Control Method and Efficient Algorithm for an Anchoring System of Vessels

Gerardo Gonzalez-Filgueira, Mario Rivera-Dominguez

Industrial Engineering Department, University of A Coruña, Ferrol, Spain

gerardo.gonzalez@udc.es; rivera.d.mario@gmail.com

***Abstract*- Industry requires more and more systems focused on Automation. This paper discusses the possibility of programming an intelligent control system, an intelligent agent, that allows reading, interpreting and modifying all the parameters involved in the anchoring of a vessel. This system provides support to crew in taking decisions about anchoring of a vessel. The system has been developed following the standard in naval electronics NMEA (National Marine Electronics Association), so that through several transformations multi-protocol NMEA-232 and RS 232/RS 485, the data can be read by a PLC and by means developing a control interface, it is possible to view and modify all the elements through a HMI panel. Finally a SCADA system is used to verify the proper functioning of the monitoring process.**

***Keywords*- Automatic Control; Marine Navigation; Centralized Control; Programmable Control; Communication System Control; PLC; SCADA Systems**

I. INTRODUCTION

The maneuver of anchoring and the subsequent permanence in the anchorage, constitutes a stage in the phase of maritime navigation in the merchant marine. Often precede the phase of detention in port, or port phase in moments of wait due the congestion in the port facilities. It is therefore to keep the vessel during a timeout, which attempts to be the minimum possible.

The recreational use of sea determines the use of the vessel, both in sailing as staying stopped, to carry out many activities; which is why the vessel remains in this condition of anchoring an important time on the total time of navigation. In the middle of the twentieth century, the popularization of the nautical activity has fostered the creation of a large fleet of yachts [1] [2] (Fig. 1) that represents one more aspect of the recreational use of the sea. The adaptation of these kinds of vessels to the activity where are going to be used [3], with the consequently differentiation from other types of vessels, constitutes one of the characteristics of the evolution of vessels: specialization in traffic or activities.

In line with this activity, the equipments must be adapted to the peculiarities of its use. The anchoring condition constitutes a source of concern for the crew of the recreational vessel. This is due to several factors: small crews, lack of professionalism or inexperience of the crew, tiredness after a long navigation, ignorance of the area of navigation, or simple lack of attention during the maneuver [4] [5] [6] [7] [8] [9] or the remaining in the anchorage, since the focus of the activity is the recreation of the participants. This concern is particularly pronounced when it decides anchoring [10] in a cove or shelter to rest or to spend the night, which makes it especially dangerous if weather conditions change during this period.

Fig. 1 A large yacht

The aim of this work is to develop, through the use of a PLC, an intelligent control system [11] [12] that allows reading, interpreting [13] and modifying all the parameters involved during the maneuver of anchoring of a vessel.

II. DESCRIPTION PLANT PROCESS CONTROL

A. *Used Method*

The system has been developed following the standard in naval electronics NMEA (National Marine Electronics Association), so that through several multi-protocol transformations NMEA-RS 232 and RS 232/RS 485, the data can be read by means of a PLC Siemens S7-224-XP, and through the development of a control interface, it is possible to display and modify all the elements with a touch panel. To achieve this, it is presented an overview (Fig. 2), where the necessary devices, sensors, are naval instrumentation available on any vessel: a digital anemometer and a weather vane, depth sounder, speed log probe with temperature sensor and inductive marine sensors. In this work are used inductive proximity sensors, IM 18 series DC, S7 plus and ST60 wind&Close Hauled instruments of Raymarine series. These signals coming from sensors are transmitted using NMEA protocol and trough a RS 232 connection. The PLC allows only connection to their communications ports through RS-485, so is necessary a conversion card of Siemens PPI RS-232/RS-485. This type of configurable integrated circuit card enables communication between the computer and the PLC, as when it is necessary to load the software in the computer by way of PPI protocol, also works as a moderator of the NMEA data frames when the connection is between the smart card and the PLC. For this to happen, the necessary adjustments should be checked always, modifying the ratio of transmission to 4800 bauds in local mode, and so to dispose an effective communication. The PLC lacks an interface able to interpret NMEA data frames, so it is necessary to integrate one, to configure their input ports in Freeport mode, and to implement an algorithm that can interpret the necessary data information.

