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FUZZY CONTROLLER DEGIGN FOR MARINE STEERING SYSTEM*

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ABSTRACT:

This paper provides a design and implementation of Fuzzy controller to keep a vessel moving along track line, Carry out the course changing manoeuvres, and compensate environmental changes such as wind speed, waves and sea currents. Data acquisition and control system (DACS) was designed for data acquisition and control of steering system. The input/output conditioning circuits were designed. A three communication ports were designed for interfacing with PC, GPS, and Gyrocompass. The operating system software of DACS were designed to achieve all functions of data acquisition, control tasks, communications, and user interface. The PC software program was designed to achieve all important functions such as data acquisition, data processing, and control functions**.** The DACS was installed in a real ship in Suez Canal Authority. Calibration of all input signals of DACS were achieved to satisfy that all input signals were correctly red. The output signal was also calibrated to give correct action in steering system. A set of rules are developed for tuning of the fuzzy controller. The fuzzy control system was finally operated to satisfy its performance.

KEY WORDS: Data acquisition and control system (DACS) - Fuzzy Control System (FCS) - Fuzzy Inference System (FIS) - Rate of Turn (ROT) – Global Positioning System (GPS) - Graphical user interface (GUI).

CONTRÔLE DE BASE PILONNANT STRUCTURES ISOLEES

RÉSUMÉ

La propriété la plus importante d'un système de base-isolement est de rendre la base plus flexible que les éléments de la superstructure, mais elle doit toujours être suffisamment rigide pour résister aux forces typiques battant, charges dues au vent, et même de faible amplitude des forces horizontales. Cependant, les conséquences potentielles du tremblement de terre induits sur les bâtiments poundings sismiquement isolées peuvent être beaucoup plus importante, et, par conséquent, devrait être évaluée. Cet article étudie, à travers des simulations numériques, les effets du potentiel des incidences à cogner sur la réponse sismique d'un bâtiment typique sismiquement isolées et de rendre le système de contrôle avec amortisseur visqueux hydraulique afin de réduire l'énergie transmise. Un logiciel spécialisé a été développé afin de s'acquitter efficacement des simulations numériques et des études paramétriques sur le système de contrôle. Les effets de certains paramètres, tels que le ratio de rigidité post-pré, la capacité de cisaillement plastique de l'amortisseur visqueux et les caractéristiques des structures adjacentes ont été étudiés en utilisant le logiciel développé. Les simulations ont révélé que l'amortisseur visqueux diminue le déplacement total et l'énergie totale transmise. Aussi le meilleur des cas des amortisseurs hydrauliques lorsque le comportement élasto-plastique avec zéro rigidité plastique**.**

MOTS CLES: isolement de base, pilage, le contrôle, les bâtiments adjacents

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1. INTRODUCTION

Autopilots for steering control have become familiar on board of all ships. The aim is to keep a vessel moving along predetermined track line with as small deviation as possible. To design an autopilot for a ship is always a challenging problem. A ship dynamics is influenced by unpredictable environmental disturbances such as waves, winds, currents, change of depth under keel, etc. as well as ship sailing conditions such as speed, loading condition, trim, etc. If the autopilot performance is far from optimum, it cause excessive fuel consumption and rudder wear.

To design an autopilot capable of taking into account all these factors is possible by proven adaptive or robust control design methods. However, both methods ask for reliable and appropriate mathematical models of the ship dynamics in quite different operating conditions. Techniques which are useful in the open sea are not appropriate in coastal regions due to various factors. If robust approach is chosen for the autopilot design, the mathematical models used are never exhaustive enough to cover all possible sailing and environmental conditions. The ship dynamics has intrinsic nonlinearities which cannot be neglected especially in maneuvers. Several effective methods have been proposed and developed for designing Ship Autopilots .

Ship Autopilots designed based on the PID controllers are simple, reliable and easy to construct, however their performance in various environmental conditions is not as good as desired. Therefore, Ship Autopilots with PID controllers are usually required aids from operators to adjust controllers' parameters corresponding to navigating conditions. A Sliding Mode Controllers Autopilots based on Variable Structure Controllers. Using this method one can construct high quality Ship Autopilots that is not much influenced by variations of parameters and disturbances. they have a very weak point that is the saturation in the sliding surface.

The approach taken in this paper tries to overcome the need for ship's mathematical models by using the fuzzy logic controller which is provided with the capability of adjustment of its scaling factors. Fuzzy controller was designed to provides the following objectives:

Keep a vessel moving along predetermined track line (keep course and track line).
- Compensate environmental changes such as wind speed, waves and currents.
- Carry out the course changing manoeuvres.

This paper also introduces a local alternative of the steering control systems to be applied in Suez Canal Authority. It has the following advantages:
- Very low cost.
- Low cost of maintenance, repair and spare parts.
- No special skills required for operation.
- The flexibility for modification and development.
- Using of fuzzy controller to achieve accurate tracking to get minimum distance, minimum trip time, minimum fuel consumption, minimum wear in equipment, and more safety.
- Using the computer adds new facilities, improve performance, and gives more flexibility of operation.

2.SYSTEM DESCRIPTION

The proposed fuzzy control system was designed to be used in marine vessels such as tugboats and ships of Suez canal authority. A salvage tugboat "Ezzat Adel" is chosen for application of the proposed steering control system. Ezzat Adel is the biggest tugboat in Suez canal authority. The main specifications are: 70 m length, 16 m width, 6 m draught, 16000 Hp main engine power, and 4x600 KW Side thrusters. Ezzat Adel tugboat has two propulsion systems and two rudders. Each rudder is controlled by hydraulic power unit. The steering system is shown in Fig(1).

