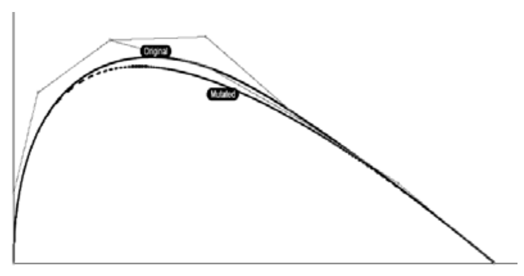
Crossover Example

The selection operator decides if an individual reproduces, survives or dies. There are two basic types of selection, roulette wheel and tournament. The most popular tournament is the two-point tournament. In this case, two individuals are drafted at random from the population and compared, the best one is stored and both are reintroduced in the population. The procedure is repeated until a new population of adequate size is reached.

Since selection does not create new individuals, crossover is need to increase diversity among the population. It is applied with a probability close to one. The operator selects at random a position in the chromosome and from that position it switches the information in the chromosome.

Another key ingredient is the mutator operator. This operator is applied because important genetic information may be lost as a result of crossovers. It is applied with a small probability and introduces random values to the chromosome.

If we describe in pseudo code a genetic algorithm we would have something similar to:



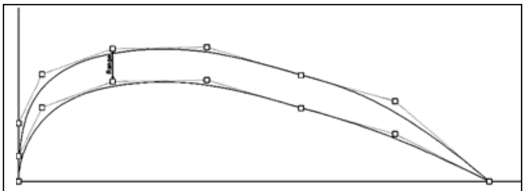
Mutation Example

```
begin
   initiate population P
   evaluate population P
   repeat
        select parents in P
        recombine parents
        mutate
        evaluate
        select
   until (termination condition)
end
```

In our case we have used a steady state genetic algorithm with two point crossover. The genome described seven parameters that represented the y coordinate of a fifth degree B-spline and a scaling factor.

GEOMETRICAL REPRESENTATION

In the way the section has been set up it is defined by the position of the control polygon of a fifth degree B-spline. These points are allowed to vary trough a definite range around the starting section. In order to cover a wider design space an scaling factor is also used that multiplies the height of all the control points.


Range

This way of representing the section allows for great variation of the shape while preserving a certain degree of smoothness.

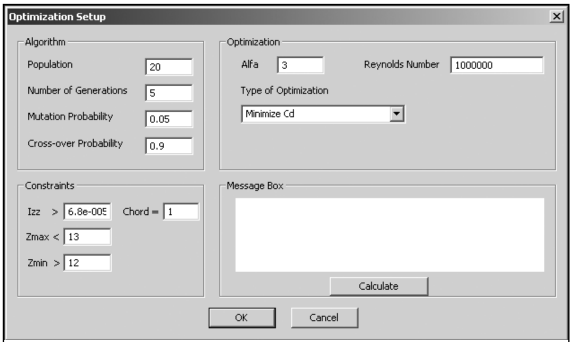
COMPUTATIONAL TOOLS

For the calculations necessary to carry out the optimization we have used varied tools. From the aerodynamic perspective we have used two distinct tools.

Firstly, we used the well know airfoil analysis code Xfoil. This is a panel code with a strongly coupled boundary layer solution. The code has been widely used in foil design for some time and is considered sufficiently accurate for the application we were after.

We have also used a graphical user interface that has been created to make the used of Xfoil more user friendly. This gui is called XFLR5. To this gui, a option to control the optimization has been added.

On the other side, we also used a CFD code, Tdyn. In this case, the code is a multi-physics finite element code. This code can be easily used from within a pre-post processing software, GiD. This software can be called in batch mode witch therefore facilitates the integration in the flow of the optimization.



Optimization Options

The structural part is considered from two different fronts. First, we take into consideration geometric constraints for the generation of individuals in the population. These constraints have a significant structural meaning. In particular, they are the maximum thickness of a section (that has to be within certain values) and the sectional inertia that can be set up either as a constraint or in a multi objective optimization.

The other structural consideration is based on the finite element analysis of the structure of the whole keel. To accomplish that, we have used the parameterization capabilities of modern modeling software. In particular, the coordinates of the control points drive the creation of the geometry in Catia. This software allows the creation of a complete parametric model that would change with each input of different coordinates. Associated to the geometric capabilities, Catia also has an integrated finite element analysis module. Once the geometry is created, with its topology defined, the finite element solver is automatically called upon to mesh the new geometry and solve the case when the geometry gets updated.

Other tools that have been used include programming libraries for neural networks and for genetic algorithms. These libraries, for example GAlib, are available as open source in C++.

GLOBAL MODEL

The different tools have been scaled with respect to their performance and quality to create a global model. The model scales each tool to use it with the part of the population that seems more adequate for it. In that context, we distinguished 3 types of solutions: those coming from the neural network, those from the panel code, and those from the CFD code.

The way this works is the following. The first step was to train the neural network. This was carried out by generating a first population of randomly generated individuals. These individuals were calculated using the panel code. This data set serves as the base training set for the NN. At this point the NN is capable of predicting aerodynamic properties from the genes of an individual.

For each subsequent generation, the neural network makes a prediction of the fitness of the individuals. The best half of the population is then evaluated with the panel code to improve the quality of the results. This method has the drawback of possibly missing good individuals that are badly predicted by the NN. This is partially avoided by the calculation of a large part of the population (half of it) with the more reliable prediction method. In order to establish another failsafe, a small number of individuals draw at random are also evaluated even if they do not belong to the top 50%.

These calculations are also used to improve the quality of the prediction by adding them to the training set.

In order to refine the search even further, it was proposed to evaluate the top 10% with the CFD code. This has the drawback of multiplying the computational effort required. Looking for ways to save computing time it was decided to evaluate these sections only at regular interval and not in every generation. This way, scores for the chosen genes are corrected once out of several generations (depending on the general number of generations). These scores are also used to improve the training set.

In the same way, these individuals that are found best fitted are used as the definition of the geometry within Catia. Simple put, another row with the coordinates of the control points is added to the table that defines the different configurations. That row is selected as the actual configuration for that particular part. With this done, the part is updated and the new mechanical properties are measured. This also calls for an update to the structural calculation. Since the topology of the part has not changed, this can all be done automatically.

OPTIMIZATION PROBLEM

In a general way, the example problem would be to find the best profile for a keel taking into account structural constraints. The keel subject to optimization is destined for a GP 42. This is a racing sailboat rule of the type known as box rules.

The GP 42 rule has been created with the target of

"...to promote the conception and construction of boats fun to sail, seaworthy and with considerable longevity."

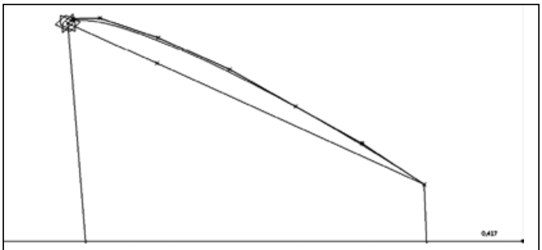
It is in this environment that the proposed problem is framed. The idea is to used the previously exposed methodology to optimize a baseline keel for its use in a GP 42.

In a very brief way, the rule sets a few limits on properties of the keels. These limits are the keel weight, and thickness measurement at three different points of the span. Of course, there is also a limit in draft for the whole boat that affects the keel span. The following table presents the measures that have to be considered:

Keel Measurements	
Keel Maximum weight.	2300 kg.
Keel Thickness 100 mm. Below hull.	0.090 m.
Keel Thickness mid-span.	0.080 m.
Keel Thickness 100 mm. Above bulb.	0.070 m.

Based on these measurements, the keel maximum thickness distribution is set. A key aspect to consider here is that the weight represents the weight of the whole keel assembly. Therefore, the parallel consideration of the structural aspect is of prime importance. A lighter keel blade that can support the same or more weight will allow for a bigger bulb.

The baseline keel was designed using a previously develop section. With respect to the plan form, it was fixed once the required blade area was determined from the sail plan.



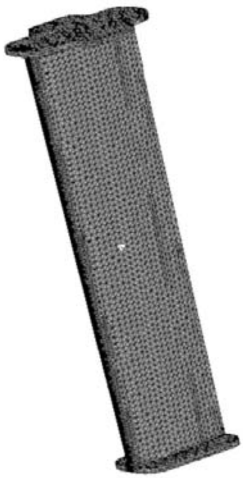
Control Points for Catia Model

These geometric restrictions were parameterized on a Catia model. For the connection to the aerodynamic part of the optimization the control points of the section are updated from the ones send by the optimizer. This way, the same genome defines the shape used for the aerodynamic calculations and for the structural calculations.

Once the model is parameterized, linking different features is possible. For example, important properties such as weight can be linked. Thus, the weight of the bulb can be changed in a way that keeps the total weight of the keel constant.

Furthermore, in the structural part, meshing properties only have to be defined once. Since the topology of the geometry does not change, only the geometry trough its control points does, the meshing can be accomplish automatically after setup of the baseline model. The load conditions for the calculation are also parameterized. Since the bulb weight changes as a function of the section so does the load.

This set up allows considering some of the downstream effects that choosing a certain section has.



Meshed Baseline Model

A very similar procedure is used to pass information to the CFD. In this case, the geometry of the baseline section is set up. This includes the meshing definition (how fine or coarse) and the boundary conditions. The pre-processing software GiD associates this definitions to geometry and passes them to the mesh just before the problem is run. By changing the geometry instead of creating a new one, all conditions are kept in the same entities. Once in place, GiD and Tdyn can be run in batch mode. The optimizer changes the geometric definition (in fact, just moves the control points) and the problem is meshed and run.

The fact that the geometry is unequivocally defined by the same genome allows the interplay of different pieces of software than can be run in batches. With this structure in place the problem is set up to run.

Geometry Definition in GiD

OPTIMIZATION FUNCTION

What needs to be optimize to improve the performance of a sailboat appendix is not always clear. The variety of operating conditions that the boat is expected to find makes it hard to decide what needs to be optimized. In this case, to test the procedure, we decided to start with a simple optimization and to progress from there.

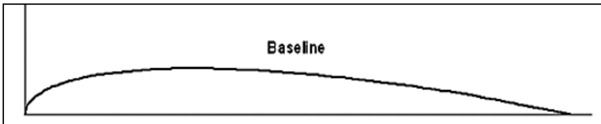
The optimization conditions where all set up at a Reynolds number of 3000000. This was considered a good starting point for the performance optimization of the vessel when we consider that in this phase only a single point of sail is treat at any one calculation.

The first optimization is designed to model the behavior of the keel on a dead run. It is probably unrealistic to set up the section at an angle of attack of zero degrees but it seems adequate to check the methodology. It could be argued, besides, that canting keels and similar could be designed to operate at or very close to zero angle of attack. It does not seem very likely that such is the case but it something that has been sometime heard.