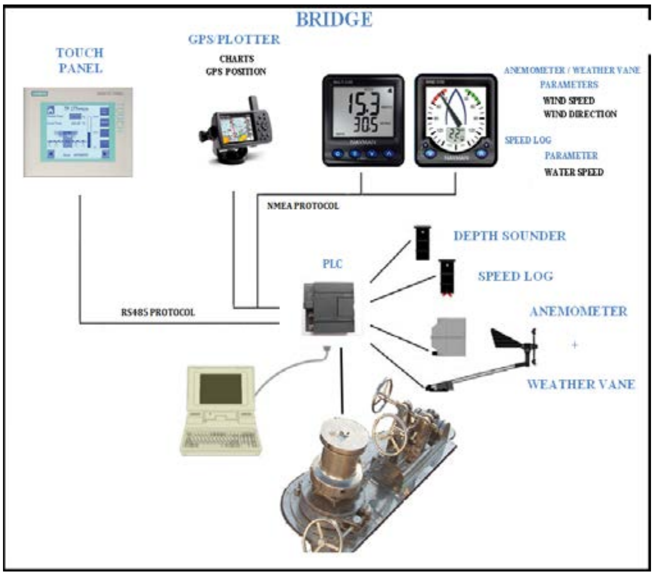

Fig. 2 Communication by means of star network topology through a PLC

The system is designed for getting the readings of the parameters of wind speed, wind direction, speed of the stream under the vessel and the depth, through the NMEA data frames. These data frames are classified according to the type of peripheral that sends these signals, and then, they are filtered for getting the necessary data information. With this information, the PLC will process certain arithmetic calculations, which it then sends to the HMI panel (touch screen) for its visualization. In this case, a prototype has been developed with products Raymarine employing its own protocol the “SeaTalk”. This involves the use of a SeaTalk-NMEA converter microcircuit card, which also filters and sorts the signal from the sensors, so that an additional multiplexer device not is necessary. Only in the case of being interested in the integration of any device of other brand, for example a drive SIMRAD GPS/PLOTTER device, it would be required the integration of the multiplexer, to deliver the PLC all the "structured" data information, and thus avoid conflicts in the data transmission.

The PLC works as DAQ system and it is used the proposed algorithm in this work, implemented in Step 7 Microwin software of Siemens, to get that the on line input data achieve to the serial ports of S7-224 PLC. In addition to the development of PLC control program, is developed also the interface that will handle the display by means a software of Supervisory and Control. The data information is displayed on a touch screen, connected via an MPI connection with another input of the PLC ports. The operator panel will be programmed using a SCADA system as WinCC by Siemens, describing all the HMI screens involved in the application. Moreover, it uses hyperterminal software of Microsoft that allows showing output data in ASCII format. To simulate SeaTalk data use Nema Talker software.

This work could be of application in all naval environment, although is especially thought for those yachts in the medium and large length field.

B. Parameters Characteristic

At the time to carry out the maneuver of anchoring is necessary to know certain parameters characteristic of the vessel, so that the calculations performed are the most accurate as possible. Of these parameters, it can be distinguished two groups: the belonging to the constructive characteristics of the vessel, and those that define the characteristics of the anchor to be used for the anchoring. The next parameters [14] are needed for identifying the vessel:

a) Length overall or length between perpendiculars, the maximum vessel length.

b) Breadth or width of the vessel.

c) Freeboard depth or height of the vessel.

d) Block coefficient. This parameter is crucial, and is usually supplied by the shipyard.

e) Draught or minimum water level needed for craft not in danger of running aground.

f) Apparent specific gravity of the chain is the ratio of the mass of chain depending on its length.

Besides also it is necessary to know the typology of anchor with the one that is going to carry out the anchoring [15], since there are great variety of them, with different characteristics that vary according to the conditions in which are going to be used.

These parameters are necessary, for the calculation that requires the program, through some mathematical algorithms and they constitute an important part of the automation.

C. Theoretical Analysis

Several physical parameters affect the anchoring of the vessel. To model this behavior, the physical equations governing those parameters must be known.

The action of the wind, for the motor vessels, is obtained from the expression [16]:

$$T_v = \frac{3}{64} k_1 \cdot v_v^2 \cdot B \cdot H \tag{1}$$

that is the wind tension, where k_1: constant that depends on the safeguard of the anchorage; v_v: wind speed in m/sec., B: breadth of the vessel, H: effective height from the waterline to the roof of the pilothouse highest with breadth of the vessel upper than $B/4$ (Fig. 3).

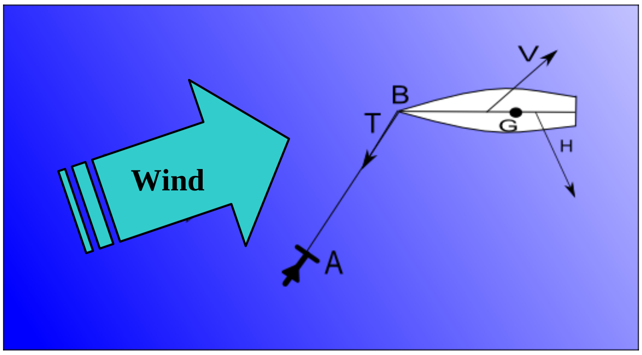

Fig. 3 System of forces acting to the variable wind direction

Where the sea stream is present [17], it shall be determined this one on based on the wetted surface of the vessel, according to the following expression:

$$T_c = 0{,}25833 \cdot (d \cdot \delta + b) \cdot (B + 2T) \cdot v_c \cdot \left(v_c \cdot L_{pp}\right)^{4/5} \quad (2)$$

where *d*, *b* are coefficients depending on the type of prow (cylindrical or bulbous), δ block coefficient, L_{pp} length between perpendiculars, *B* breadth of vessel, *T* draught, v_c stream velocity.