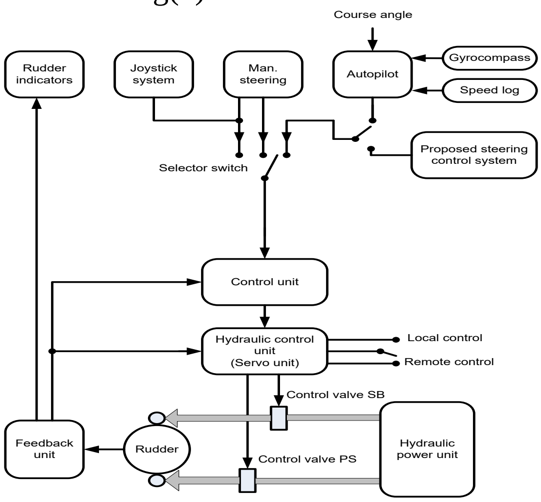
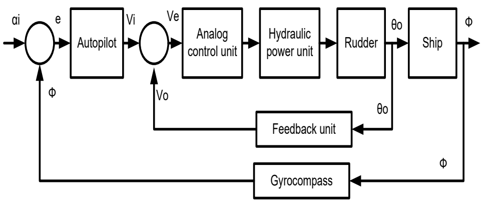


Fig. (1) The steering system of Ezzat Adel tugboat.

The block diagrams of rudder control system is shown in fig(2).



Fig(2) Autopilot control system

3. DESIGN OF PROPOSED FUZZY CONTROL SYSTEM

The proposed fuzzy control system was designed to be installed alone on marine vessels or in parallel to already installed autopilot. The control can be switched between the proposed system and onboard autopilot via changeover relay. The proposed system is shown in fig(3).

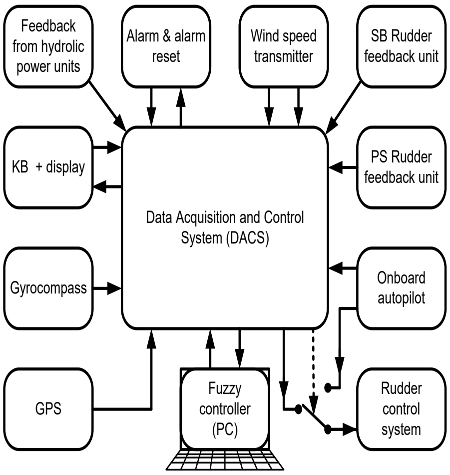


Fig. (3) The proposed fuzzy control system

The proposed fuzzy control system is consists of two main parts:

1. ***Data acquisition and control system (DACS)*** is connected to all I/O devices.
2. ***Personal computer or laptop*** contains the software program of fuzzy controller.

4.FUZZY CONTROL SYSTEM (FCS)

The fuzzy controller was designed, implemented and tested by using Matlab toolboxes. The FCS is simulated at different conditions for all inputs, such as error, differential error (or Rate of Turn ROT), integral error, wind speed, and ship speed. The results are plotted, analyzed, and used to modify the membership functions and rules of the fuzzy controller. The fuzzy control system will perform the following functions:

- Track-keeping problem, the maneuver of way-point turning and ship guiding through a complex path (trajectory)

- Compensate environmental changes such as wind speed, waves and currents.

The general structure of the fuzzy control system (FCS) is shown in fig(4).

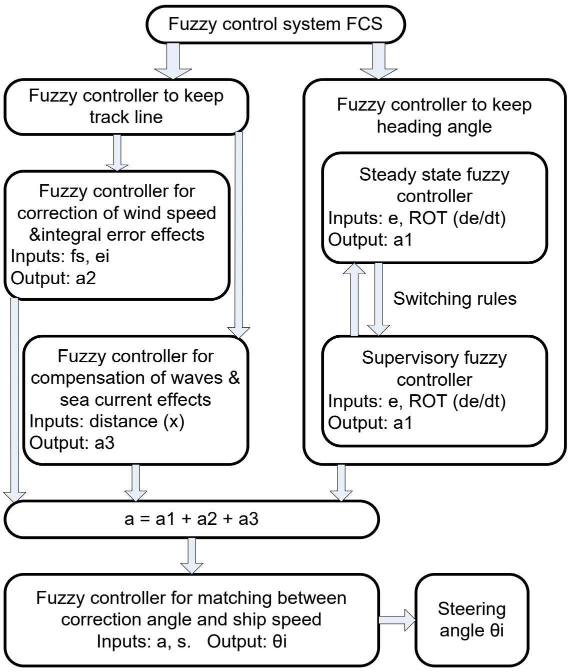


Fig. (4) The general structure of the fuzzy control system FCS

5. TRACK-KEEPING AND COURSE CHANGING MANEUVERS

A multilevel fuzzy controller (supervisory fuzzy controller) was used to keep the heading angle of the ship. The main controller is used in steady state operation. When the situation tends to become dangerous from the stability view point, another controller has to take control. The top level controller was designed with a small number of inputs and rules to provide fast convergence of the outputs to desired value. The low level controller achieves the desired steady state and time response characteristics. The fuzzy controller inputs for both low and high level fuzzy controllers are:

- Heading error (e) = Φ - α
- Differential error (*de/dt*) or rate of turn (ROT)

Where: α: Course angle (set point)

Φ: Heading angle (measured value)

The fuzzy controller output is correction angle (a1)

Fuzzy Inference System (FIS) of the steady state fuzzy controller was created. The FIS consists of input membership functions, output membership function, and rules. The input membership functions, rule table, and output membership function of the main controller are shown in fig(5- a, b, c). The input membership functions, rule table, and output membership function of the supervisory controller are shown in (6- a, b, c).

