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PID Based Rudder Controller

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Abstract:—Accurate controlling of Rudder is a challenging issue, it demands co design approach. Researchers are trying to provide solutions by upgrading hardware functionalities and by reducing the computational complexity of algorithm. PID, Adaptive and Predictive algorithms are the most widely used algorithm for Rudder control. This paper discusses simple, cost effective, PID based, 8051 microcontroller Rudder controller. The hardware results have shown the angle accuracy of 2◦ and reaction time of 0.132s.

Keywords:— Rudder, PID, GPS, MEMS, Triangulation

I. INTRODUCTION

A Rudder [1] is a device used to steer a ship, boat, submarine, hovercraft or other conveyance that moves through water. In small craft the rudder is operated manually by a handle termed a tiller or helm. Tiller or Helm cannot be used for large ships. In larger ships, the rudder is turned by hydraulic or rudder actuators. Hydraulic actuators have the following disadvantages: low reliability, high pressure seals which may leak, pumps or drive couplings which may be misaligned, high consumables like oil / cleaning / flushing fluid are required, requires more weight and space, requires more power consumption.

There are various types of rudder steering control systems available for navigation. Depending on the working principle and mode of steering they are classified into 3 types. They are electro-mechanical and electro-hydraulic and electronic rudder actuation systems

Electro-mechanical [3] steering gear is found on small ships. The working principle of the electro-mechanical systems is that the electrical command signals are converted into mechanical motions with the help of transducers or mechanical drivers. Electro-mechanical steering system is simple, less expensive, easy maintenance, no leakage problems. But these systems requires huge amount of power to turn rudder and also less accurate in terms of rudder deflection.

Electro-hydraulic [2] Ship / rudder Steering System is based on the principle of pressure of the fluid. It consists of a hydraulic device which sets the position of the rudder by means of fluid pressure produced by a pump. Electro-hydraulic systems have good equipment manoeuvrability, but require high maintenance and also they are less accurate.

Micro Electro-mechanical systems (MEMS) [4] are extensively used in modern navigational methods. In this method rudder motion is controlled by the motor, which is internally controlled by a microcontroller. Usually servo motors are used to control the rudders because they have high torque at all speeds, capable of holding a static (no-motion) position, able to reverse directions quickly and able to accelerate and decelerate to reach a position quickly.

This paper discusses the design of PID based, 8051 microcontroller Rudder controller. Section-2 Discusses in brief hardware implementation, Section-3 Discusses MATLAB simulation results along with hardware results, Section-4 compares all the results obtained from various types of PID controller.

II. HARDWARE IMPLEMENTATION

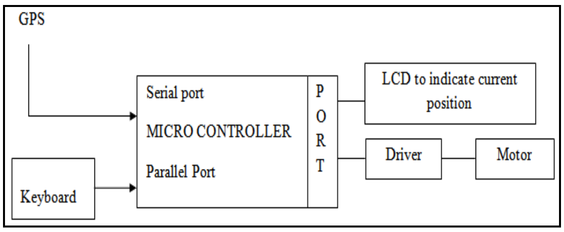

Figure 1: System Block Diagram

The block diagram consists of following blocks: 8051 Microcontroller, keypad, LCD Screen, GPS, Driver and DC motor.

User feeds the target information through keypad to the microcontroller. GPS is used to extract current location of the ship. Using the source, destination, and current position values of latitude and longitude (triangulation), the controller calculates the desired angle to which the rudder has to be rotated.

III. MATLAB SIMULATIONS

3.1 Proportional Controller:

The closed loop 8051 based proportional controller is implemented for ship rudder angle generation. Figure 2 illustrates the step response of the Proportional controller.

Table 1 indicates the obtained MATLAB rudder angles in accordance with triangulation formulae and compares the same with the practically obtained rudder angle along with the time taken by controller to attain the desired angle.