MINIMUM DRAG SECTION

The optimization goal in this case is to find the minimum drag coefficient for a section operating at zero degrees angle of attack and at a Reynolds number of 3000000.

In these conditions, the performance of the baseline section and keel is:



Geometry of Baseline Section

Baseline Keel	
C_d	0.00548
Maximum Thickness	0.090 m.
Inertia	$1.834e^{-5}$ m^4.
Blade Weight	725 kg.
Bulb Weight	1575 kg.
Max. Von Misses Stress	76.98 MPa
Maximum Displacement	15.69 mm.
Factor of Safety (Yield stress 700 Mpa)	9.09

From this keel, an optimization is carried over. In this optimization the score of each individual is develop simply by calculating the inverse of the drag coefficient. This is done in such a way because it permits configuring any optimization as a maximization problem.

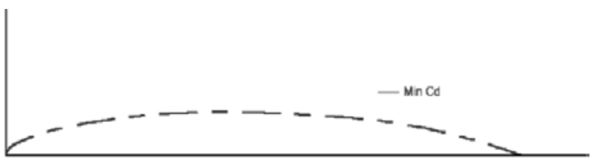
$$Score = \frac{1}{C_d}$$

The restrictions applied to the problem are:

Restrictions	
Minimum Thickness	0.09 m
Minimum Inertia	$1.834e^{-5}$ m^4.

The inertia is used as a restriction here to try not to be in a worse position structurally than with the baseline design.

The restrictions are imposed as "*soft*" barriers. This means that a violating genome (one that lays outside the genotype) is not directly given a score of 0. Instead, other criteria are applied to allow for solution that are very close to the restrictions. For example, if a genome violates the minimum thickness criteria it is given a score inversely proportional to its distance to that constraint.



Geometry of Minimum Drag Section

Thus, the population naturally evolves towards genes that are inside of the constraints.

In addition, the top five sections are analyzed using finite elements and their scores corrected. The results obtained are reflected in the following table.

Minimum C_d Keel	
C_d	0.00317
Maximum Thickness	0.090 m.
Inertia	1.995 e^{-5} m^4.
Blade Weight	760 kg.
Bulb Weight	1540 kg.
Max. Von Misses Stress	68.74 MPa
Maximum Displacement	14.25 mm.
Factor of Safety (Yield stress 700 Mpa)	10.18

In this case, the drag coefficient is reduced notably. The trade off, however is present on the weight of the blade that has increase. Therefore, the vertical weight distribution has changed as the bulb has to be made lighter. An added benefit is the increase in factor of safety for this geometry.

MAXIMUM Cl/Cd

As mentioned before, considering the keel operating at zero angle of attack is not very realistic. A modern design such as this will almost never sail dead downwind. For this reason, the objective of the optimization was changed to maximizing the ratio of lift over drag. The operating point used in this case was 3 degrees angle of attack at a Reynolds number of 3 million.

In these conditions, the performance characteristics of the baseline keel are a little different with respect to lift and drag. The lift in this case is C_l = 0.283 while the drag is C_d = 0.586.

Therefore, the score function used in the optimization becomes:

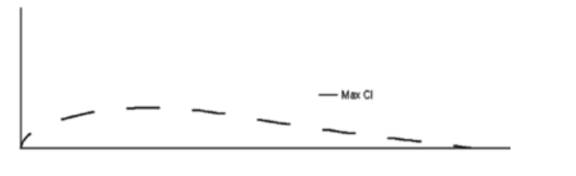
$$Score = \frac{C_l}{C_d}$$

In turn, the performance of the optimized keel is:

Maximum C_l/C_d Keel	
C_d	0.00467
C_l	0.34019
Maximum Thickness	0.102 m.
Inertia	2.497 e^{-5} m^4.
Blade Weight	775 kg.
Bulb Weight	1525 kg.
Max. Von Misses Stress	62.49 MPa
Maximum Displacement	11.58 mm.
Factor of Safety(Yield stress 700 Mpa)	11.20

After the optimization, the section thickness has increase. This, however, has not come associated to an increase in drag from the baseline keel. In fact, the drag has come down from 0.00548 to 0.00468. The draw back in this case is the increase in weight of the blade that comes associated to a thicker section. Of course, on the up side, there is an improvement in safety factor for this keel as compared with the baseline.

MAXIMUM LIFT



Geometry of Maximum Cl

A very desirable characteristic for a foil is its ability to produce a great amount of lift. This is a requirement most often look after in rudder sections than in keel sections, although for a rudder is ultimate lift what one is usually after. However, modern race boat plan forms that have little surface may be required at times (out of a tack or at the start) to produce a high amount of lift. From that perspective, it seemed interesting to find what the optimum section would be for a keel producing high lift at low angles of attack.

With that in mind, an optimization was carried over for the keel at 3º angle of attack and for the same Reynolds number. The score function used in the optimization process is setup directly from the lift coefficient.

$$Score = \frac{C_l}{C_{l_0}}$$

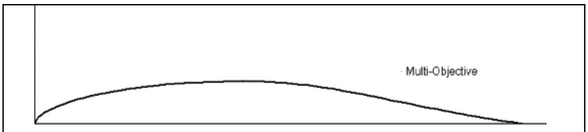
The result is summarized in the following table:

Maximum C_l Keel	
C_d	0.00592
C_l	0.3454
Maximum Thickness	0.097 m.
Inertia	1.21 e^{-5} m^4.
Blade Weight	679 kg.
Bulb Weight	1621 kg.
Max. Von Misses Stress	83.79 MPa
Maximum Displacement	17.01 mm.
Factor of Safety (Yield stress 700 Mpa)	8.35

In this case, the price to pay for a high lift coefficient is a high drag. On the other hand, the weight of the blade is notably reduced. This allows for a bigger bulb at the cost of a reduced safety factor.

MULTI-OBJECTIVE

As was to be expected, the mixed requirements that are asked from a modern keel calls for a more refined optimization that the mere consideration of one characteristic. To accomplish that, it was decided to carry out a multi-objective optimization.



Geometry of Multi-objective Optimization

A classical way of dealing with multi-objective optimization is by weighting the different objectives that are to be optimized. It is a somehow simplistic approach but it is quick to set up. The function that we want to optimize should include, as we have seen, drag coefficient, lift coefficient, and measures of structural performance.

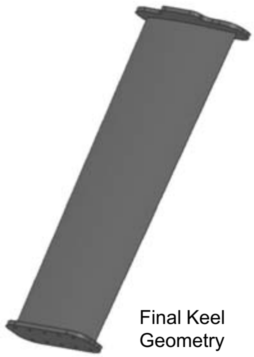
In that light, we introduce two other objectives, sectional area and inertia with respect to the chord axis. These become objectives and not restrictions. The restriction of minimal section thickness is kept due to the limitations of the rule.

The score function thus becomes:

$$Score = \frac{C_l}{C_{l_0}} + \frac{C_{d_0}}{C_d} + \frac{Area_0}{Area} + \frac{I}{I_0}$$

The sub 0 values come from the baseline section. Thus, all values are normalized with the original section. Usually, weighting factors are given to each variable to reflect what features are sough after. In this case, we did not use any differentiation between optimization objectives. The results from this optimization are reflected in the following table.

Multi-Objective Optimization Keel	
C_d	0.00461
C_l	0.3428
Maximum Thickness	0.091 m.
Inertia	1.748 e^{-5} m^4.
Blade Weight	693 kg.
Bulb Weight	1607 kg.
Max. Von Misses Stress	82.8 MPa
Maximum Displacement	16.89 mm.
Factor of Safety (Yield stress 700 Mpa)	8.45



Final Keel Geometry

With this optimization we have develop a section with a lower drag and better lifting potential than the baseline. The blade is also lighter therefore we can make the bulb bigger also. The only draw back is the reduction on safety factor. This comes to be expected as we have reduced quite a bit the amount of supporting material in the keel. However, the righting moment has increased considerably.

CONCLUSION

We have presented a methodology for the systematic optimization of foil sections. This optimization has been carried out for a keel section for a GP 42 racing sailboat. A first baseline keel was created to evaluate performance gains over it. Different objectives have been evaluated and finally integrated into a multi-objective optimization. The optimization did not only include aerodynamic characteristics but also took consideration of structural features both as optimization variables and as restrictions.

The final section found presents good characteristics for the presumed use. It has lower drag than the baseline model, higher lift and a lower weight for the structure. It can be argued that the margin of safety for the keel, although considerable, has been reduced. An alternative approach could be to use righting moment as the characteristic to maintain constant. This way, the reduced weight of the blade would come associated to a reduced weight of the bulb. The complete keel assembly would be lighter but the righting moment would be the same. At the same time, the lighter bulb would help keeping safety factors contained.

Summary Table (% change from base at 3º) *bold italics mean improvement*				
	Min C_d	Max C_l/C_d	Max C_l	Multi-O
C_d	**-20.14**	**-20.31**	1.02	**-21.33**
C_l	-67.61	**20.42**	**22.01**	**21.09**
Blade Weight	4.83	7.03	**-6.34**	**-4.41**
Bulb Weight	-2.22	-3.24	**2.92**	**2.03**
Max. Stress	**-8.51**	**-16.82**	11.53	10.21
Max. Displ.	**-10.71**	**-27.45**	6.52	5.8
S.F.	**9.30**	**20.23**	-10.34	-9.26

FUTURE WORK

There are some other things to consider when it comes to the optimization of sailboat appendices. Two things jump quickly to mind. The first is the fact that our real measure of merit should be the speed of the boat and not directly characteristic of any of its parts. Second, a classical approach to multi-objective optimization does not give enough insight into the trade-offs present in the problem, more flexible optimization schemes are needed.

A logical next step will be to link the optimization process to a velocity prediction program. This would allow us to better grasp what the real improvements can be and help us make a more educated choice.

From the optimization point of view it seems logical to do the optimization looking for non-dominated solutions. Therefore, we will be looking after obtaining the pareto front of solutions. This would improve the value of the solution by helping the designer make choices that adjust better to the requirements while not damaging much other characteristics.