The tension T_x at any point of a catenary [18] is function of the voltage at the vertex:

$$T_x = T_o + T_d = T_o + f.P_a \quad (3)$$

donde T_0 es is the gripping force of the anchor at the seafloor, *Td* is the weight of the chain, *f* is depth in meters. (considering the height of the prow), P_a is apparent weight of each meter of chain.

In the case of combined action of wind and stream, the expression of the total force acting [19] [20] [21] depends on the angular values α1 and α2 that forming the wind and the stream impinging with the centreline in the final equilibrium position:

$$T_o = T_V \cos\alpha_1 + T_c \cos\alpha_2 \quad (4)$$

The length of chain along is determined by the expression:

$$S_x = \sqrt{f \frac{\left(2 \cdot T_x + P_a \cdot f\right)}{P_a}} \quad (5)$$

where *f* is depth in meters (considering the height of the prow); P_a apparent weight of each meter of chain, T_x force acting on the vessel.

The safety factor is given by the following expression:

$$T_{01} = Type\,of\ anchorage \cdot Power\ grip \quad (6)$$

The maximum depth of the anchorage (Fig. 4) where it can anchor for a given wind condition, is determined by calculating the positive root in f, by means the following equation:

$$T_{02} = P_a \cdot \frac{\left(s^2 - f^2\right)}{2 \cdot f} \quad (7)$$

where s: long chain length; f depth in meters; P_a, unitary weight of the chain in water.

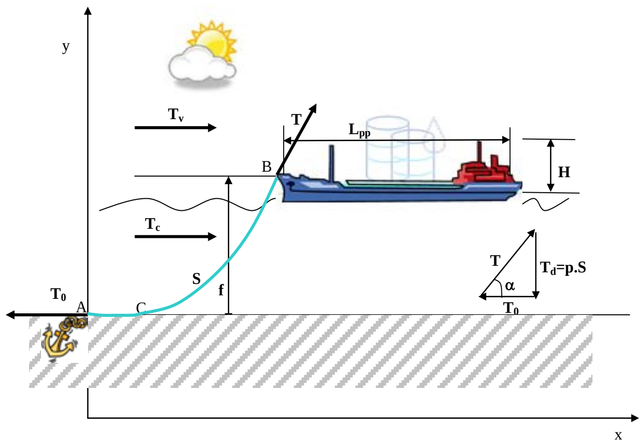

Fig. 4 Main parameters of housing and dropping of the anchors

Finally, the maximum tension supported is given by:

$$T_m = \frac{3}{4} \cdot v_{max}^2 \cdot B \cdot H \quad (8)$$

where v_{max} is the maximum speed, *B*: breadth of the vessel; *H*: effective height from the waterline to the roof of the pilothouse highest with breadth of the vessel upper than *B/4*.

III. COMMUNICATIONS PROTOCOLS

A. NMEA Protocol

The NMEA 0183 or NMEA protocol is a combined specification from electrical characteristics and data, for communication between marine and electronic devices. The NMEA standard uses a serial communications protocol based on ASCII, which defines how data information is transmitted through lines or data frames from a talker or emitter device, and one or more listeners or receivers. In this way, a large number of sensors can return data to a single serial port on a computer. The NMEA data are transmitted in two ways, i.e., there is one input port and one output port. The standard transmission ratio must be of 4800 baud, with 8-bit data without parity and with a single stop bit. The NMEA message structure is equal to any data frame type, only being modified in some of them, where the amount of data information that can be sent is much higher. The communication begins with the emission of the character "$" followed by two letters that identify the sender of the message. The three characters that follow are identifiers data frame, followed by the data information fields separated by commas. The end of the message is composed by a carriage return and a linefeed in ASCII. When one of the fields of data information is not available, the field is ignored, but the delimiting commas are also sent without spaces between them. If is necessary, the data frame has a "checksum" composed of a * and two hexadecimal digits representing the OR-Exclusive of the characters within the data frame, excluding characters "$" and "*". In summary, the structure of the standard remains in the following way: $TTSSS, D1, D2, ... <CR> <LF>. In this work, the sender identifier is always "$ II" since all the sensors are from marine instrumentation and the system will act only as a supervisor, never it will issue data frames to the instrumentation. Although the NMEA protocol is standardized internationally, many equipment manufacturers introduce their own data frame identifiers. In this case, it has been used Raymarine instrumentation, so it is necessary a Sealtalk converter card to NMEA.

B. *Standard RS-232C*

The RS-232C serial port, is the most commonly used for data transmissions between computers. The RS-232C is a DB-25 connector of 25 pins. Signals works with this serial port are digital, +12 V (logic 0) and-12V (logical 1), for input and output data, and reverse control signals.

C. *Freeport Mode*

The freeport mode allows configuring the serial ports of S7-224 PLC, so that it can be varied, the reading speed of these ports. This one is an extended mode in communication of industrial factory, used for example for configuring a printer or connecting a bar code reader. The activation of the Freeport mode is through special marks, SMB30 and SMB130. These marks, are used for reading and writing of PLC instructions that control the communication Freeport in ports 0 and 1, respectively. These bytes configure the communication Freeport mode in the respective ports and allow select whether must be supported the Freeport mode or the protocol of the system.