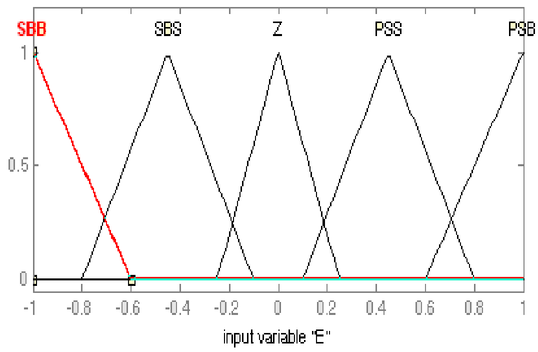


Fig. (5- a) Heading angle error membership function

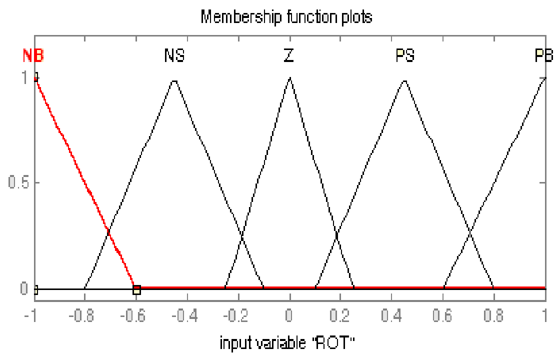


Fig. (5- b) Differential error membership function

Rule table of the main controller

e / rot	SBB	SBS	Z	PSS	PSB
NB	PB	PB	PM	PS	Z
NS	PB	PM	PS	Z	NS
Z	PM	PS	Z	NS	NM
PS	PS	Z	NS	NM	NB
PB	Z	NS	NM	NB	NB

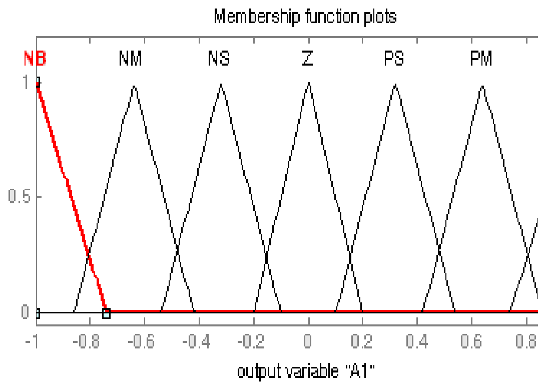


Fig. (5- c) The output membership function of correction angle (a1)

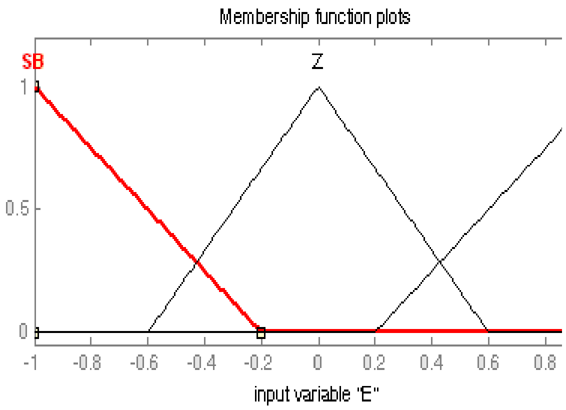


Fig. (6- a) Heading angle error membership function

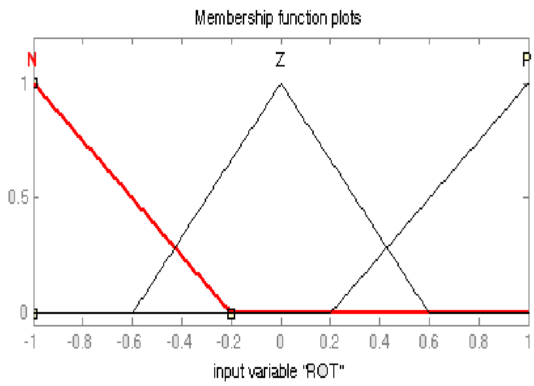


Fig. (6- b) Differential error membership function

Rule table of the supervisory controller

e / rot	SB	Z	PS
N	PB	PM	PS
Z	PM	Z	NM
P	PS	NM	NB

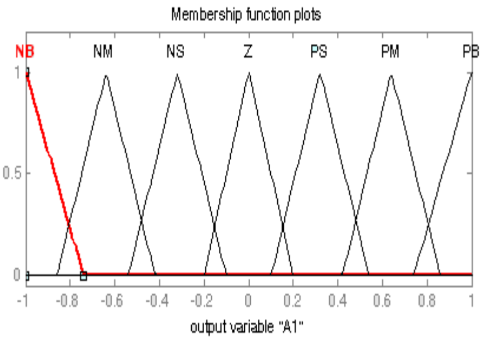


Fig. (6- c) The output membership function of correction angle (a1)

The control transfers between top level and low level fuzzy controllers according to the following rules:

- IF heading error (e) OR rate of turn (ROT) Greater than specified limit (L1), THEN the control is switched to top level controller.
- IF (e) AND (ROT) Less than specified limit (L2), THEN the control is switched to low level controller

Limit (L1) must be greater than limit (L2) to make a dead band. This dead band prevents oscillation between top level and low level controllers.

Deviation from the predefined track line comes due to the following reasons:

1. Side force of wind (Fs)
2. Integral error of heading angle (ei) = $\int e\,dt$
3. Effect of waves and sea currents

Two fuzzy controllers are used to keep track line. The first one is used for correction of track line due to side force of wind and integral error of heading angle. The second is used for compensation of waves and sea currents effects.

6. FUZZY CONTROLLER FOR WIND EFFECT AND INTEGRAL ERROR CORRECTION

The wind speed and direction are measured by using data acquisition and control system. The average speed and direction are estimated along a time period. The average side force is proportion to the side component of average speed. The wind speed components are shown in fig(7).

The side component of wind speed = wind speed . cos Φ

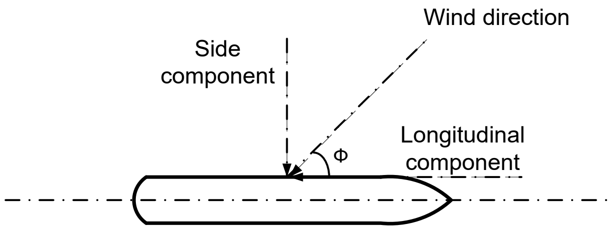


Fig. (7) wind speed components

The side force of wind moves the ship to line parallel to the track line. So that, the actual motion of ship will be shifted from the actual direction by angle (θw) although the heading angle is correct. The track line error due to side force of wind is shown in fig(8). The shift angle (θw) is relatively small and has similar effect to the integral error of heading angle. A fuzzy controller is used to calculate the correction angle (a2) for effect of them.