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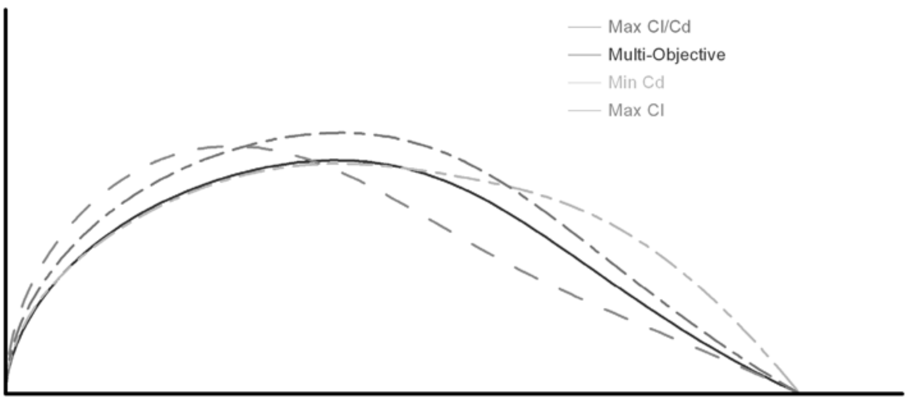
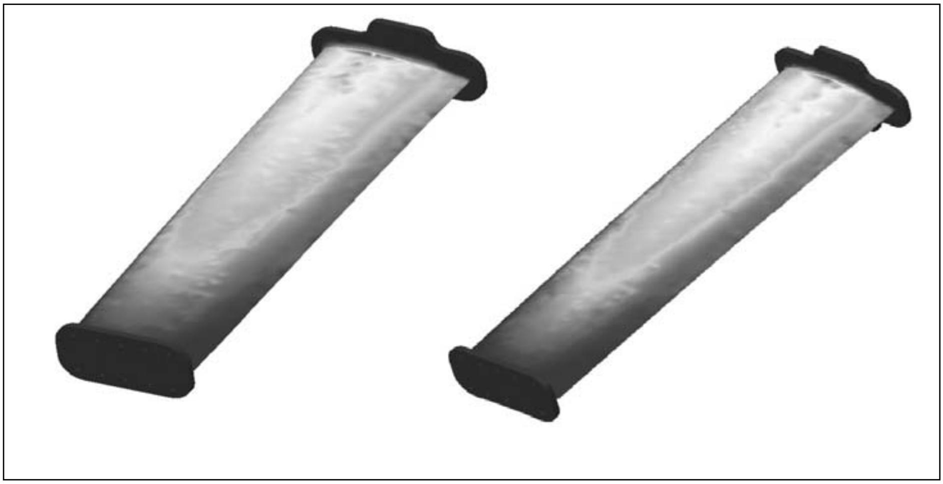
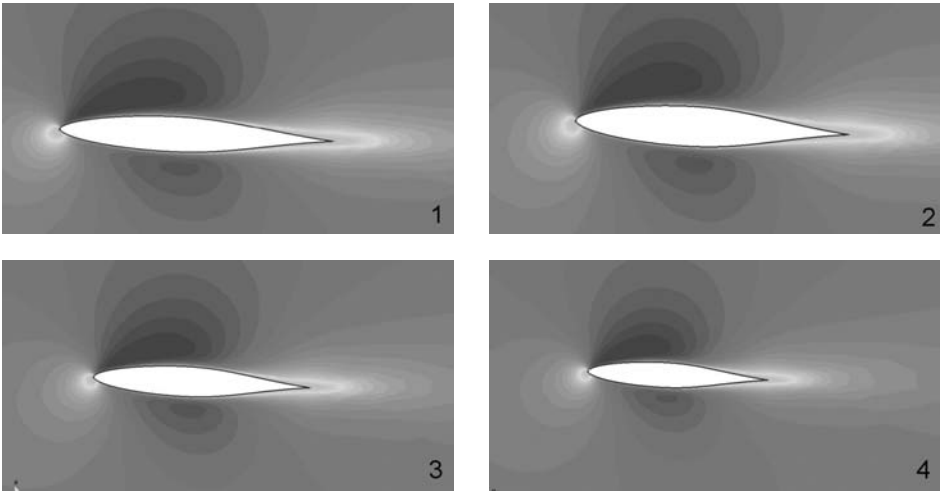
APENDIX



Best Sections for each Optimization



Stress on Baseline Keel and on Multi-Objective Optimization Keel



Velocity Distribution of Best Four Sections for Multi-Objective Optimization

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THE ANFIS BASED ROUTE PREFERENCE ESTIMATION IN SEA NAVIGATION

Natasa Kovac[1] and Sanja Bauk[1]

Abstract

This paper considers developing the ANFIS system based upon functional equivalence between the two-input first-order Takagi-Sugeno-Kang (TSK) fuzzy inference system and radial basis network (RBN). The input values are the linguistic qualifications related to the criteria: the wind strength and the traveling distance, in the long-ocean sailing zone, treated here since they are of upmost importance from the aspects of the traveling safety and efficiency. The output value is the degree of particular traveling direction preference. In the paper considered, hybrid neuro-fuzzy system, could be used as a theoretical support for developing the system with power of assistance in preferential sailing direction selection in long-ocean navigation.

Key words: adaptive neuro-fuzzy inference system (ANFIS), hybrid learning, Takagi-Sugeno-Kang (TSK) fuzzy inference system (FIS), radial basis network (RBN), preferential sailing direction selection.

INTRODUCTION

The input data in most of real world selection processes are not always precise. The same is in the case of preferential sailing direction selection in long-ocean navigation. Let's suppose that the mariner needs to navigate the vessel from one port to another one, and that he has a few different sailing directions from which he must choose one. His choice will depend of a large number of parameters, such as the wind strength, the total traveling distance, the traffic density, the fuel consumption,

[1] Faculty of Maritime Studies, University of Montenegro, Dobrota 36, 85330 Kotor, Serbia & Montenegro.

the demand for transport, etc. In aim to simplify this problem, since our work is attended to be rather theoretical then practical, we will be interested only in two criteria: the wind strength and the traveling distance. The parameters related to these two criteria will be in fact the input values for the hybrid neuro-fuzzy system, while the desired output is a numerical value that corresponds to the degree of considered sailing direction preference.

The first step is to define the decision selection rules based on inputs, using experts' knowledge for a certain sailing zone. Here are the two most important rules:

— If the wind strength and the traveling distance are small, than the decision selection will have high value, and
— If the wind strength and the traveling distance are high, than the decision selection will have small value.

Then, an ANFIS is to be designed and trained, in aim to simulate experts' knowledge in the observed sailing area. Finally, the adequate example with numerical and graphical results will be given.

THE MOTIVATION

The question is: where the motivation for the problem previously defined can actually be found? An explanation could be the following: now-a-day in order to navigate the vessel from one to another point, in the most efficient way, the mariner uses the actual digital technology of the electronic chart in the same manner as the traditional paper chart. The elements of route planning in electronic chart technology are waypoints and the line legs, which connect the waypoints. While waypoints may stand alone or may be connected to legs, legs are always bounded by waypoints. The leg lines can be constructed for a preplanned speed, while waypoints can carry information about the turning radius of the course change, etc. The leg lines and the waypoints are created in the electronic chart-planning mode. The alternate routes are connected to waypoints to form a network of leg lines that represent all the routes a vessel could use on her voyage. After the alternate routes are planned, the actual route, that is the route which the vessel will use, must be selected. The electronic chart supports this operation with its auto selection function. If the way through the possible routes net is unambiguous, this function will trace the preferential route automatically. But, if more than one leg departs from a waypoint (Figure 1), then electronic chart's auto selection function asks for the mariner's decision. That is why various decision support methods in preferential sailing direction selection are required

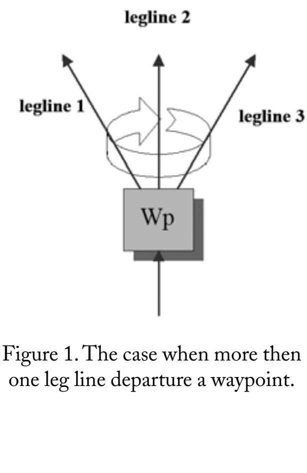

Figure 1. The case when more then one leg line departure a waypoint.

and are to be conceived, developed and implemented into up-to-date navigational equipment. This was in a way the motivation for developing the TSK and RBN based ANFIS devoted to the route, that is, its segments preference estimation (Bauk and Avramović, 2004; Bauk, 2003, 2005).

LINGUISTIC VARIABLES AND MEMBERSHIP FUNCTIONS

In the cases similar to the previously mentioned one, we often relay on qualitative features, since it is not convenient to consider numerical values in the system input segment. Namely, in such cases the input numerical data are not sufficiently precise. The main problem appears because of the different system's users estimations: someone will characterize the wind as a strength one with number 6 in Beaufort's scale, but someone else will characterize the same wind with number 7 in Beaufort's scale. In aim to resolve this problem and avoid numerical values at the system input part, the linguistics variables are to be introduced into the neuro-fuzzy modeling process.

Thus, the words or the sentences in natural or artificial languages are values of linguistic variables. According to the basic fuzzy rules mentioned in the section one, it is obvious that the inputs should be characterized with at least two linguistic constants: *small* and *high*, but we will incorporate *very small, medium and very high* as new categories in aim to increase the system precision. Each linguistics constant has its own membership function.

Let X be a set of objects, called the universe, whose elements are denoted as x. The membership in a subset A of X is the membership function μ_A from X to the real interval [0,1]. The universe consists of various elements which will be of concern in the particular context. A is called a fuzzy set and is a subset of X that has no sharp boundary. The function μ_A is the grade of membership x in A. The closer the value of μ_A is to 1, the more x belongs to A. The total allowable universe of values is called the domain of the fuzzy set. The domain is a set of real numbers, increasing monotonically from left to right where the values can be both positive and negative. A is completely characterized by the set of pairs $A=\{(x, \mu_A(x)), x \in X\}$. The degree of membership is known as the membership or truth function since it establishes a one-to-one correspondence between an element in the domain and a truth value indicating its degree of membership in the set. It takes the form $\mu_A(x) \leftarrow f(x \in A)$ (Fuller, 1999). There are few commonly used membership functions. In this work we prefer that each input has five membership functions (MF) represented by Gaussian functions given in the following form:

$$f(x) = e^{\frac{-(x-\mu)^2}{\sigma^2}} \tag{1}$$

where μ is the location parameter and represents a MF center and σ is the scale parameter which determines the MF width. The function (1) has maximum equal to one and minimum equal to zero.

FUZZY INFERENCE SYSTEM

The concept of a fuzzy set has been proposed by Zadeh (1965). Namely, the fuzzy sets were introduced as a generalization of conventional set theory. The fuzzy logic, based upon the fuzzy sets, implements human experiences and preferences via membership functions and fuzzy rules. The fuzzy sets are functions that map a value that might be a member of the set to a number between zero and one indicating its actual degree of membership. A degree of zero means that the value is not in the set, while a degree of one means that the value is completely representative of the set. This produces a curve across the members of the set. The fuzzy models manipulate linguistic variables. A linguistic variable is the representation of a fuzzy space which is essentially a fuzzy set derived from the evaluation of the linguistic variable. It encapsulates the properties of approximate or imprecise concepts in a systematic and computationally useful way. Although a linguistic variable may consist of many separate terms, it is considered as a single entity in the fuzzy proposition. The fuzzy if-then rules or the fuzzy conditional statements are expressions of the form IF *A* THEN *B* where *A* and *B* are labels of fuzzy sets characterized by appropriate membership functions (Zadeh, 1965). The if-then rules determine the system behavior. A knowledge base, decision making unit, fuzzification interface and a defuzzification interface construct a fuzzy inference system. The knowledge base comprises if-then rules and the appropriate MF associated to the linguistic constants. A decision-making unit performs the inference operations on the rules. The fuzzification interface determines the membership degree of crisp inputs to the linguistic constants, while defuzzification interface transforms the out coming fuzzy result into the crisp output. The basic structure of a fuzzy inference system is presented schematically in Figure 2.