IV. SOLUTIONS AND RESULTS

A. *Solutions*

The tasks that must monitor the control system are:

a) Development of PLC control algorithm to allow the reading and interpretation of the data.

b) Development of control screens.

c) Assembly of a Simulator.

B. *Flux Data Information: Instrumentation – PLC*

For the reception data through the PLC of information from the instruments, is required to identify, as a first step, what and how many of the frames received (Table I), are necessary in order to provide which subroutines should be implemented in the main program (Fig. 5). The next step is to connect the NMEA/RS-232 card output to the serial port of a computer. By applying of the Windows hyper-terminal, setting it to 8 bit without parity, 4800 baud, without flow control, the data information is received as shown on the Table I. For the present application are only required frames, DBT, BWC, MWV and VHW, since the rest, in spite of transmit data information, are not usable. Having identified the patterns, need to be read by the PLC. For this, the Freeport mode must be activated (SMB30) (Fig. 6) that will let to set the communications port to proper velocity and will configure the parameters of the control of messages reception, composed of:

a) Activating the control of incoming messages (SMB87).

b) Start of message character (SMB88).

c) Character to end of message (SMB89).

d) Maximum length of message (SMB94).

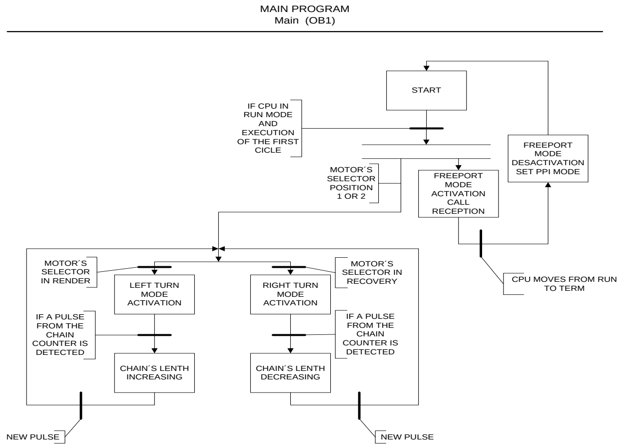

Fig. 5 Flowchart of main program

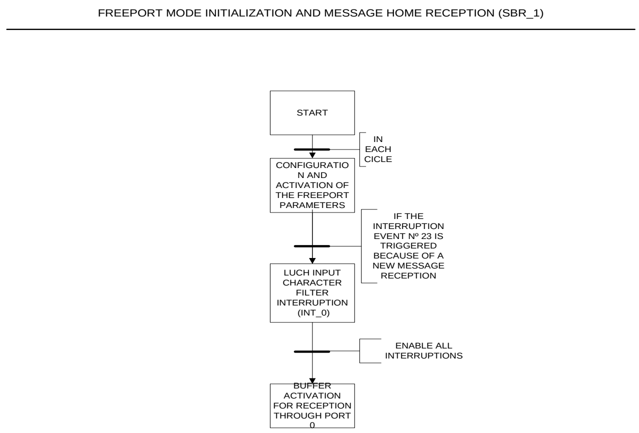

Fig. 6 Flowchart of freeport mode initialization and message home reception (SBR_1)

TABLE I INPUT DATA FRAMES TABLE

Number	Data frame
1	$IIMTW,31.1,C*10
2	$IIDBT,,f,,M,,F*3F
3	$IIBWC,,,,,,,T,,M,,N,*01
4	$IIMWV,092.0,R,0.0,N,A*36
5	$IIMWV,180.0,T,0.0,N,A*32
6	$IIVHW,,T,,M,0.00,N,0.00,K*55
7	$IIVPW,0.00,N,0.00,M*52
8	$IIVWR,092.0,R,0.0,N,0.0,M,0.0,K*42
9	$IIVWT,180.0,R,0.0,N,0.0,M,0.0,K*46

Due to the NMEA data frames have the same header and end, so that SMB88 mark can be configured for upon receipt of the character the "$" character, to initiate the message reception, and ends the same one when it received the character “<LF>” (linefeed). Both characters are present in all data frames (Fig. 7). Once set the parameters, to start the operation, only need to activate the port and activate the listening, specifying the port number, and the buffer, where it will store the received message. It is used:

$	I	I	V	H	W	,	0.0	,	T	,	0.0	,	M	,	0.0	,	N	,	0.0	,	K	*	55	<LF>
V 101	V 102	V 103	V 104	V 105	V 106	V 107	VD 108	V 112	V 113	V 114	VD 115	V 119	V 120	V 121	VD 122	V 126	V 127	V 128	VD 129	V 133	V 134	V 135	V 136	V 137
#HEXADECIMAL																								
24	49	49	56	48	54	57	X_1	2C	54	2C	X_2	2C	4D	2C	X_3	2C	4E	2C	X_4	2C	4B	2A	37	<LF>