Fuzzy controller inputs:

1. Side force of wind (Fs)
2. Integral error of heading angle (ei)

Fuzzy controller output: correction angle (a2)

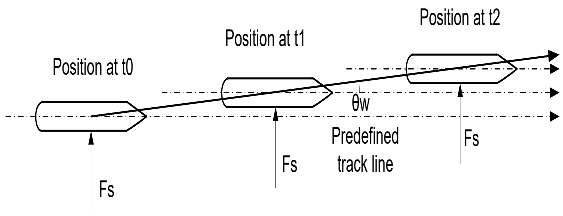


Fig. (8) The track line error due to side force of wind

Fuzzy Inference System (FIS) was created by fuzzy logic toolbox. The input membership functions, rule table, and output membership function are shown in fig(9- a, b, c):

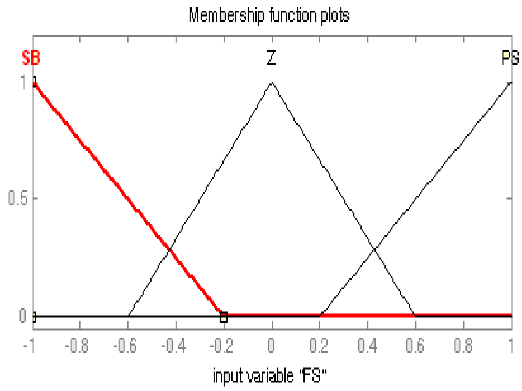


Fig. (9-a) Side force of wind membership function

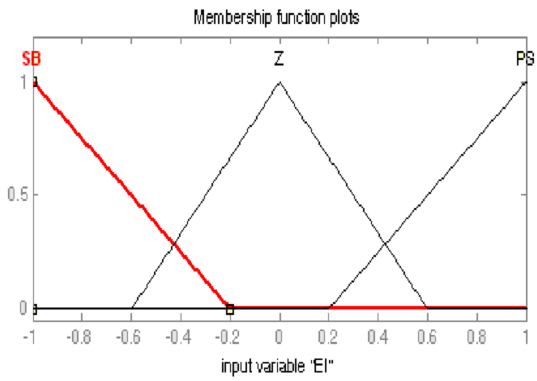


Fig. (9- b) Integral error of heading angle membership function

Rule table

Fs / ei	SB	Z	PS
SB	PSM	PSS	Z
Z	PSS	Z	SBS
PS	Z	SBS	SBM

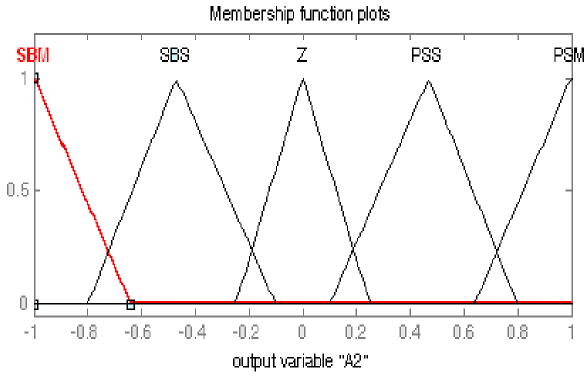


Fig. (9-c) Correction angle (a2) membership function

7. FUZZY CONTROLLER FOR COMPENSATION OF WAVES AND SEA CURRENTS EFFECTS

It is difficult to measure waves and sea currents effects but it appear as a deviation from the track line. The ship position is determined by using GPS. The deviation from predefined track line is the distance between the ship position and the nearest point at the predefined track line. The distance (x) is calculated by the main program and then, the fuzzy controller calculates the correction angle (a3) that smoothly restores the ship to the track line. The deviation from predefined track line is shown in fig(10)

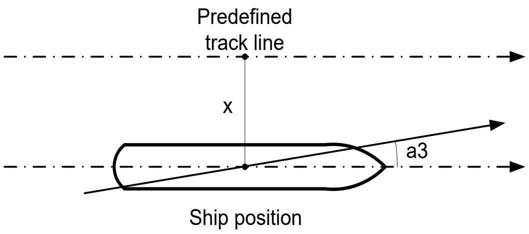


Fig. (10) the deviation from predefined track line

Fuzzy controller input: distance (x)
Fuzzy controller output: correction angle (a3)

Fuzzy Inference System (FIS) was created including the input membership functions, rule table, and output membership function as shown in fig(11- a, b):

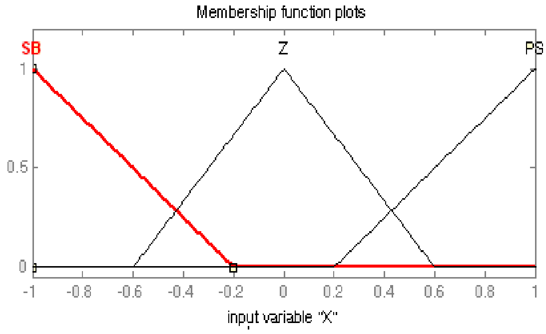


Fig. (11- a) Distance membership function

Rule table

x	SB	Z	PS
a3	SP	Z	PS

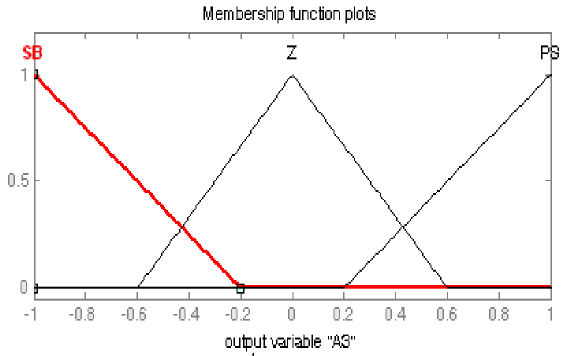


Fig. (11- b) Correction angle membership function

The total correction angle is the sum of correction angles of a1, a2, and a3

$$a = a1 + a2 + a3$$

8. FUZZY CONTROLLER FOR MATCHING BETWEEN TOTAL CORRECTION ANGLE AND SPEED OF SHIP

The steering force is proportional to the ship speed, so that, the rudder angle that give specific heading angle is decreased by increasing of ship speed and vice versa. We use a fuzzy controller to match between the correction angle and ship speed and calculate the required steering angle (θi).