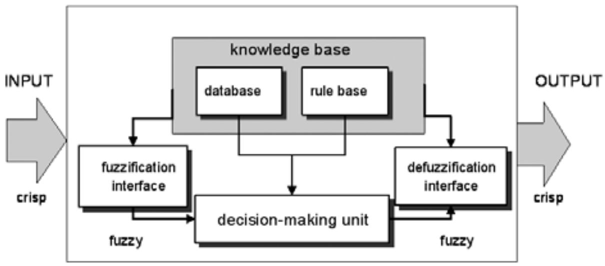

Figure 2. Fuzzy inference system.

The fuzzy inference system performs a fuzzy reasoning (inference operations upon fuzzy if-then rules) through next steps:

1. Comparing the input variables with the membership functions on the premise part to obtain the membership values of each linguistic label;

2. Combining through a specific T-norm the membership values on the premise part to get firing strength (weight) of each rule;
3. Generating the qualified consequent of each rule depending on the firing strength and
4. Aggregating the qualified consequents to produce a crisp output.

Several types of fuzzy reasoning have been proposed in the literature (Lee, 1990). A mathematical model which in some way uses fuzzy sets is called a fuzzy model. Here, we shall use Takagi–Sugeno model with incorporates fuzzy if-then rules where the output of each rule is a linear combination of input variables plus a constant term, and the final output is the weighted average of each rule's output (Takagi and Sugeno, 1983). The first order TSK fuzzy model is outlined in the Figure 3.

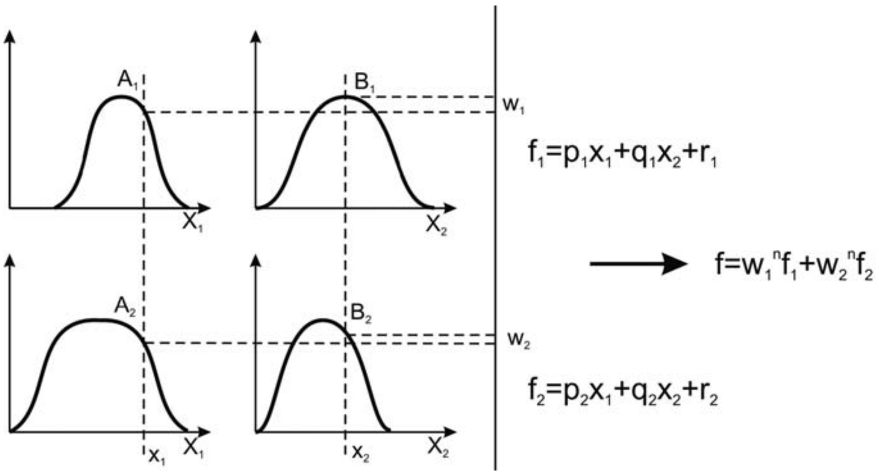

Figure 3. The Takagi-Sugeno-Kang (TSK) fuzzy inference system

THE ADAPTIVE NEURO-FUZZY INFERENCE SYSTEM - ANFIS

An adaptive network is a multi-layer, feed-forward network in which each node performs a particular node function based on incoming signals, as well as, on the set of parameters related to this node. Namely, each node function depends on the set of parameters which are associated to it. In the training process these parameters are being corrected in the aim of overall error minimization at the output of the network.

The ANFIS is the hybrid neural-fuzzy system. It has the capability of simulating the expert knowledge in the domain for which it has been constructed, on the basis of the expert knowledge represented by the if-then rules, and after the hybrid learning procedure has been realized. Thus, if an unknown input has been represented to the ANFIS, after the hybrid learning process, it can successfully predict the adequate output for the given input.

Now, let's consider our primer problem of route, or its part, preference estimation, and mark the wind strength with x_1, the traveling distance with x_2, and MFs attached to inputs with A_i and B_i respectively, where i=1,2,3,4,5. Our ANFIS is based on Takagi-Sugeno fuzzy inference system (Jang, 1993) and employs fuzzy rules of the next kind: if x_1 is A_i and x_2 is B_i then $f_1 = p_i x_1 + q_i x_2 + r_i$, where p, q and r is parameter set of function f. The number of these rules is 25. The ANFIS has five layers where all nodes from one layer have the same functions and its structure is represented in Figure 4.

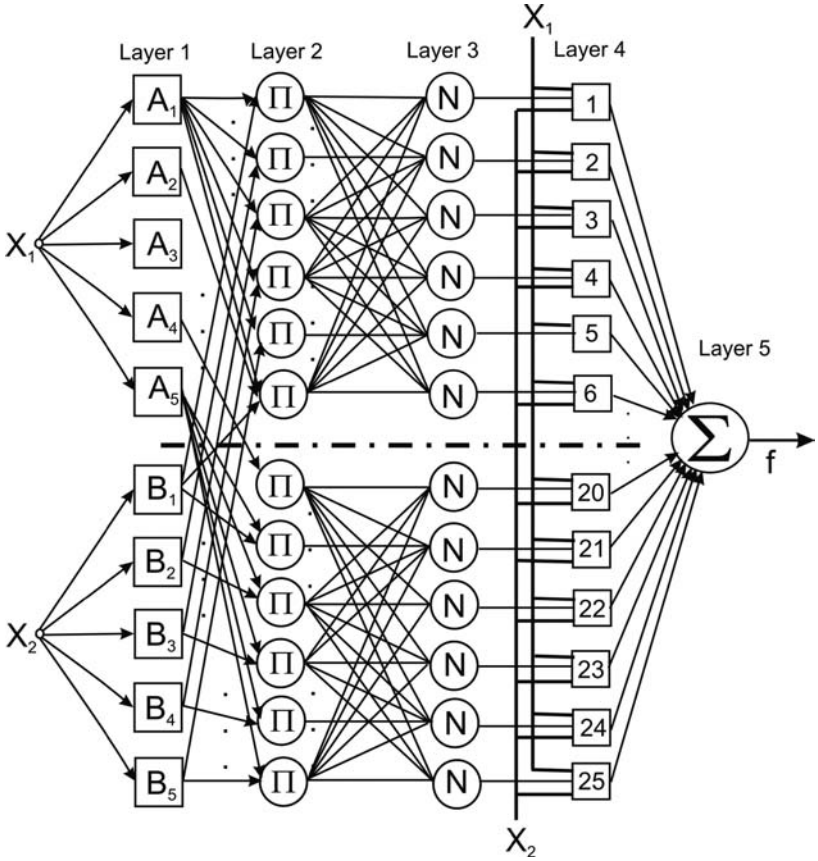

Figure 4. The ANFIS structure, here used as a navigation decision support tool

Each node represented with a square has a parameter (adaptive nodes), while nodes represented with a ring are fixed (fixed nodes). The parameters related to the adaptive nodes are presented by the set of training data in the learning process.

— Layer 1: The inputs to this layer are crisp x_1 values and x_2. The nodes are implemented as MFs and will determine the degree in which the inputs satisfy the MF. Each Gaussian function depends on its center and spread constant and these parameters are referred to as *premise parameters*.

— Layer 2: The number of the nodes is determined with the number of the fuzzy rules: with 2 inputs and 5 MFs, this layer consists of 25 nodes. The overall output of the nodes is the product of all incoming signals. Any T-norm operator can be used as fuzzy AND operator in this layer.

— Layer 3: The number of nodes in this layer is 25, too. Every node is a fix node and calculates the ratio of the *j*-th fuzzy rule firing strength (RFS) to the sum of RFS according to formula:

$$\overline{w_j} = \frac{w_j}{\sum_{i=1}^{25} w_i}, \text{ where } j = 1,2,\ldots,25 \tag{2}$$

— Layer 4: Every node in this layer is adaptive node with node function:

$$\overline{w_i} f_i = \overline{w_i}(p_i x_1 + q_i x_2 + r_i), \text{ where } i = 1,2,\ldots,25 \tag{3}$$

and p_i, q_i, r_i are parameters named *consequent parameters*.

— Layer 5: There is only one node that computes the output f of the ANFIS as the sum of incoming signals:

$$f = \sum_{i=1}^{25} \overline{w_i} f_i \tag{4}$$

The premise part of a rule defines a fuzzy region, while the consequent part determines the output within this region. The total number of these regions in case of here considered ANFIS is 25 (Figure 5).

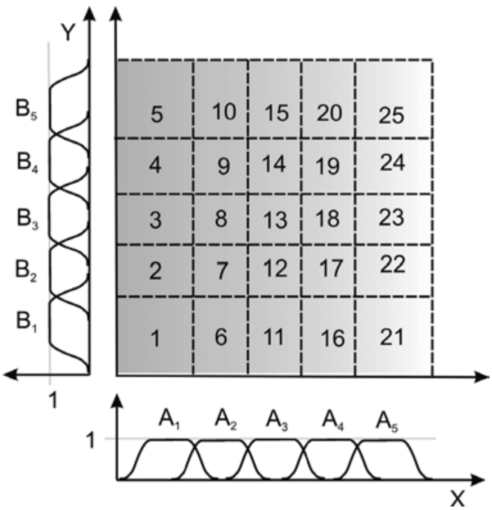

Figure 5. The partition of the input space into 25 fuzzy regions.

THE HYBRID LEARNING ALGORITHM

The gradient method can identify a parameter in an adaptive network, but its disadvantages are slowness and huge possibility to be troubled in local minimum. This is the main reason why the hybrid learning method, which combines gradient descent and least squares estimate (LSE) methods, has been exploited here.

The ANFIS uses back propagation to learn the premise parameters and least mean square estimation to determine the consequent parameters. In batch learning mode, which we have used in this paper, backward pass and premise parameters update, take place after the whole training data set has been presented to the ANFIS. Namely, premise parameters have been tuned after each epoch.

Generally, the hybrid learning algorithm in each epoch is developed through two phases: forward pass and backward pass, as it is summarized in the Table 1.