$	I	I	D	B	T	,	0.0	,	f	,	0.0	,	M	,	0.0	,	F	*	14	<LF>
V 101	V 102	V 103	V 104	V 105	V 106	V 107	VD 108	V 112	V 113	V 114	VD 115	V 119	V 120	V 121	VD 122	V 126	V 127	V 128	V 129	V 130
#HEXADECIMAL																				
24	49	49	44	42	54	2C	X_1	2C	66	2C	X_2	2C	4D	2C	X_3	2C	46	2A	0E	0A

Fig. 7 Loch Data data frame position (VHW) (Figure above) and deep storyline data frame position (DBT) (Figure below)

RCV Nº Port, Buffer

In this case, the used port is the 0, and the beginning of the buffer is the VB100 position, so that the command is:

RCV, 0, VB100.

In this way, ensures that the PLC is able to receive incoming data frames, but is not still able to filter the data information. So, each time a data frame is received, it is necessary to configure an interruption event so that the PLC is able to get and process the data information, before the reception of the next data frame. For this, it is used the interruption event number 23, that is triggered every time that the final character is received. In terms of the programming complexity, this approach is very simple and fast, because it uses a single interruption by received data frame.

In the interruption (Fig. 8), it is checked the identifier that comes from the instrumentation, and if the operation is right, it will activate the operation light, proceeding to the filtering of data frame. If it is not so, then buffer is re-enabled waiting for a valid data frame. Then if the data frame is validated, the interruption compares the identifiers, and by supplying the data frame is received, it is called to its associated subroutine.

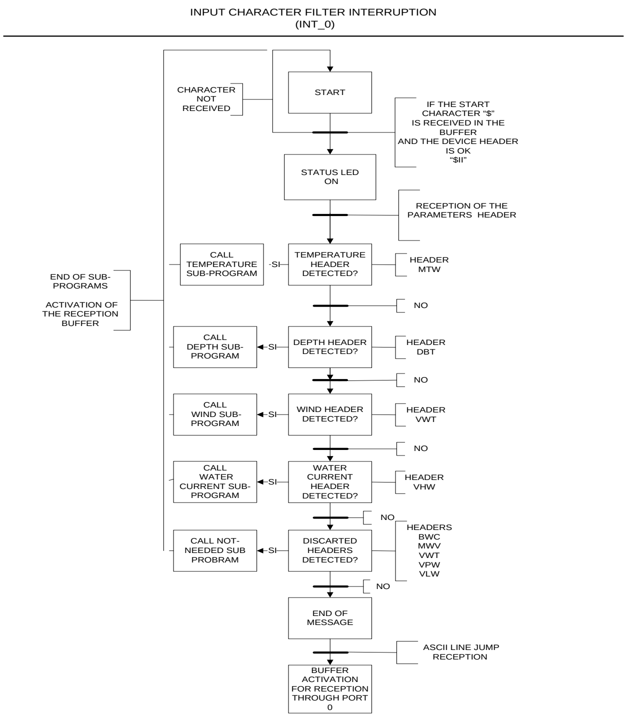

Fig. 8 Flowchart of Input Character Filter Interruption (INT_0)

The operation of each subroutine is similar, according to the memory location occupied by each comma, the positions of the characters with data information are identified. Example:

*$IIDBT,2.8,f,0.85,M,0.46,F*14*

Value required: X_2 *= depth in meters.*

However, as it has been mentioned earlier, the data frame can be more or less longer according to the number of characters of the value transmitted. Therefore, within the subroutine, according to distance between commas, various modes of filtering are differenced, which differ depending on the origin of the subroutine.

Once it has been identified and copied the characters of the data information, a conversion is needed because the resulting value is not a number, but a succession of characters. In the S7-200 PLC does not exist this conversion function, so is necessary an alternative method. The ASCII character "0" is set to 48 decimal, with the rest of the consecutive numbers. If each character is converted to integer and subtracted 48, the difference is the number in integer format. Therefore, it is necessary to convert to real format, (float values), and assemble them all so that they take up their decimal units, tens, dividing or multiplying by powers of 10 as needed. With the values in format of real numbers, the data are moved to a memory location, in which the parameter is stored, allowing its export to link with the screen. As many times the value is changed in the PLC, this can be visualized on the screen, with a minimum delay. The variables that are necessary in calculations are copied to operating variables to perform the relevant calculations, that once completed, copy the results in a corresponding variables (Table II).

TABLE II INPUT DATA FRAMES TABLE

PLC			
Symbol	**Adress**	**Comments**	
Tv	VD600	Wind Tension	
Tc	VD604	speed log probe	
SCREEN			
Name	**Conexion**	**Length**	**Adress**
Tv	Conexion_1	4	VD600
Tc	Conexion_1	4	VD604
To	Conexion_1	4	VD608

Since the implementation of the PLC is linear, it is no possible to design a subroutine for being running constantly, unless that it is placed in the OB1 main. However, this would slow down too much the PLC cycle, interrupting the data input. To avoid this, the implementation of the subroutines depends on the received data frames. Thus, every time it runs a data frame, then the associated calculation subroutines are run, so that the operation values are always stored in memory. In this way, there is no need to be constantly running the subroutine. So the cycle of the PLC is fast enough, to receive the data information, process, and transmit it, as if it were a computer server.