Fuzzy controller inputs are:

1. Total correction angle (a)

2. Ship speed (s)

Fuzzy controller output: Rudder correction angle (θi)

The input membership functions, rule table, and output membership function are shown in fig(12- a, b, c):

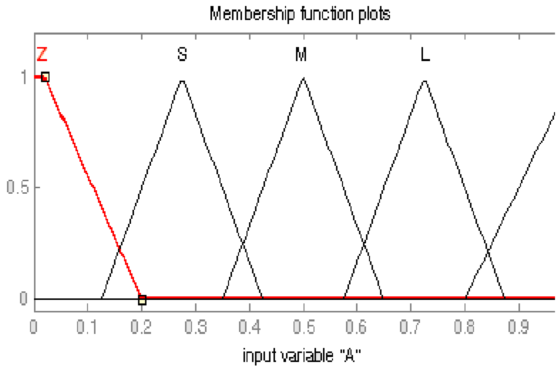


Fig. (12- a) Total correction angle membership function

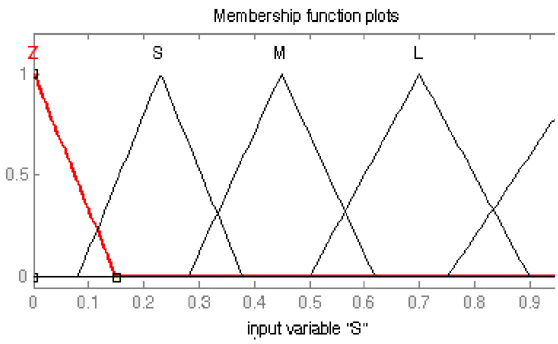


Fig. (12- b) Ship speed membership function

Rule table

a s	Z	S	M	L	VL
Z	Z	L	VL	VL	VL
S	Z	M	L	VL	VL
M	Z	S	M	L	VL
L	Z	S	S	M	L
VL	Z	S	S	S	M

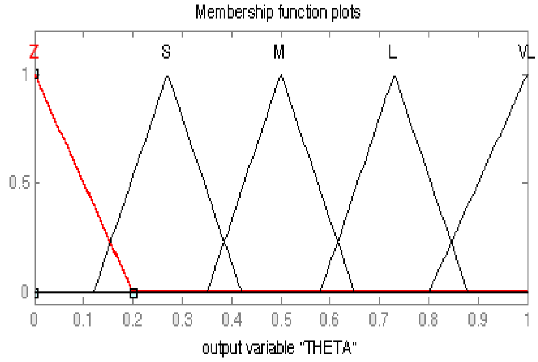


Fig. (12- c) Rudder correction angle membership function

9. DESIGN OF DATA ACQUISITION AND CONTROL SYSTEM (DACS)

The proposed data acquisition and control system (DACS) is designed based on AVR microcontroller ATMEGA8535 as a main processor, another AVR microcontroller ATMEGA162 is used to establish serial communication ports for GPS and Gyrocompass.

Analogue inputs: The analogue inputs are connected to the main microcontroller for measurement of feedback signals of SB and PS rudders, wind speed and direction signals, and output signal of onboard autopilot. A conditioning circuits of the analogue inputs are also designed.

Digital I/O: A three digital inputs are connected to the main microcontroller via conditioning circuits. A three digital outputs are used to control the output relays. The output relays are used for activation of audible alarm and to drive the changeover relay to switch the proposed steering control system.

RS-232 Serial communication port: The terminals RxD and TxD of the RS-232 serial port is connected to the main microcontroller via logic converter/driver for interfacing with the PC.

LCD display and Key bad: An 4-line 20-character LCD is used and Key bad is designed to be used for user interface.

PWM output: The pulse width modulation (PWM) output is used to produce analogue control signal for the steering signal of ship. An active low pass filter is used to convert PWM to DC signal. An amplifier circuit is designed using instrumentation amplifiers for producing of dual polarity output to control the rudder angle.

RS-422 Serial communication ports: An AVR ATMEG162 microcontroller is used to establish two RS-422 serial communication ports for GPS and gyrocompass. The microcontroller works as listener for GPS and gyrocompass that send data periodically. The microcontroller extracts the important data form stream of data received from GPS and gyrocompass. The ATMEG162 microcontroller sends the extracted data to both PC and main microcontroller.

Design considerations:

An important considerations are taken in design of the DACS. All inputs are isolated. A proper derivers are used for outputs. A precision amplifier is used in output stage. The analogue inputs have a separate ground plan on the PCB. The analogue signal paths are kept as short as possible and are kept away from high frequency digital paths.

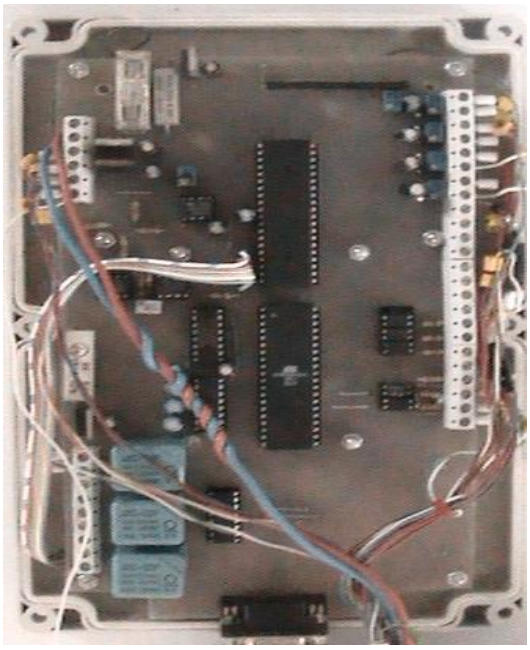
Programming of DACS:

The operating system of DACS were designed, written, and tested for both main and ATMEGA162 microcontrollers. They are designed to cover all functions of data acquisition, data processing, control signals, communications, and user interface.

The extracted data from GPS include Latitude position, Longitude position, and Ground speed of ship. The extracted data from GPS include Heading angle of ship and Rate of turn (ROT) of ship.

Implementation of DACS

The PCB was manufactured and the DACS was operated and tested. Testing of all analogue inputs, digital I/O, and PWM was carried out. The DACS was interfaced to PC to ensure that data is transmitted correctly between DACS and PC. The DACS was interfaced to GPS and Gyrocompass to ensure that the data is correctly received from GPS and Gyrocompass. The extraction of important data from GPS and Gyrocompass messages was successfully achieved. Fig(13) shows the PCB of the data acquisition and control system DACS.