	Forward pass	**Backward pass**
Premise parameters	Fixed	Gradient descent
Consequent parameters	LSE	Fixed
Signals	Node output	Error rate

Table 1. The hybrid learning procedure

In the forward pass a set of training data formed from input values and desired corresponding output value is presented to the system. Layer by layer, every node output is calculated. According to described ANFIS structure, the overall output from the ANFIS can be represented as:

$$f=\sum_{i=1}^{25}\overline{w_i}f_i=\left(\overline{w_1}x_1\right)p_1+\left(\overline{w_1}x_2\right)q_1+\left(\overline{w_1}\right)r_1+\ldots+\left(\overline{w_{25}}x_1\right)p_{25}+\left(\overline{w_{25}}x_2\right)q_{25}+\left(\overline{w_{25}}\right)r_{25} \tag{5}$$

This means that the output is a function of the input variables and the set of parameters. More formally, output can be rewritten as:

$$f=F(I,S) \tag{6}$$

where I is the vector of input variables and S is the set of parameters. This set of parameters can be decomposed in two subsets from the perspective of output: linear parameters and nonlinear parameters. From equation (5) it is obvious that the output is linear in the consequent parameters $\{p_i, q_i, r_i\}$ $i = 1,2,\ldots,25$, so we can apply least squares method to identify these parameters. Also, after presenting a set of training data to the system, the ANFIS output can be described as matrix equation,

$A\theta = B$ where θ is an unknown vector whose elements are consequent parameters. The best values for these parameters can be calculated by the least-squares estimator $\theta^* = (A^T A)^{-1} A^T B$ where A^T is the transpose matrix of A. This method can be used if $A^T A$ is nonsingular matrix.

In the backward pass, all consequent parameters are fixed, since their best values are identified in the forward pass, and the error is calculated for each training pair. Let's assume that there are P training data pairs and that the ANFIS has L layers. With $N(L)$ we denoted the number of nodes in the layer L. The node in the i-th position of the k-th layer, as well as this node output, is symbolized with O_i^k. For the p-th training data, where $1 \le p \le P$, we can define the error, as a sum of the squared errors:

$$E_p = \sum_{m=1}^{N(L)} \left(T_{m,p} - O_{m,p}^L\right)^2 \tag{7}$$

where $T_{m,p}$ is the m-th component of p-th target output vector, and $O_{m,p}^L$ is the m-th component of actual output vector obtained by the presentation of the p-th input vector to the network. The overall error measure is:

$$E = \sum_{p=1}^{P} E_p \tag{8}$$

and needs to be minimized. Now, the error rate $\frac{\partial E_p}{\partial O}$ for p-th training data and for all node output O has to be calculated. According to the formula (7) the error rate for the output node in the i-th position is

$$\frac{\partial E_p}{\partial O_{i,p}^L} = -2\left(T_{i,p} - O_{i,p}^L\right) \tag{9}$$

while the error rate for the node in the i-th position of the k-th layer, where $1 \le k \le L-1$, can be derived by the chain rule:

$$\frac{\partial E_p}{\partial O_{i,p}^k} = \sum_{m=1}^{N(k+1)} \frac{\partial E_p}{\partial O_{m,p}^{k+1}} \frac{\partial O_{m,p}^{k+1}}{\partial O_{i,p}^k} \tag{10}$$

The equation (10) means that the error rate for the node from k-th layer can be calculated as a linear combination of the error rates of the nodes in the $(k+1)$-th layer. Consequently, the formula (9) needs to be applied first. After that, backward layer by layer, the formula (10) can be applied, until all error rates are calculated. The error signals propagate from the output to the input end, so this learning paradigm is called the *back-propagation* (Rumelhart *et al,* 1986). We need to apply the chain rule again, to find the *gradient vector*. Gradient vector is the derivative of the error measure with respect to each parameter. If q is a parameter of the network, we have:

$$\frac{\partial E}{\partial q} = \sum_{p=1}^{P} \frac{\partial E_p}{\partial q} = \sum_{p=1}^{P} \sum_{O^* \in S} \frac{\partial E_p}{\partial O^*} \frac{\partial O^*}{\partial q} \tag{11}$$

where S is the set of nodes containing q as a parameter. The update formula for the generic parameter q is:

$$\Delta q = -\eta \frac{\partial E}{\partial q} \tag{12}$$

in which η is a learning rate which can be expressed as:

$$\eta = \frac{k}{\sqrt{\sum_q \left(\frac{\partial E}{\partial q} \right)^2}} \tag{13}$$

where k is the step size. In the batch learning, the update formula for parameter q is (11), since update action occurs after each epoch, i. e. when all training data are presented to the network. At the end of the backward pass all the premise (nonlinear) parameters are updated by the gradient descent.

The hybrid learning algorithm pseudo – code

This subsection contains the applied pseudo-code for the hybrid learning method and its technical explanation in some more details.

The values necessary for creating the ANFIS are defined in the main program. The procedures ***Set*** set the value of the variable being denoted as the first argument to the numerical value representing the second argument of the procedure. Here are given the concrete numerical values being used in the paper. The first one ***for statement*** determines the initial values for MF, that is its centers and σ values. This has been achieved in a way that for each input – Gaussian functions are uniformly distributed in the given range of inputs. After entering the data being used for the network training, the set of rules is to be formed and the procedure of training can start through *Learning* procedure. In aim to test in this manner trained network, the appropriate testing procedure is to be realized by the procedure *Testing*.

```
Set (NumberOfInputs,2);
Set (NumberOfOutputs,1);
Set (NumberOfMF,5);
For input := 1 to NumberOfInputs do
      Begin
      Read(minValue[input], maxValue[input]);
      EvenlyAllocateMFs(maxValue[input]-minValue[input], NumberOfMF);
      For k:= 1 to NumberOfMF do
          Remember(Center[input,k], Sigma[input,k])
      end;
Read(TrainingData);
Determine(TrainingDataNumber);
Calculate(NumberOfRules);
CreateRules;
Set (EpochNumber,100);
Learning;
Testing;
```

The procedure *Learning*, as we shall see later, calls the procedure *UpdateStepSize* to realize possible correction of the variable *StepSize* values. The correction of this variable is to be done after each fourth epoch, counting from the epoch in which the previous correction has been done. It is realized on the base of the rules listed below:

1. If the error undergoes four reductions, then increase *StepSize* by 10%. This condition is checked with the function *Increase*.
2. If the error goes through combination of increase and decrease, then decrease *StepSize* by 10%. This condition is confirmed with the function *Decrease*.

The variable *Epoch* contains the index of the current epoch, while the variable *lastChanged* stores the index of the epoch in which the variable *StepSize* has been changed previously.

```
procedure UpdateStepSize(var lastChanged : integer; epoch : integer;
                          var StepSize : integer;)
begin
      if Decrease(lastChanged,epoch) then
          DecreaseStepSize(StepSize, 10);
      if Increase(lastChanged, epoch) then
          IncreaseStepSize(StepSize, 10);
      lastChanged := epoch;
end;
```

The pseudo-code for the key procedure *Learning* containing all the theoretical statements from the section 6, follows:

```
procedure Learning;
     var epoch, lastChanged, i, j, k, ErrorMeasure : integer;
        y, grad : real;
begin
     set MinError to huge value;
     lastChanged := 1;
     for epoch := 1 to EpochNumber do
        begin
           ErrorMeasure := 0;
           for j := 1 to TrainingDataNumber do
           begin
              for k := 1 to NumberOfInputs do
                  ReadInputValue(TrainingData[j]);
                  DesiredOutput[j]:= exstract last value from
                      TrainingData[j];
              { forward pass for all layers }
              for i := 1 to NumberOfNodes do
                      Calculate Node[i] output based on InputValues;
              LSE;
              { calculate error measure }
              ErrorMeasure := ErrorMeasure +
                   sqr(DesiredOutput[j] - ObtainedOutput[j]);
              OutputNode.de_do := -2*(DesiredOutput[j]-
                                      obtainedOutput[j]);

              Perform backward calculation for all inner layers;

              y := exp(-sqr((x-c)/sigma)/2);
              for i := FirstNodeFromLayer1 to LastNodeFromLayer1 do
                    for j := 1 to 2 do
                        begin
                          do_dp[1] :=
                              y*sqr(x-c)/(sqr(sigma)*sigma);
                          do_dp[2] := y*(x-c)/sqr(sigma);
                          node[i].de_dp[j] := node[i].de_dp[j] +
                              node[i].de_do*do_dp[j];
                      end;
        end;
        Calculate (Error[epoch]);
        if Error[epoch] < MinError then
              begin
                      MinError = Error[epoch];
                      remember all current parameters as best
                                                             parameters;
              end;
        { update parameters: sigma and center }
        grad := 0;
        for i := FirstNodeFromLayer1 to LastNodeFromLayer1 do
              for j : = 1 to 2 do
```

```
                grad := grad + sqr(node[i].de_dp[j]);
         grad := sqrt(grad);
         for i := FirstNodeFromLayer1 to LastNodeFromLayer1 do
               for j : = 1 to 2 do
                   node[i].para[j] := node[i].para[j] -
                       StepSize*node[i].de_dp[j]/grad;
         UpdateStepSize(lastChanged,epoch,StepSize);
      end
end;
```

The ending of this procedure, means that the network has been trained.

The last phase in ANFIS creation process is its testing. This procedure has been realized upon the set of test data, by the procedure ***Testing***, and after the testing, we have clear picture of the network efficiency.

```
procedure Testing;
var   i :  integer;
      TestingError : real;
begin
      Read(TestingData);
      Determine(TestingDataNumber);
      for i:= 1 to TestingDataNumber do
         Determine(inputs[i], DesiredOutput[i]);
      for i:= 1 to TestingDataNumber do
         begin
               ObtainedOutput[i] := CalculateOutput(inputs[i]);
               Error[i]:= DesiredOutput[i]-ObtainedOutput[i];
         end;
      TestingError := 0;
      for i := 1 to TestingDataNumber do
         TestingError := TestingError + Error[i];
      TestingError := TestingError/ TestingDataNumber
end;
```

This is the summarized presentation of the original code in Pascal being applied for the appropriated calculations in the paper, but it contains all cardinal elements of the proposed methodology for creating, training and testing the ANFIS based upon TSK and RFN functional equivalence. The obtained results, which will be presented within the next section, confirm its applicability in solving the real problem, as well as, its validity.

THE SIMULATION RESULTS

According to the problem formulation in section 2, we have to determine the preference of the route in long-ocean navigation, or even the preference of its segment, upon two criteria: the wind strength and the traveling distance in the sailing zone. Only two criteria have been considered in aim to simplify the problem, though the very similar procedure based on TSK and RFN equivalence could be applied to more complex problems of this kind with three, four or more criteria relevant for the degree of the route preference estimation.

Let's us suppose that we have the elementary fuzzy rules, formed on the base of expert knowledge related to the wind strength and the traffic density (which usually implies traveling distance between departure and arrival port, or between two waypoints) for the observed sailing zone (Table 2).

