Fuzzy logic controller based ship navigation system

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Abstract: This research work deals with more proficient and at ease to design the fuzzy logic controller (FLC) meant for course-changing. A new system in tuning a rule base in fuzzy controller system. Agreeing to the modification status of system error, the proposed real-time tuning algorithm is used in tuning the subsequent portion of fuzzy values, later the rule base is controlled. This proposed work also links the more performance of FLC at several working situations with conventional PID controller. In our proposed method we joined the PID with Fuzzy logic to build the strong and adaptive controller. The Simulation results are valuable to demonstrate this method.

Keywords: fuzzy logic controller, conventional PID controller, course-changing and course-keeping.

1. Introduction

PID controllers are extensively used in ship steering control. The key problem in using conventional PID autopilot has not maintained optimal control. It lacks in the active eccentric and it is also firm tuning the regulatory parameters. In the intelligent vehicle control system the integral part is Automatic steering control, which comprises course keeping and changing. There are number of techniques for process control system that are useful in analysis and design. Among those techniques, linear and non-linear process control system technique has been preferred. The conventional methods can’t be used for complex processes such as the cargo ship with liquid fuel, slosh of aviation fuel in an aircraft, liquid load in a railway wagon tanker, movement of the fuel load in a Formula 1 car and for economical and/or safety reasons, these process loops to be operated in unstable steady state are unstable. Therefore the engineers have constantly been in search for automatic tuning methods and have come up with fuzzy logic PID controller. Therefore, there has arisen a need for a controller which can overcome the above said disadvantages of PID controller. They are extremely complex and highly challenging to control. The dynamics of process offers great difficulty in controller design. When the process deviates from the steady state, the performance of linear controllers tends to deviate. The non-linearity in the process performance needs tuning of parameters in the controllers. The key reason in making that automatically ships sails in the particular path even if there is any change in sea environment like wind and other disturbances. It is very tough in tuning the PID controller and obtaining a good performance during all circumstances. For that a fuzzy expert system comprises base rules, fuzzy interface device etc is designed.

2. Fuzzy logic control system

An idea in Fuzzy logic is mere equivalent to the individual’s reaction and inference methods. Disparate conventional controller approach is point-to-point control, FLC is range-to-point or range-to-range control. The membership functions in a fuzzy controller derive the output from fuzzifications
of responses and yields. According to Mochamad Yusuf Santoso, Shun-Feng Su and Aulia Siti Aisjah (2013), Rudder roll stabilization for ship steering is to only use the rudder as the actuator for maintaining the autopilot heading and reducing the roll angle. In this study, a nonlinear control scheme for RRS was proposed based on Fuzzy Gain Scheduling (FGC)-PID. The proposed method was applied to a nonlinear multirole naval vessel model. Their method is being compared with the traditional PID and LQR. FGS-PID has more robust performance than the counterparts in yaw motion. For roll motion, the proposed control method has bigger roll reduction than Ziegler-Nicholas PID. Based on the tracking control simulation result, FGS-PID can follow the desired heading changing very well, as well as in maintaining the roll angle below the limit. In this method, they have maintained the ship heading and stabilized the ship rolling using one actuator: the rudder. In RSS, two controllers- the yaw controller and the roll damper are designed. Each controller has three fuzzy systems to arrange the corresponding PID gains. The function of rudder in roll stabilization is to control the heading and reducing the roll motion. Here, the wave is considered as a disturbance and is model based on the wind-generated wave principle. The wave model depends on the significant wave height. The FGS-PID control is applied to the system both with wave disturbance and without wave disturbance. The results of FGS-PID are compared with the traditional counterpart, PID controllers and Linear Quadratic Regulators (LQR). Wang Minghui, Yu Yongquan and Zeng Bi (2005) had proposed a more efficient and easier design of the Fuzzy Logic Controller (FLC) for course-changing and course-keeping. This method is to tune the rule base in fuzzy control system. According to the change status of the system error, the real time tuning algorithm is proposed to tune the consequent part fuzzy values; hence the rule base is regulated. PID autopilot could not obtain and maintain optimum control because of the lacking the capacity to tune the controlling parameters or dynamic characters, establish accurate mathematics model according to the different dynamic of every ship and dynamic difference. In their system, the autopilot design is based on the fuzzy interference mechanism to control the course changing and course-keeping manoeuvres in ship manipulating system. The proposed system gives more robust performance than the others. The oscillation of FGS-PID in the steady state is smaller for the three disturbed sea conditions in multirole naval vessel model.

Based on empirical methods the Fuzzy control system is designed, A basic methodical approach for Trial and error. The process is given below.

For a real time application the execution of fuzzy logic technique requires the subsequent stages:

1. Fuzzifications
2. Fuzzy Inference Process

2.1 Tuning PID using Fuzzy Controller:

The procedure for tuning the PID controller gain using fuzzy logic controller is shown below
2.2. Fuzzy PID Controller Structure:

A feedback loop in the fuzzy control(FC) computes the PID-like performance through fuzzy inference. The Simulink diagram of the loop structure is given below.
The parallel structure of fuzzy PID controller as displayed under is a grouping of fuzzy PI and PD control.