Fig(13) PCB of the data acquisition and control system DACS

10. THE PC SOFTWARE PROGRAM

The main program is designed to achieve all important functions of the fuzzy control system, such as data acquisition, data processing, control functions, and graphical user interface (GUI) functions. The GUI was designed and implemented for displaying of all important data in graphical manner, switching between operation modes, carrying out control actions, data entry, course modification, and trajectory plotting.

11. CALCULATIONS OF POSITIONS AND TRACK LINES

The main program converts the latitude and longitude positions to grid form to achieves calculations of positions and track lines. To calculate track line equation, assume that a ship moving from source position p0(x0, y0) to target position p1(x1, y1) in x-y plan (or long-lat plan) as shown in fig(14).

The equation of track line is:

$x = ay + b$

where: a is slop of track line.

$a = (x1 – x0)/(y1 - y0)$ (1)

$a = \tan \Theta$

where: Θ is track angle.

$\Theta = \tan^{-1}a$ (2)

To calculate the constant b, assume point p(x, y) at the track line

$a = (x0 – x)/(y0 - y)$

at x-axis: (y = 0 and x = b)

$a = (x0 – x)/y0$

$x = x0 – ay0$

$b = x0 – ay0$ (3)

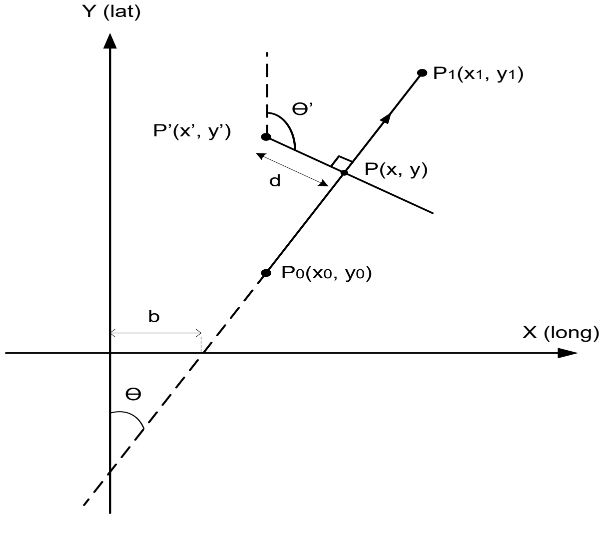


Fig. (14).

At point p(x, y) the distance to source point p0(x0, y0) is d0 and the distance to target point p1(x1, y1) is d1 so that:

$d0 = \sqrt{[(x – x0)^2 + (y - y0)^2]}$ (4)

$d1 = \sqrt{[(x – x1)^2 + (y - y1)^2]}$ (5)

To calculate deviation from the track line; If a ship at position p'(x', y'), the deviation from the track line (d) is the distance between point p'(x', y') and crossing point p(x, y) of track line and quadratic line.

$\Theta' = \Theta + 90$

$a' = \tan \Theta' = \tan(\Theta + 90)$ (6)

where a' is slop of quadratic line and Θ is angle of quadratic line.

The equation of quadratic line is:

$x = a'y + b'$

$b' = x – a'y$

$y = (x – b')/a'$

$a' = (x' - x)/(y' - y)$

at x-axis: y = 0 and x = b'

$a' = (x' - x)/y'$

$x = x' – a'y'$

$b' = x' – a'y'$ (7)

From equations of track line and quadratic line:

$ay + b = a'y + b'$

$(a – a')y = (b' - b)$

$y = (b' - b)/(a – a')$ (8)

$x = ay + b$ (9)

Deviation (d) = $\sqrt{[(x' - x)^2 + (y' - y)^2]}$ (10)

The equations (1) to (10) are used for calculations of positions and track lines.

12. INSTALLATION OF DACS

The DACS was installed in Ezzat Adel tugboat. A conditioning circuit is used to adjust the output signal of the autopilot to be suitable for measuring by DACS. All terminals were checked to ensure that it were correctly connected. The terminals of output signal were checked to satisfy that the movement of rudders is achieved in the correct direction. Fig(15) shows the front panel of the data acquisition and control system DACS.

13. CALIBRATION

Calibration of all input signals of DACS were achieved to satisfy that all input signals were correctly red. The output signal was also calibrated to give correct action in steering system. The calibration process consists of two steps; hardware calibration and software calibration.

Fig. (15) The front panel of the data acquisition and control system DACS.

13.1 Hardware calibration:

Conditioning circuits of analogue inputs and outputs were designed to give facility of hardware calibration by using potentiometers. The hardware calibrations include main points:

- Calibration for zero position adjustment.
- Calibration for upper and lower limits adjustment.

The zero position adjustment is very important factor in the steady state performance of the control system. Zero position errors in measurements and output signals cause a permanent bias in one direction. The upper and lower limits errors has bad effect in the measurement accuracy.

13.2 Software Calibration

Calibration of all measured values were achieved by adjusting of its parameters in the software program (digital signal processing stage). Calibration of output signal was also achieved to give the desired action of the rudder steering system. Errors in parameters of measured signals cause errors over the all range of reading. Errors in parameters of output signals cause undesired effects in the control action.

The reading of each input was compared with the reading of corresponding meter in the tugboat at different conditions. If there is difference, the corresponding parameters in the software program are modified. Finally, we got a similar reading to the meter reading for each input.

14. TUNING OF FUZZY CONTROLLER

Tuning of the fuzzy controller is very important for stability and performance of fuzzy controller. A three steps of tuning are carried out as follow:

1. Initial tuning (after simulation of fuzzy control system).
2. Main tuning (after onboard testing of fuzzy control system).
3. Fine tuning (after operation of fuzzy control system).

14.1 Initial tuning:

An initial values for all input and output scaling factors was chosen. Choice of initial values of scaling factors is based of human experience and sense. A good choice of scaling factors fasten the convergence to acceptable level of stability and performance. after choice of scaling factors, the fuzzy control system was simulated at different conditions to cover the total range of all inputs. The results was plotted and analyzed, and accordingly, the input and output membership functions, rules, and scaling factors was modified. The test results are shown in fig.(16).