Following the requirements of the system mentioned in the previous point, it has been implemented a flow chart on the program, which meets the specifications.

C. PLC – Touch Panel

So much for performing operations in the PLC, as to export the values to the screen, variables associated with memory locations must be defined previously. By this method, is minimized the mistakes that can be committed when the equations are implemented in the program, in addition to control what data information is saved and what one is discarded. There are difference between variables used in HMI for storing values and logic variables used in PLC. They share same memory locations (Table II). The main menu screen, in the SCADA system, shows the two options from which it is possible to access: the system configuration and the application start up. The system configuration allows specifying the type of anchor, the characteristics of the same (length, weight, chain's diameter, chain's material) (Fig. 9) and the characteristics of the vessel. The start of the application consists of main 4 sub-applications:

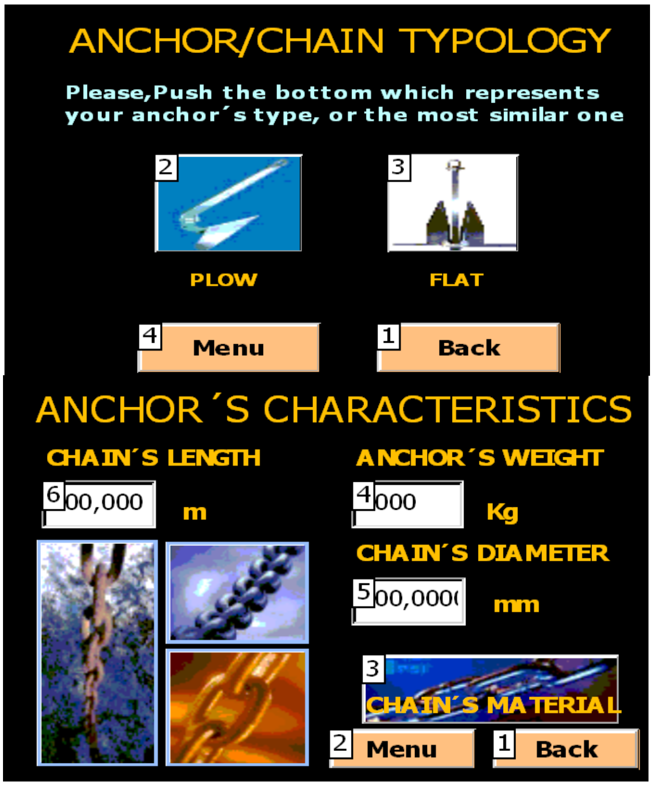

Fig. 9 Screen that alows to Choice Anchor/chain Typology

a) Anchoring Procedure (Fig. 10). The system reads the parameters of the instrumentation and runs, simultaneously, the subroutines of calculation, implemented in the PLC. Then it displays a protocol, with the next step, and the amount of chain necessary, according to the actual conditions (Fig. 11).

b) Anchoring Simulation. It allows the user, entering the data, to make an estimate of the choice of anchorage.

c) Keeping of the situation (Fig. 12), it corresponds to automatic monitoring mode. The user introduces a limit parameter, so that the PLC checks the values. If these values are exceeded, within a margin of tolerance, above the configured value, the PLC runs the alarms, warning to the vessel's crew of imminent danger.

d) Parameters Supervision (Fig. 13). Finally, the parameter monitoring mode, where it is possible displays all parameters in real time by means graphs or bar chart [13].