Rule	**Traveling distance**		**Wind strength**		**Preference**
No.	Linguistics value (fuzzy)	Num. value, e. g. (crisp)	Linguistics value (fuzzy)	Num. value, e. g. (crisp)	Value (crisp)
1	very small	500	very small	0.20	1.00
2	very small	500	small	2.70	0.75
3	very small	750	medium	4.00	0.50
4	very small	550	high	6.00	0.25
5	very small	500	very high	7.60	0.00
6	small	1550	very small	0.00	0.75
7	small	1630	small	2.75	0.75
8	small	1600	medium	4.75	0.50
9	small	1630	high	5.75	0.25
10	small	1500	very high	8.00	0.00
11	medium	2750	very small	0.60	0.75
12	medium	2100	small	2.00	0.75
13	medium	2700	medium	4.50	0.50
14	medium	2500	high	6.00	0.25
15	medium	2750	very high	7.80	0.00
16	high	4100	very small	0.00	0.25
17	high	4250	small	2.00	0.25
18	high	4000	medium	4.00	0.25
19	high	4100	high	6.10	0.25
20	high	3600	very high	7.90	0.00
21	very high	4900	very small	0.10	0.25
22	very high	4600	small	1.80	0.25
23	very high	5000	medium	4.75	0.00
24	very high	4900	high	5.50	0.00
25	very high	4900	very high	7.60	0.00

Table 2. The basic fuzzy rules for the sailing zone.

The exact numerical values in Table 2 (columns: 3rd and 5th) are given as some "crisp samples" for linguistics values *small*, *medium*, *high*, etc. These are the basic or “rough” fuzzy rules used for defining training and testing sets. Namely, the example being considered here is based upon the MFs of the wind strength and the traveling distance presented in Figures 6 and 7. The wind strength in the sailing area is usually between numbers 0 and 8 of Beaufort scale, while traveling distance is a number from the interval between 500 Nm (nautical mile) and 5000 Nm.

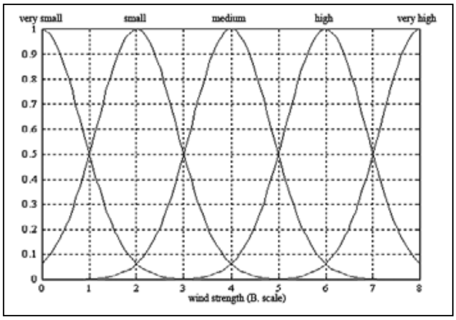

Figure 6. The MF of the wind strength.

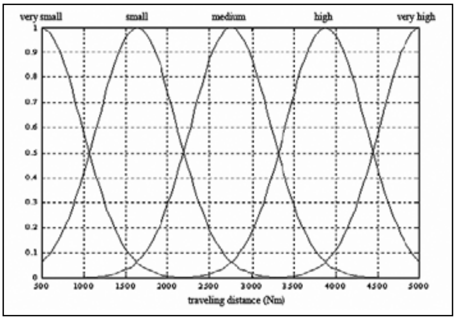

Figure 7. The MF of the traveling distance.

The values of the MFs centers and spread constants can be easily read from the presentation given above. The shapes of the wind strength MF before learning procedure are given in Figure 6, while the case after parameter regularization produced with hybrid learning algorithm (section 5) is presented below, in Figure 8. It is obvious that the centers of MFs have been shifted in a way, i.e. they have been tuned properly in aim to reduce errors between obtained and target outputs (the degrees of the route preference). Thus, this MFs tuning implies the least level of the output error in the model.

It is to be summarized that the total number of nodes in the ANFIS is 75. Though, the applied ANFIS model has 25 fuzzy rules, 25 linear and 20 nonlinear parameters. The 436 data pairs have been used in its training process. The average error after training process was $E = 0.038793$. The training error minimization, which is a result of the described hybrid learning completed after 100 epochs, is presented in the Figure 9. Obviously, the error curve decreases permanently and approaches to its minimal obtained value.

The route preference surface produced on the base of the 25 fuzzy rules previously defined and the corre-

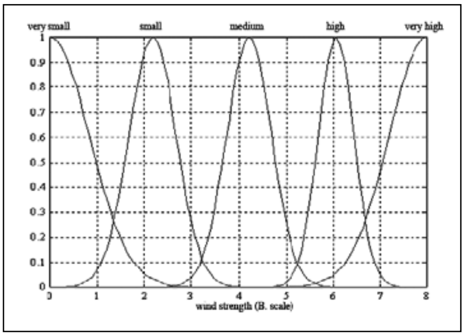

Figure 8. The wind strength MFs' tuning (the MFs after learning).

sponding outputs within corresponding fuzzy regions are presented graphically in 3D space in Figure 10.

Within the ANFIS creation procedure, the testing phase follows after the training process. We used 50 data pairs as testing data to calculate the ANFIS output.

The proposed ANFIS efficiency has been presented in Figure 11. Here, 50 training data pairs have been used and the system output has been shown with "*", while the expected value has been represented with "·". (Figure 11). The average testing error was 0.014781. It is clear that in the most cases they are at the same position or next to each other. This confirms validity of the proposed ANFIS and the applied hybrid learning procedure.

Some of the illustrational samples, chosen from these 50 tested cases, are given in Table 3.

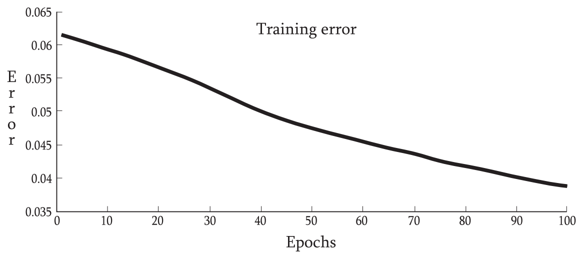

Figure 9. The error curve for the ANFIS.

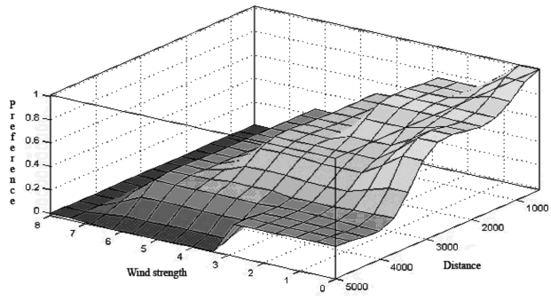

Figure 10. The output regions and the corresponding output values.

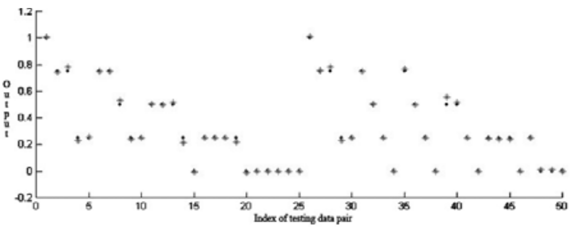

Figure 11. The desired outputs judging against the obtained ones.

On the base of the numerical data given in Table 3, it is obvious that the error is of E-02 or E-03 order, which is satisfying accuracy for a decision support method, like this of route preference degree estimation in long-ocean navigation.

How this model can be practically used in navigation? It could be used in the following manner: mariner gives the inputs to the computer, i.e. its own estimations for the wind strength and the traveling distance, and according to that how do they "fit" into the expert knowledge base – the degree of the route preference (or its segment) will be obtained automatically by the computer. This could be, in a way, a great help in ship maneuvering, particularly when larger number of criteria is to be considered and when it is not so easy to estimate a certain route (or its segment) preference. Surely, this is still more theoretical then practical approach to the optimal long-ocean route selection, but it can be, undoubtedly, used when the appropriate knowledge base for some sailing zones become available.

Inputs		**Outputs**		**Error**
Wind strength [B. scale]	Traveling distance [Nm]	Desired output	Obtained output	
1.00	555	1.00	0.9919	0.0080968
0.30	510	1.00	0.9863	0.0136330
0.10	1500	0.75	0.7573	0.0073257
0.90	1700	0.75	0.7582	0.0082239
4.00	1728	0.50	0.4988	0.0012556
3.90	2500	0.50	0.5075	0.0075517
5.80	1500	0.25	0.2501	0.0001391
3.00	4128	0.25	0.2485	0.0014879
4.00	4921	0.00	0.0076	0.0076976
7.50	4800	0.00	0.0083	0.0083899

Table 3. The calculated data for some sample testing data.

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SIMULATION FOR TANKERS TOPPING-OFF CARGO LOADING

E. Barsan[1], L. C. Chiotoroiu[2], D. Dinu[3] and R. Hanzu-Pazara[4]

Abstract

The main goal of the joint research undertaken in projects SITUMET and OPTIMPORT is focused on maritime distant learning and design of WEB based loading simulator for tanker operation. The strategy adopted for better located maritime education and training (MET) in the work processes on board has three components: distant simulation learning technology – on board and ashore; experiential learning on board and teaching (training) in the classroom or in the simulators. The WEB based Liquid Cargo Handling Simulator is a new generation of training tools, allowing trainees to perform online training when their ship arrives in port.

The main part of the paper is the module developed by the authors regarding Topping Off. That means to fill the tanks to the maximum 98% of the volume, representing the end of loading procedures. The module is reserved for working personnel on board Product Carrier Tankers and is designed to develop the competencies required to execute and monitor the loading/discharging process.

The implementation of Liquid Cargo Handling (LCH) Simulator Software –tankers topping off included– into a learning-management-system (LMS) is a tool to close the gap between theoretical learning and practical experience in maritime education.

Key words: tankers, simulation, e-Learning, training.

[1] Head of Navigation Dep. Constantza Maritime University (ebirsan@internav.com), Mircea cel Batrin no. 104, 900663, Constantza, Romania. [2] PhD Mechanical Dep. Constantza Maritime Univesity (lchiotoroiu@imc.ro), Mircea cel Batrin 104, 900663, Constantza, Romania. [3] PhD Mechanical Dep. Constantza Maritime University (ddinu@imc.ro), Mircea cel Batrin no. 104, 900663, Constantza, Romania. [4]Assistant Navigation Dep. Constantza Maritime Univerity (raduhanzu@yahoo.com), Mircea cel Batrin Street no. 104, 900663, Constantza, Romania.

INTRODUCTION

Starting nowadays, the distance learning system is and will be a useful tool especially in those working area where the people will not be able to join daily seminars and laboratories in order to improve their knowledge's. This is the shipping industry case, where the performances of the personnel involved are in close relation with their learning process. As in other technical work systems, expertise of workers in the maritime domain is declining as a consequence of true apprenticeship experiences. While the complexity of work processes on board have increased due to factors like:

— Automation of ships functions;
— Reduction of crew sizes and
— Multinational crew composition,

The performance of nautical and also technical officers draws on a considerable amount of procedural and conditional knowledge. Nevertheless the listed factors above obstruct both direct and indirect experiential learning, that is, *learning by doing* and *learning by communication* as keys to practically acquire the procedural knowledge of "good seamanship" (Chiotoroiu, 2005).

Modern maritime education and training requires the fulfillment of many educational objectives to train and assess students (cadets and junior engineers) and officers of the watch at operational and management level in accordance with the provisions and requirements of STCW 95 and specific IMO courses.