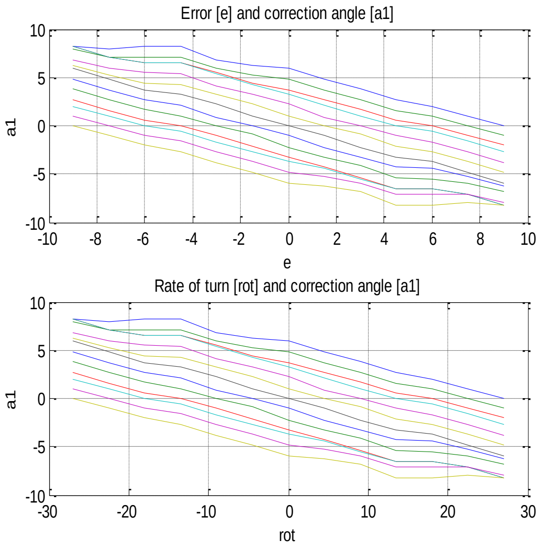


Fig.(16 - a) main fuzzy controller.

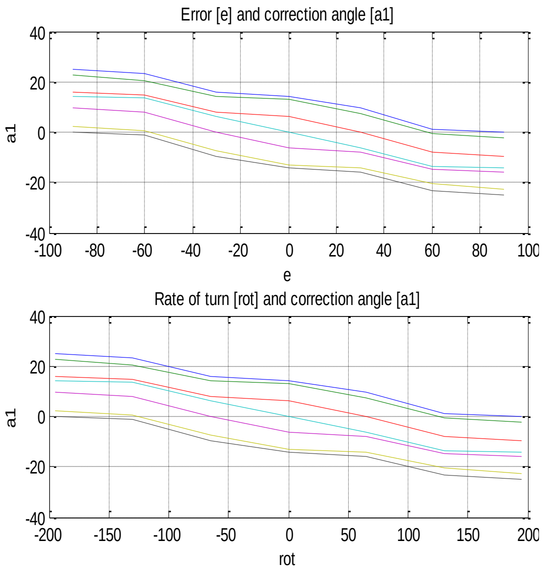


Fig.(16 - b) supervisory fuzzy controller.

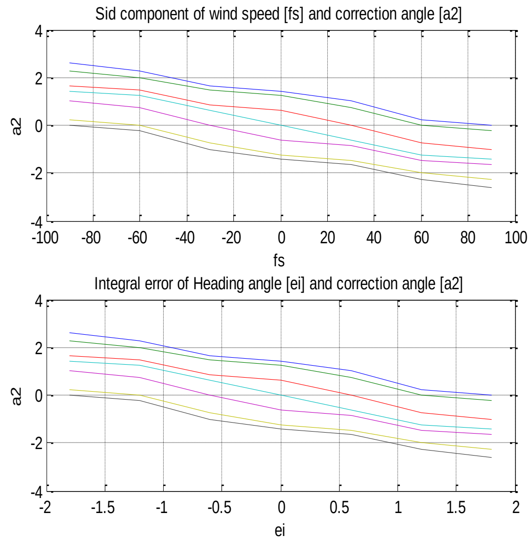


Fig.(16 - c) wind speed and integral error fuzzy controller.

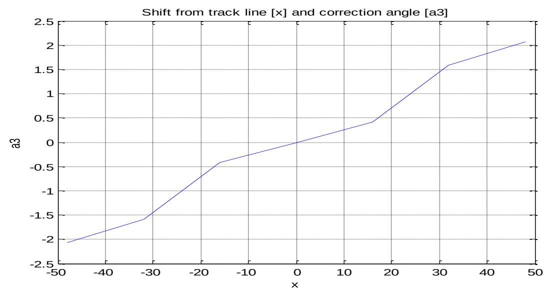


Fig.(16 - d) fuzzy controller.

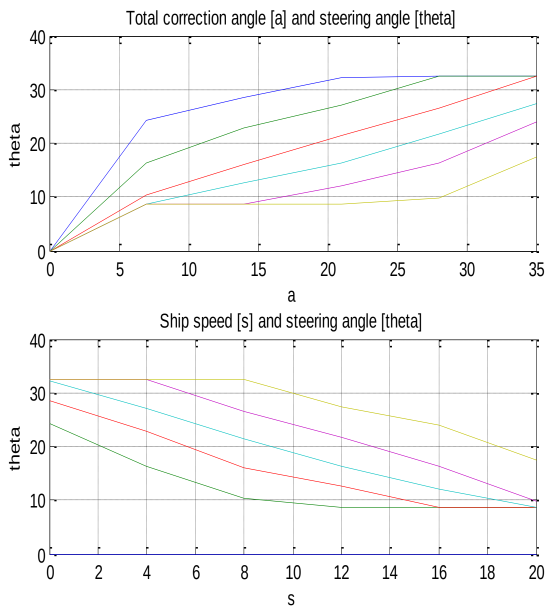


Fig.(16 - e) ship speed and total angle fuzzy controller.

14.2 Main Tuning:

To carry out the main tuning of the fuzzy controller, the tugboat started sailing. The onboard autopilot was selected to control the steering system and the fuzzy control system was operated. Both autopilot and fuzzy control system were adjusted to the same course. The output control signals from Both autopilot and fuzzy control system were observed, recorded, plotted and analyzed. The results are used for tuning of the fuzzy controller.