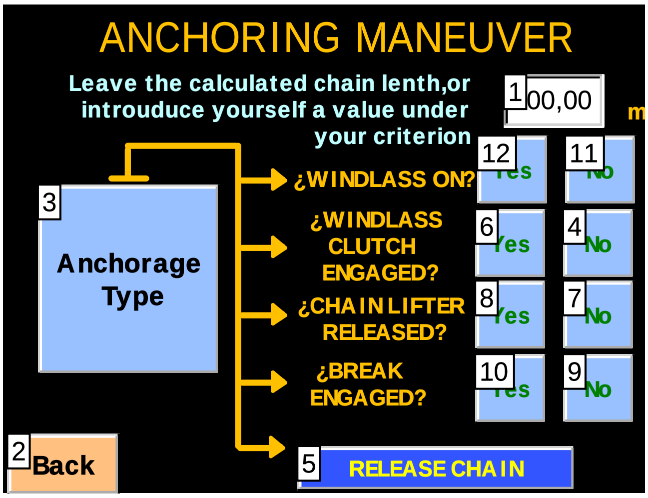

Fig. 10 Anchoring maneuver with wind and ocean current

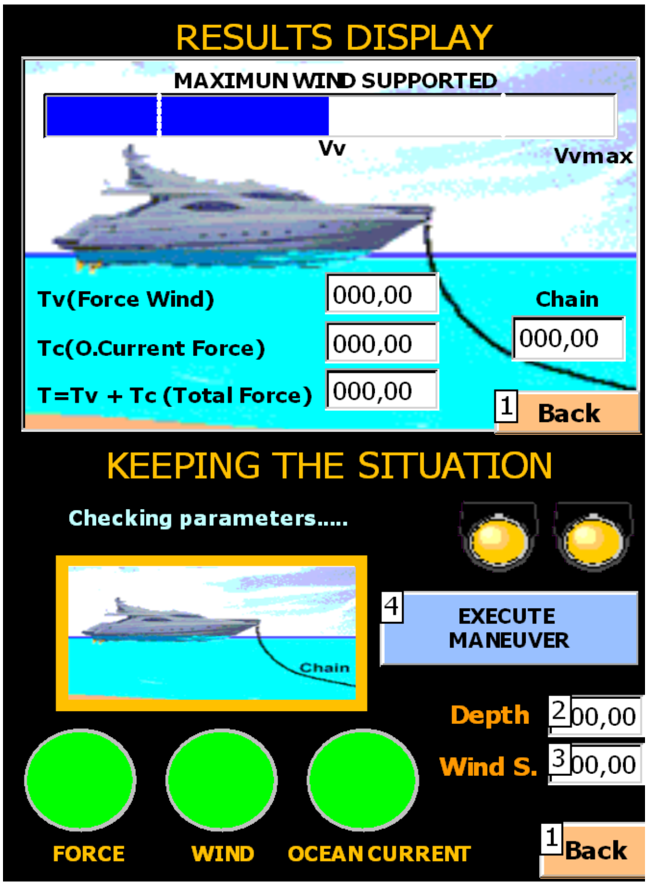

Fig. 11 Anchoring manoeuvre protocol

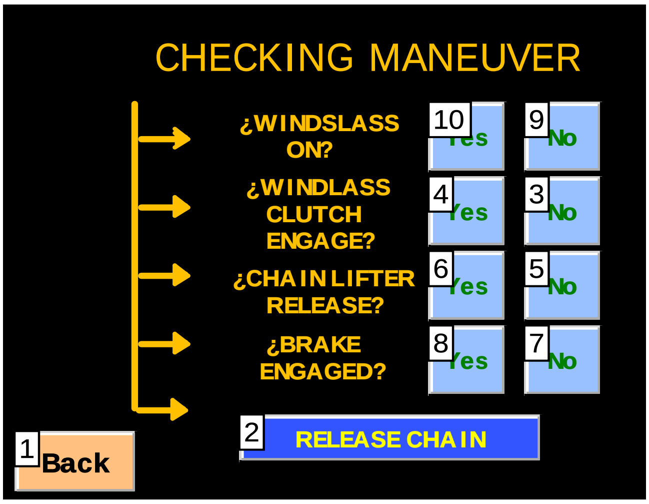

Fig. 10 Keeping the situation and checking maneuver

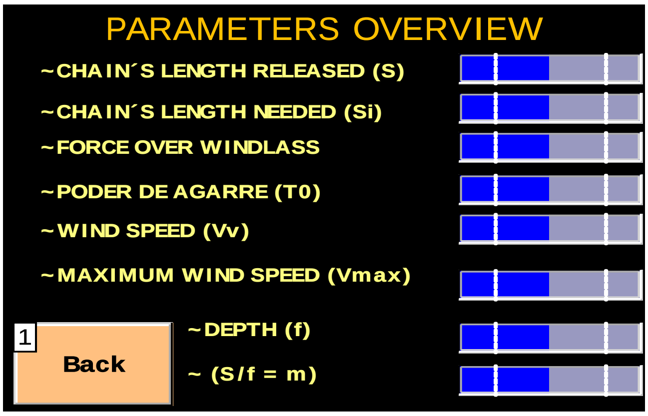

Fig. 11 Checking Maneuver. This screen shows the reading of all parameters in real time by means bar charts

D. Assembly of a Simulator

Finally Figure 14 shows the assembly and check for correct simulation of the system before its implementation on board the vessel.

Fig. 12 Assembly control system in vessel

The vessel, once implemented the system with a single anchor in static equilibrium is able to withstand the wind and current that is exerted on the vessel based on the holding power anchor. On the other hand the chainstopper support the weight of the catenary which shape the chain. Finally the chain, either by its length or its weight keeps the shank horizontal (values below 5 degrees).

V. CONCLUSIONS

In this work has been obtained an automated system for the acquisition, keeping and supervision of the necessary data on a vessel, supporting to the captain or responsible for the same, for successfully maneuver anchoring. With the development of this system has been achieved closer to the general public, something that so far was accessible to a few people given the preparation required. On the other hand is obtained a suitable system in the sense that is compatible with a normal functioning of the vessel, detects faults in the anchoring system, and is responsible for monitoring all parameters of the process. The system designed takes many advantages, among of them supported to crew inexperienced, provision of greater security in nocturnal schedule, great versatility, limited errors by human intervention, and presents great potential for expansion. In this sense can be used in any type of vessel equipped with necessary instrumentation.