There are certain cases where the only solution to fulfill these demands is the maritime simulators training, like navigation deck management, engine room management and training for familiarization with different kind of ships. In this last category are included petroleum and derivates products carriers, gas carriers and chemical carriers.

The maritime simulators represents in fact a virtual copy of the real ships, including details for on board operations, like load/discharge operations, normal or abnormal functions of different installations.

Consequently, starting with 2003, several advanced simulators have been acquired at the Constantza Maritime University (CMU). As a result, CMU owned a simulation complex comprises of 3 state of the art simulators covering Full Mission Navigation, Global Maritime Distress and Safety System (GMDSS) and Engine Room Simulators (Chiotoroiu, 2005), Moreover, CMU has recently joint an EU project for distant simulation and tutorial systems on board. This will grant CMU a license to use the 4th web-enabled simulator for Liquid Cargo Handling.

For the implementation of this distance learning concept on board ships, EU funds this program for setting up and development of e-Learning modules addressed to the seamen's, packages which allowed training and assessment on board via maritime communication system.

WEB SIMULATION LEARNING TECHNOLOGY

The distance learning system became one of the principal ways of studying for many students worldwide. Many Universities and Training Centers have already developed their own e-Learning platforms to help trainees having the opportunity to increase their study level or to renew the knowledge's acquired in the school years.

In the same time, there is a great push ahead for advanced distant learning. New development in simulation using Internet has contributed to make the MET systems more flexible. Standards like Sharable Content Object Reference Model (SCORM) or High Level Architecture (HLA) have been developed in support for Advanced Distributed Learning (ADL).

Our goal is to support and optimize experiential learning in tanker operations by means of web-based simulation. This is in fact our present developing stage and represents authors' participation into the program referring to web enable simulation. The European pilot project SITUMET and the Romanian Ministry of Education project OPTIMPORT, represents a consortium between the manufacturer's of simulation products (Kongsberg Norway), four Maritime Universities in Europe, included CMU and also seven Tanker shipping companies.

The first step is referring to the tanker related IMO model courses. The main idea is that maritime education and training has to be anchored and (re)located in the work process on board (Schütte, 2003).

Distance, separation, and distribution, not at last, are inherent characteristics of the maritime industry, requiring special solutions for vocational education and training as well as human resources development. From this point of view, e-Learning in general and web-based simulation in particular is a promising way to (re)establish work process oriented MET (Chiotoroiu *et all*, 2005).

A central effort into this project was the implementation of an internet based infrastructure for distant learning and tutoring that can be used for the distribution of courses tailored (Figure 1) to offer guidance for investigative learning but also theoretical reflection of personally experienced tasks and events (Wand, 2003).

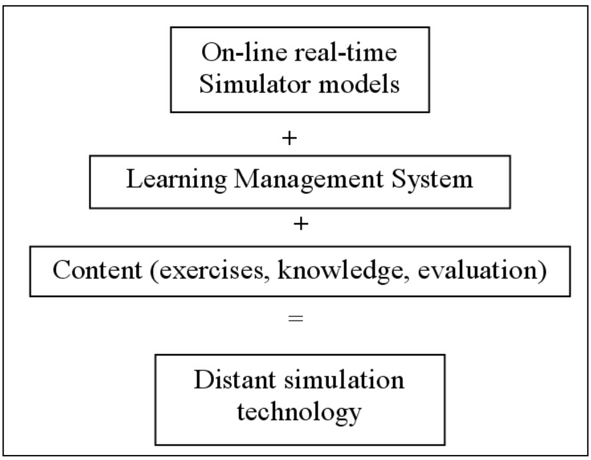


Figure 1. Concept of Distant Simulation Technology

The main tool to close the gap between theoretical learning and practical experience is the implementation of liquid-cargo-handling-simulator-software into a LMS. Basically, a LMS is software that automates the administration of training events. Thus, LMS ensures easy access to the students, monitoring and tracking for the instructors. Either via internet or a locally-installed learning-management-system, the tool shall ensure that students acquire qualitative mental models and generic intellectual capacities as critical ingredients of proficient work on board. Within this project we are involved, the LMS Scorm® 1.2 compliant is open source software *Ilias v. 3.4.4.*, used in present in different German and French universities (Köln, Bremen, Bordeaux).

Regarding the author ware tool, with respect to LMS compatibility, a multimedia *Macromedia® Authorware 7* is used. For simulation exercises, screenshots, interactive demonstrations and courses content, a multimedia software *ViewletBuilder 4 Professional*™, created by Qarbon Inc. USA has acquired. This way, the new IMO Model Courses will combine different learning forms: simulation, practical tasks and theory modules. Simulation in particular is utilized as a substitute for concrete experience through job performance, providing opportunities for explorative learning without risk.

E-LEARNING MODULES FOR TANKER OPERATION TRAINING

Distant learning or web based training courses through simulation represent without any doubt a new training method in the maritime field (Barsan, 2002). It is suitable for all seafarers and within a Maritime University like ours, especially for the undergraduate extramural studies or post graduates. The advantages are the asynchronous teaching and distant on-line evaluation and assessment on these new courses based on e-learning. Our intention is to develop in the near future new packages of e-learning (courses, laboratories and tutorials), using this new technology (Chiotoroiu and Dinu, 2004). Besides the already mentioned simulators, the software programs available in CMU for the time being are as follows:

— Neptune Liquid Cargo Handling Product Carrier desktop Simulator, Kongsberg Norway (2005)
— Neptune LCH Chemical Carrier desktop Simulator, Kongsberg Norway (2006)
— ViewletBuider & Cam, multimedia tool, (2005)
— e-Coach Editor, Kongsberg Norway (2006)
— Neptune Launcher, Kongsberg Norway (2006)
— Macromedia Authorware 7.0, USA (2005).

These e-Learning modules we are creating basically consist of:

— Theory module (in .pdf or Macromedia format) - is presented in a comprehensive way and can be found and access from the LMS (Figure 2).

Training Objectives and Initial Condition (of the exercise) - according to IMO model courses and standard procedures, any exercise we are creating has a specific format which highlights the initial condition of the exercise, the training objectives which has to be fulfilled and final instructions for the trainee before start up the exercise (Figure 3). We have to underline that the online tutorial and training objectives are design similar with the Computer Based Training (CBT) software, because they have to replace the physical presence of the teacher.

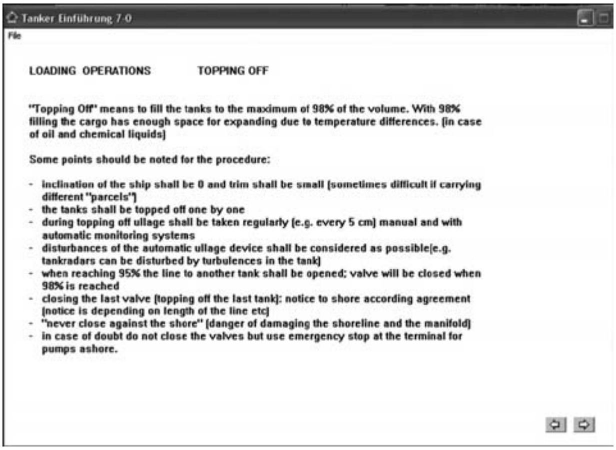
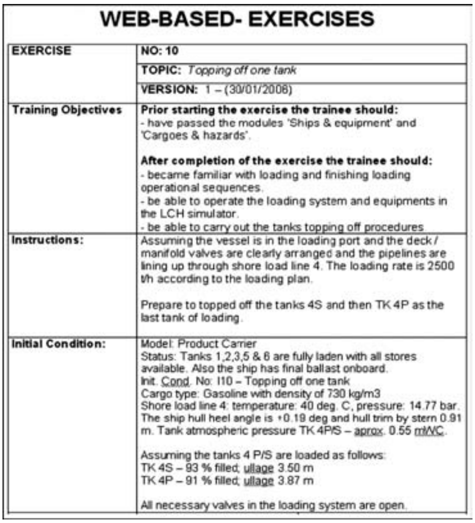


Figure 2. Example of LMS theory module for Topping Off one tank.

— Step by step demonstrator (simulator interactive demonstration, in ViewletBuilder format). This represent all steps the students need to follow when a specific process is running on the simulator. The step by step demonstrator Figure 4) is needed because using a simulator, without the supervision of an instructor could be a very difficult task for the trainee. Only help files and tutorials could not be sufficient for explaining the correct operational steps of a real time process. More than that, loading/discharging oil products is a high risk operation, that must be executed in accordance with the specific procedures and monitored all time long. The main role of the online simulator training is to give to the trainee the opportunity to learn the correct procedures and to gain the required skills in order to perform without mistakes the real life job.

— Simulator exercises (e-Coach/ Evaluation editors) - until recently, simulator exercises have been monitored by skilled teachers present at all times with students. As a result, Kongsberg Norway has developed a new simulation tool for increasing training efficiency and students throughput, named e-Coach. This feature is very important and



WEB-BASED- EXERCISES

EXERCISE	**NO: 10**
	TOPIC: *Topping off one tank*
	VERSION: 1 – (30/01/2008)
Training Objectives	**Prior starting the exercise the trainee should:** - have passed the modules 'Ships & equipment' and 'Cargoes & hazards'. **After completion of the exercise the trainee should:** - became familiar with loading and finishing loading operational sequences. - be able to operate the loading system and equipments in the LCH simulator. - be able to carry out the tanks topping off procedures
Instructions:	Assuming the vessel is in the loading port and the deck / manifold valves are clearly arranged and the pipelines are lining up through shore load line 4. The loading rate is 2500 t/h according to the loading plan. Prepare to topped off the tanks 4S and then TK 4P as the last tank of loading.
Initial Condition:	Model: Product Carrier Status: Tanks 1,2,3,5 & 6 are fully laden with all stores available. Also the ship has final ballast onboard. Init. Cond. No: I10 – Topping off one tank Cargo type: Gasoline with density of 730 kg/m3 Shore load line 4: temperature: 40 deg. C, pressure: 14.77 bar. The ship hull heel angle is +0.19 deg and hull trim by stern 0.91 m. Tank atmospheric pressure TK 4P/S – aprox. 0.55 mWC. Assuming the tanks 4 P/S are loaded as follows: TK 4S – 93 % filled; ullage 3.50 m TK 4P – 91 % filled; ullage 3.87 m All necessary valves in the loading system are open.

Figure 3. Example of LMS Training Objectives for Topping Off one tank.

mainly compulsory in an online training system, because is the only way to replace the standard debriefing session after an simulation exercise. Through this software, instructor have to be no longer present all the time, allowing for "self-study" to be accomplished by students running e-Coach exercises with assessment features (Figure 5). Using of the e-Coach is not very easy task, because the instructor that have to prepare the scenario and to create the evaluation form, must identify the main events of the simulation and the moments where the trainee could have some difficulties in finding the correct actions.