A set of rules for tuning of the fuzzy controller are expressed from experience, common sense, and understanding of fuzzy controller behavior. The output control signals from autopilot at different conditions were used as a reference for tuning of the fuzzy controller. The rules are as follow:

- If output of the fuzzy controller is simultaneous with output of the autopilot in both directions (SB and PS) and has the same amplitude at different conditions. Then, no tuning is required.
- If output of the fuzzy controller is simultaneous with output of the autopilot in both directions (SB and PS) but with different amplitude. Then, the output scaling factor will be modified. If the output of fuzzy controller is small, the output scaling factor will be increased and vice versa.
- If repetition rate of the fuzzy controller output is relatively high but with small amplitude. Then there is an excessive sensitivity. The input scaling factors will be decreased. If repetition rate still high. Then, stability of the system is low. The system stability will be improved by increasing of the width and overlap of the input membership functions.
- If repetition rate of the fuzzy controller output is relatively low. Then the sensitivity is low. The sensitivity will be improved by increasing of scaling factor of the input membership functions.
- If duration time of the fuzzy controller output is relatively large but its amplitude is relatively small. Then the response is slow. The no. of input membership functions will be increased to fasten the response.
- If duration time of the fuzzy controller output is relatively small but its amplitude is relatively large. Then the response is fast and stability is low. The width and overlap of the input membership functions will be increased.
- If both duration time and amplitude of the fuzzy controller output are relatively large. Then, the stability is poor. It will be improved by reducing of output scaling factor.
- If both duration time and amplitude of the fuzzy controller output are relatively low. Then, the response is weak. It will be improved by increasing of output scaling factor.
- If behavior of the fuzzy controller output is conflicting at different operating areas, i.e. the response increases in operating area and decreases in another one, the response in direction in operating area and in opposite direction in another one, or the response exists in operating area and no response in another one. Them the performance indicator is poor. To improve the performance, the rules will be

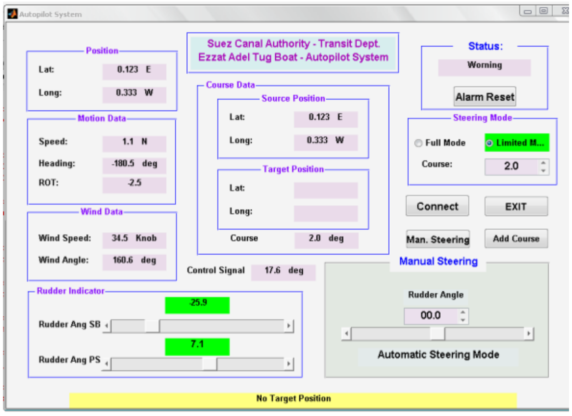
modified in some areas. The idea is to try to identify which rule is responsible for the current poor control performance, and then to replace it with a better rule.

14.3 Fine Tuning

After operation of fuzzy control system on the tugboat, tugboat started sailing. The fuzzy control system was selected to control the steering system. The output control signals from fuzzy control system were observed, recorded, plotted and analyzed. The results are used for fine tuning of the fuzzy controller according to the previous rules.

15. OPERATION OF THE FUZZY CONTROL SYSTEM

The fuzzy control system was carefully operated. The operation was achieved in partial steps to avoid unexpected dangers. The manoeuvres of course changing were smoothly achieved to avoid sudden change of course. Fig(17) shows the main and sub GUI of the fuzzy control system and application of the system in "Ezzat Adel" tugboat.



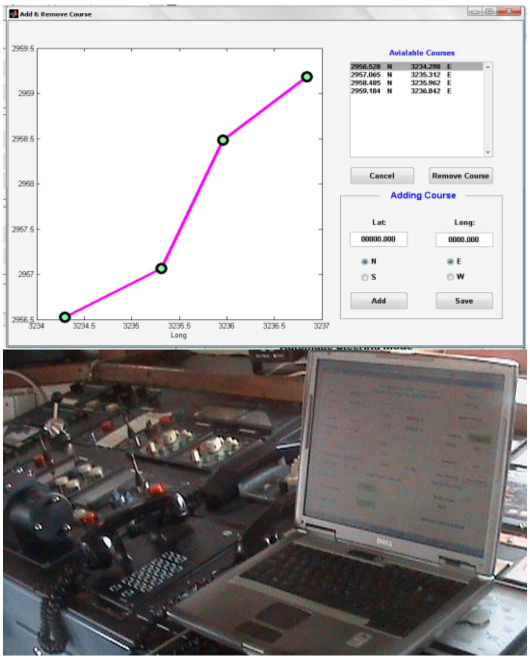


Fig. (17) GUI of the fuzzy control system and application of the system in "Ezzat Adel" tugboat.

16. CONCLUSION

The proposed fuzzy control system was designed, implemented, and tested. The DACS was designed and implemented for data acquisition and control of steering system. The input conditioning circuits were designed and implemented including analogue and digital inputs. The output circuits were designed and implemented including output relays and amplifier of output control signal. The circuits of communication ports were designed and implemented including RS-232 serial port for interfacing with PC, RS-422 serial ports for interfacing with GPS and Gyrocompass.

The operating system of DACS were designed, written, and tested to cover all functions of data acquisition, data processing, control signals, communications, and user interface.

The fuzzy controller was designed and implemented to keep heading angle and to keep the ship at track line. The testes are carried out at different conditions for all inputs, such as error, differential error (ROT), integral error, wind speed, and ship speed. The results are plotted, analyzed, and used to modify the membership functions and rules of the fuzzy controller.

A multilevel fuzzy controller was used to keep the heading angle of the ship. Two fuzzy controllers were used to keep track line. The first one was used for correction of track line due to side force of wind and integral error of heading angle. The second was used for compensation of waves and sea currents effects. fuzzy controller to match between the correction angle and ship speed and calculate the required steering angle is used.

The software program was designed, written, and tested by Matlab 2007 software package. The Matlab program consists of main program GUI functions. The main program is designed to achieve all important functions of the fuzzy control system, such as data acquisition, data processing, and control functions. GUI was designed and implemented for displaying of all important data, switching between operation modes, carrying out control actions, data entry, course modification, and trajectory plotting.

The DACS was installed in Ezzat Adel tugboat. Calibration of all input signals of DACS were achieved to satisfy that all input signals were correctly red. The output signal was also calibrated to give correct action in steering system. The hardware calibrations and software calibration were achieved. Calibration of output signal was also achieved to give the desired control action.

Tuning was carried out to satisfy the stability and performance of the fuzzy control system. The tuning include Initial tuning after simulation, Main tuning after onboard testing of fuzzy control system, and Fine tuning after onboard operation. A set of rules are developed for tuning of the fuzzy controller.

The fuzzy control system was operated to satisfy the performance of the fuzzy controller. The manoeuvres of course changing were smoothly achieved to avoid sudden change of course. This fuzzy control system will be applied in marine vessels of Suez canal authority.

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