In addition could be used in research stations exposed to sudden change of the weather.

REFERENCES

[1] Robert. B. Zubaly, Applied Naval Architecture, Centreville (MA): Cornell Maritime Press. ISBN 0-87033-475-1. 1996.

[2] D. J. Eyres. Ship construction. 6th ed. Elsevier, 2007.

[3] Cyrus Hamlin. “Preliminary design of boats and ships”. Centreville, Maryland, cop. 1989.

[4] Tran, T.; Harris, C.; Wilson, P.; “Vessel management expert system,” Intelligent Transportation Systems, 2001. Proceedings. 2001 IEEE, pp.1102-1107, 2001.

[5] Sosnin, P.; “Question-answer expert system for ship collision avoidance,” ELMAR, 2009. ELMAR '09. International Symposium, pp. 185-188, 28-30 Sept. 2009.

[6] Hu Qinyou, Hu Qiaoer, Shi Chaojian, “A Negotiation Data framework for Automatic Collision Avoidance between Vessels,” Intelligent Agent Technology, 2006. IAT '06. IEEE/WIC/ACM International Conference on, vol., no., pp. 595-601, Hong Kong, 18-22 Dec. 2006.

[7] Shelton, J. T.; “OMNI-Maxtrade anchor development and technology,” *OCEANS 2007*, vol., no., pp. 1-10, Sept. 29 2007-Oct. 4 2007 doi: 10.1109/OCEANS.2007.4449415.

[8] Clarence J. Ehlers, Alan G. Young, and Jen-hwa Chen, “Technology Assessment of Deepwater Anchors,” Offshore Technology Conference, Houston, Houston, May 2004, Paper No. OTC 16840.

[9] Evan H. Zimmerman, “Update on Past MODU Mooring Failure Analysis & Anchor Research Activities”, 2006 Hurricane Readiness & Recovery Conference, New Orleans - Presentation.

[10] McNutt, P.; Stephens, R. I.; Reeve, P. J.; “Use of anchor pattern modelling in the control of floating production vessels,” *Physical Modelling as a Basis for Control (Digest No: 1996/042), IEE Colloquium on*, pp. 7/1-7/5, London, 29 Feb 1996.

[11] Hans H. Eder, “Management and process control: a permanently open loop?,” *Control Engineering Europe,*

Control, Instrumentation and Automation in the Process and Manufacturing Industries, pp. 38-41, Nov/Dec 2006.

[12] Warden, W. H., "A control system model for autonomous sailboat navigation," *Southeastcon'9., IEEE Proceedings of* , vol., no., pp. 944-947 vol. 2, 7-10 Apr 1991.

[13] Kose, E.; Gosine, R. G.; Dunwoody, A. B.; Calisal, S. M.; "An expert system for monitoring dynamic stability of small craft ," *Oceanic Engineering, IEEE Journal of* , vol. 20, no. 1, pp. 13-22, Jan 1995.

[14] G. Gonzalez-Filgueira et *Al*. "Caracterización de las variables necesarias para la Supervisión y Control en el Fondeo de Embarcaciones de Recreo". XXI Copynaval 2009. Uruguay. Montevideo. Uruguay, 18-22 October 2009.

[15] L. Carral, G. Gonzalez-Filgueira et Al. "Algoritmo para la preparación y mantenimiento de la condición de fondeo en yates". XXI Copynaval 2009, 18-22 Oct. 2009.

[16] R. Quereda Laviña. "Análisis de esfuerzos en la cadena y el ancla de buques fondeados a la gira" Revista de Ingeniería Naval, March. 2000.

[17] H. M. Morishita and B. J. J. Cornet, "Dynamics of a turret-FPSO and shuttle vessel due to current", *IFAC Conf.*, 1998.

[18] C. P. Pesce, J. A. P. Aranha, C. A. Martins, O. G. S. Ricardo, and S. Silva, "Dynamic curvature in catenary risers at the touch-down point region: An experimental study and the analytical boundary-layer solution", *Int. J. Offshore Polar Eng.*, vol. 8, no. 4, pp. 302 -310 1998.

[19] Wangqiang Niu; Jianxin Chu; Wei Gu, "Constant Tension Control of the Anchor Chain of the Windlass under Sea Wind," Education Technology and Training, 2008. ETT and GRS 2008. International Workshop on, vol. 1, no., pp. 622-626, 21-22 Dec. 2008.

[20] Godoy Simoes, M.; Leonidas Merma Tiquilloca, J.; Mitio Morishita, H.; , "Neural-network-based prediction of mooring forces in floating production storage and offloading systems," *Industry Applications, IEEE Transactions on* , vol. 38, no. 2, pp. 457-466, Mar/Apr 2002.

[21] J. Takashina, "Ship maneuvering motion due to tug boats and its mathematical model", *J. Soc. Naval Architects Jpn.*, vol. 160, 1986.