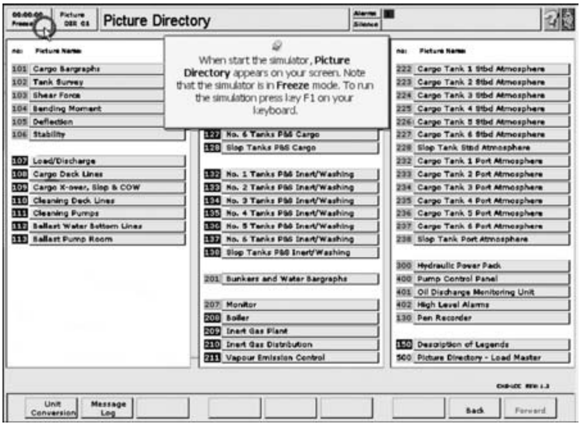


Figure 4. Step by step demonstrator made for the LCH simulator.

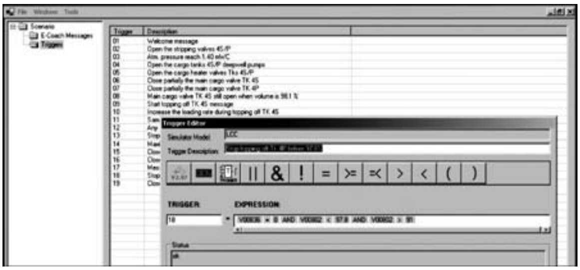


Figure 5. Example of triggers for Topping off exercise.

The e-Coach editor consists of two editors: the Trigger Editor and the Message Editor. The first is use to monitor certain variables to trigger the appropriate message.

The second one is used for editing text messages boxes, based and linked to the triggers. The e-Coach messages pop up on the student screens and are categorised as follows:

— Information - which can be general information, hints and tips, positive feedback etc.

— Warning - giving the student a warning when he/she is moving towards situations which may lead to malfunctions or shutdown of equipment.

— Errors - tells the student that he/she has carried out an incorrect action that will cause a critical situation and that the simulation will be terminated.

Simulator exercises on-line assessment - when creating simulators exercises, specific procedure discussed and approved within the partnership shall be followed. It has 22 steps, starting with the need analysis for the exercise to be carried out and finishing with implementing in the LMS after successful testing and improvement the package. Each exercise has an evaluation form consisting of various evaluation criteria (Figure 6). We think that from the point of view of the instructor preparing the web based simulation scenarios, the most difficult task is to established the evaluation criteria and to define the actions that must be evaluated. The evaluations sheet that will be displayed to the trainee at the end of the simulation scenario must contained a sufficient level of details in order to give to the trainee a full understandable picture of his behavior during the exercise.

The score is less important than the explanations of the mistakes and errors done, taking into account that practically, the debriefing is replaced only by the scoring sheet

EXERCISES – EVALUATION FORM

EXERCISE	NO: 10
	TOPIC: *Topping off one tank*
	VERSION: 1 – (30/01/2006)

Line	Description	Pass Criteria	Remarks
1.	Cargo pump stripping valve TK 4S	Closed	V00753
2.	Cargo pump stripping valve TK 4P	Closed	V00853
3.	Cargo pump TK 4S	Closed	R00735
4.	Cargo pump TK 4P	Closed	R00835
5.	Tank top overflow (CT 4S)	G = 0	G00717
6.	Tank top overflow (CT 4P)	G = 0	G00817
7.	Total tank overflow oil mass	G = 0	M03634
8.	Total manifold spill oil	G = 0	M03626
9.	Tank 4S volume	93< V <98.1 %	V00702
10.	Tank 4P volume	91< V <98.1 %	V 00802
11.	Hull trim	0.86< L < 0.92	L04013
12.	Hull heel angle	-0.1<X< 0.2	X04914
13.	Metacentric height GM	2.83< GM< 2.90	L06075
14.	Loading rate shore line 4	0<G< 2510	G43705
15.	Total mass TK 1S	4099.35 <M< 4099.39	M00103
16.	Total mass TK 1P	4117.35 <M< 4117.39	M00203
17.	Total mass TK 2S	5361.58 <M< 5361.62	M00303
18.	Total mass TK 2P	5372.04 <M< 5372.10	M00403
19.	Total mass TK 3S	5367.18 <M< 5367.24	M00503
20.	Total mass TK 3P	5375.85 <M< 5375.89	M00603
21.	Total mass TK 5S	5367.60 <M< 5367.62	M00903
22.	Total mass TK 5P	5375.85 <M< 5375.89	M01003
23.	Total mass TK 6S	5187.99 <M< 5188.04	M01103
24.	Total mass TK 6P	5189.08 <M< 5189.12	M01203

Remarks:
Line 1 – 4: Stripping valves and cargo tanks should remain closed during topping off.
Line 15 – 24: Total mass in the other tanks already topped off should remain the same.

Figure 6. Example of LMS evaluation form for Topping Off one tank.

All these evaluation figures became evaluation actions inside the simulator. After the student/ trainee runs a specific e-learning package and therefore a simulator exercise, the LMS monitors and track all his exercise and finally, by accessing a .txt file from Desktop/My Documents/ Neptune /Assessment, the instructor have the students exercise results as indicated in Figure 7.

Then, the results can be converted into grades, based on total sum achieved by the student. The evaluation sum is a function of magnitude and duration of the deviation. The deviation occurs when the evaluation criteria value is outside its preset range, as define by its high and low limits (see Figure 7). Thus, a total sum between 0.00 and 0.15 will means grade 10; 0.16 – 0.20 = grade 9; 0.21 – 0.30 = grade 8; 0.31 – 0.40 = grade 7; 0.41 – 0.50 = grade 6 and 0.51 – 0.60 means grade 5. For any other score exceeding 0.61 the student have to repeat the entire module from the beginning.

```
                                Topping off TK 4 S P.txt
EVALUATION REPORT - Wed Feb 15 12:24:37 2006

SCENARIO    : Topping off TK 4 S/P
REPORT MODE: manually print
SIM. TIME   : 00:10:20

 ID : Description         (trigger:   ID) LOW-LIM  HIGH-LIM WEIGHT   SUM
---------------------------------------------------------------------------
+E20: Hull trim           (trigger: +X01) 0.00     0.93     2.00     0.00
+E21: Hull heel angle     (trigger: +X01) 0.00     0.01     2.00     0.17
 E22: ---
 E23: ---
+E24: Cargo pump strippin (trigger: +X00) 0.00     0.00     1.00     0.00
+E25: Cargo pump strippin (trigger: +X00) 0.00     0.00     1.00     0.00
+E26: Cargo pump TK 4S    (trigger: +X00) 0.00     0.00     1.00     0.18
+E27: Cargo pump TK 4P    (trigger: +X00) 0.00     0.00     1.00     0.00
+E28: Tank top overflow 4 (trigger: +X00) 0.00     0.00     1.00     0.00
+E29: Tank top overflow 4 (trigger: +X00) 0.00     0.00     1.00     0.00
+E30: Loading rate shore  (trigger: +X00) 500.00   2500.00  1.00     1055.01
+E31: Tank level TK 4S    (trigger: +X00) 16.98    18.48    3.00     0.00
+E32: Tank level TK 4P    (trigger: +X00) 16.96    18.47    3.00     0.00
+E33: Shore load line 4 p (trigger: +X00) 0.00     1.00     1.00     0.00
+E34: Shore line 4 shut o (trigger: +X00) 0.00     1.00     1.00     0.00
+E35: Main cargo valve TK (trigger: +X00) 0.00     100.00   1.00     0.00
+E36: Main cargo valve TK (trigger: +X00) 0.00     100.00   1.00     0.00
+E37: Valve cargo to heat (trigger: +X00) 0.00     1.00     1.00     0.00
+E38: Valve heater bypass (trigger: +X00) 0.00     1.00     1.00     0.00
+E39: Valve cargo to heat (trigger: +X00) 0.00     1.00     1.00     0.00
+E40: Valve heater bypass (trigger: +X00) 0.00     1.00     1.00     0.00
+E41: Cargo manifold valv (trigger: +X00) 0.00     1.00     1.00     0.00
+E42: Cargo shore connect (trigger: +X00) 0.00     1.00     1.00     0.00
+E43: Hull trim           (trigger: +X00) 0.00     0.93     2.00     0.00
+E44: Hull heel angle     (trigger: +X00) 0.00     0.01     2.00     1.19
---------------------------------------------------------------------------
 TOTAL SUM:                                                          0.17
---------------------------------------------------------------------------
```

Figure 7. Example of exercise results for topping off.

CONCLUSIONS

The encouraging results obtained during testing phase by our students give us the right to consider that the use of multimedia tools, computer programs and web enable simulation modules must be constantly improved and extended to all the subjects and disciplines studied in the CMU in relation with Neptune simulators (Barsan, 2002b). Also, the interactive methods prove to be efficient and have to be developed widely in the future.

The paper has presented the implementation of the new LCH simulators as part of the teaching process. The use of maritime simulators represents an advantage for our University and for the trainees (students or seafarers) in the future because of the:

1. Many simulation scenarios we can create and develop.
2. Total scenario reproducibility.
3. Abnormal situation scenarios created without having any real consequences.
4. On line training/evaluation for students or graduated officers.

These total packages of e-learning programs we are creating will be certificated courses based on e-learning or web-enabled simulation. This will relocate maritime education and training of the work process on board, while developing a network for cooperation between maritime training institutions and shipping companies. In our opinion, the success criteria for this new approach of MET will be the following:

— Reduction of contact hours in maritime training and education (free training and education capacity on shore to serve the growing need for nautical officers in the coming years);

— Harmonization of maritime education in Europe (common standards, methods and a network for knowledge cooperation);

— Employability of entry-level nautical officers;

— Tanker safety (increased human reliability and expert knowledge on board);

Distant learning combined with simulators will make a new and flexible training approach possible. Therefore, we can finally consider that e-Learning has a great and positive impact on Romanian maritime education and moreover learning combined with training will be by far the most effective way to increase skills and competence.

Using of WEB based simulators will facilitate also the up-to-date training for officers and other onboard technical staff, bringing maritime training to an upper level of technology and offering more opportunities then the stand alone computer based training (CBT). For the last 10 years, the CBT was the only training system that was found suitable for the seafarers, onboard ships. For ships, real time connection to the Internet via satellite remains an expensive gadget, an during the sea voyage time, onboard training must continue to use CBT or other forms of stand alone PC courses.

When ship arrives in ports, seafarers will have the opportunity to access the Internet directly from their cabins, using a low cost (or free) wireless connection provided by the port administration. Constantza Maritime University is undertaking a series of test in Constantza Port, in order to determine practical solutions for providing wireless Internet in the port area. In accordance with these tests, almost in all terminals, wireless connections could be provided using appropriate radio senders and signal could be detected on the laptops located on the alongside board in the upper floors of the ship's castle.

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