3. Design flow for Fuzzy PID Controller:

To design a fuzzy PID controller organizing the FIS also the need to set four mounting factors; GE, GCE, GCU and GU.
1. An unoriginal linear PID controller has to design

2. A corresponding linear fuzzy PID controller has to design

3. Regulate the FIS to attain nonlinear exterior control

4. The nonlinear fuzzy PID controller is Fine-tuned

**Process 1: Conventional PID Controller Design**

The discrete time PID controller which uses Backward Euler numerical integration method in both Integral and derivative actions is known as conventional PID controller. The controller gain is $K_p$, $K_i$ and $K_d$. The Simulink is implemented in the controller.

![Figure 4. Conventional PID Controller](image)

Analogous the fuzzy PID controller, an input signal is the derivative achievement is $-y(k)$, as a substitute of $e(k)$. The PID controller gain is tuned by physically or procedures.

**Process 2a: Equivalent Linear Fuzzy PID Controller Design**

A linear fuzzy PID is obtained while configure and select the FIS and four scaling factors, which replicates the precise control performance like conventional PID controller. In primary, organize the FIS then it generates a linear control surface from inputs to outputs using Mamdani style fuzzy inference system.

**Constructing fuzzy inference system:**

- Define input yaw error
- Define input yaw rate
- Define output Rudder Angle
- Define the rules
FIS is built using commands. To design the system FIS Editor GUI tool has to be used. 3-D plot has the surface view of the linear control. Scaling is determined (ie) GE, GCE, GCU and GU from the PID.Controller gains damaged as usual. The terms of the outdated PID are compared with the linear fuzzy PID, and the variables are correlated.

**Process 2b: 2-D Lookup Table based F1 System**

- The fuzzy controller slab contains 2 inputs and 1 output substituted with a 2-D lookup table.
- The 2-D lookup table F1 System produces twisting the common input and calculating the output by evalfis command.
- The fuzzy PID controller with 2-D lookup table is presented beneath. The FLC block is substituted with a 2-D Lookup Table.

![Diagram of Fuzzy PID controller with 2-D lookup table](image)

**Figure 5. Fuzzy PID controller with 2-D lookup table**

**Process 2c: Pretend Closed-Loop Response**

There are three changed sub-systems used in the model, namely Conventional PID, Fuzzy PID and Fuzzy PID using Lookup Table, to regulate the plant. The Scope shows the closed-loop replies in step reference modification are similar.
Process 3: Nonlinear Control Surface with Fuzzy PID controller

The verification of the linear fuzzy PID controller is completed, to alter the FIS situations like smartness, membership functions and rule base to acquire a preferred nonlinear control surface. The inputs have two set terms (+ve and -ve) and four reduced rules. A high gain is obtained in between the center of two inputs level than the direct exterior, helps to reduce the fault quickly even for minor fault. A larger fault is happen, controller develops fewer violent then the control exploit is very restricted which is to dodge potential capacity. The lookup table is reorganized with the fresh control exterior data.

A change in step response of a closed-loop is displayed in the scope. A linear PID controller, is compared with the nonlinear fuzzy PID controller condenses 50% of over shoot. The overlapping of 2 reaction curves from the nonlinear fuzzy controllers shows that the 2-D lookup table estimates a fit FIS.

Figure 6. Fuzzy PID Controller With Nonlinear Control Surface
A fuzzy interference system editor is given below.

![Fuzzy Interference System Editor](image)

| FIS Name: | FIS Type: | mamdani |
|-----------|-----------|--------|
| And method | min | 
| Or method | max | 
| Implicator | min | 
| Aggregation | max | 
| Defuzzification | centroid | 

**Figure 7. FIS Editor**

The input yaw error, yaw rate and the output rudder angle are given below.

![Input Yaw Error](image)

**Figure 8. The Input Yaw Error**

![Input Yaw Rate](image)

**Figure 9. The Input Yaw rate**
The rule base and rule based output is given below.

Figure 10. The Output Rudder Angle

Figure 11. Rule Base

Figure 12. Rule Base Output

The output of the rudder response in surface and scope view are given below.
Figure 13. Rudder response Surface View

Figure 14. Rudder response with PID Controller
4. Conclusion

A ship motion is a kind of complicated nonlinear motion. It is very tough to determine the exact hydrodynamic limitation in the course of the ship in sea. Besides, the external trouble impending from wind, tides and marine current are moving at every instant. The use of fuzzy logic PID controller in the determination of the different controller parameters is feasible due to their fast convergence and reasonable accuracy. This can be seen by comparing the results of the fuzzy logic PID controller and the conventional controller. The comparison is based upon the loop transient response characteristics and errors. The simulation outcomes displays that the new control technique is active with durable and adaptive proficiency and the same is implemented in all maritime active location arrangements.

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