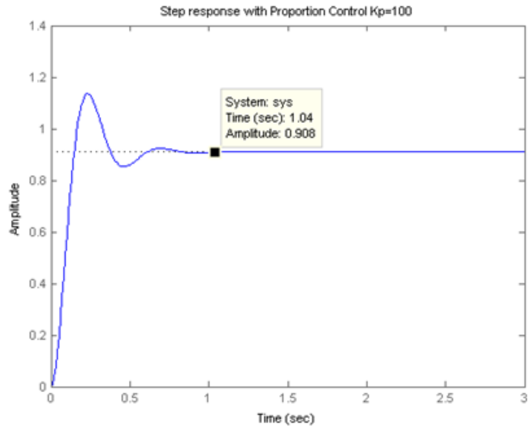

Figure 2: Step Response of P-Control

Table 1: Simulated Vs generated angles P Control.

MATLAB calculated angle	Controller attained angle	Error	Time (s) required
122.57	121.17	1.4	3.70
147.83	146.17	1.4	4.45
28.52	27.12	1.4	0.88
32.53	31.13	1.4	1.00
23.11	21.71	1.4	0.70
45.50	44.10	1.4	1.39

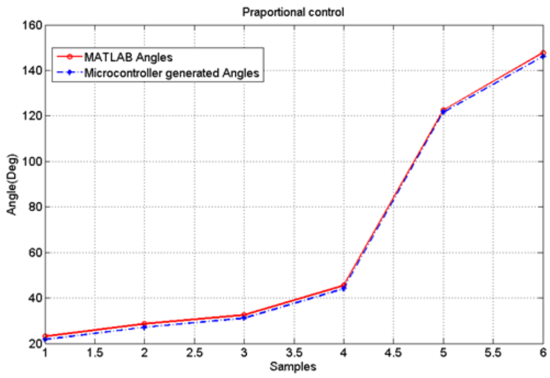

Figure 3: MATLAB Angle versus Attained Angle

Figure 3 illustrates that an angle deviation of 1.4^0 exists, when compared with the MATLAB generated angle and the time taken to attain the set angle is also comparatively high (4.45 second is required to attain 147.83 degrees). Thus Proportional based controller is not suitable for rudder actuation system.

3.2 Propotional - Integral Controller

The closed loop 8051 based Proportional - Integral controller is implemented for ship rudder angle generation. Figure 4 illustrates the step response of the Proportional – Integral controller

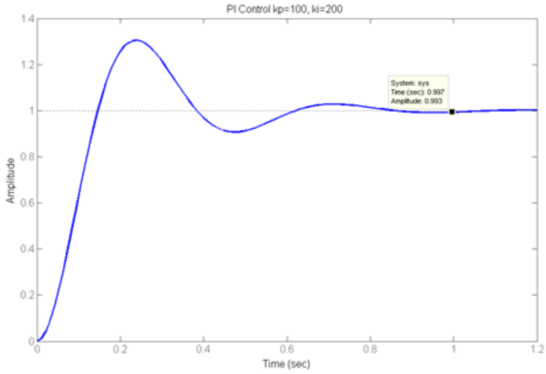

Figure 4: Step response of PI Control

Table 2 indicates the obtained MATLAB rudder angles in accordance with triangulation formulae and compares the same with the practically obtained rudder angle along with the time taken by controller to attain the desired angle.

Table 2: Simulated angles Vs Controller generated angles

MATLAB calculated angle	Controller attained angle	Error	Time (s) required
122.57	121.97	0.6	3.27
147.83	147.23	0.6	4.02
28.52	27.92	0.6	0.45
32.53	31.93	0.6	0.57
23.11	22.51	0.6	0.27
45.50	44.90	0.6	0.96

Figure 5 illustrates that an angle deviation of 0.6^0 exists, when compared with the MATLAB generated angle and the time taken to attain the set angle is high (4.02 second is required to attain 147.83 degrees). Thus Proportional-integral based controller is not suitable for rudder actuation system, (even though the error is less, more time is required)

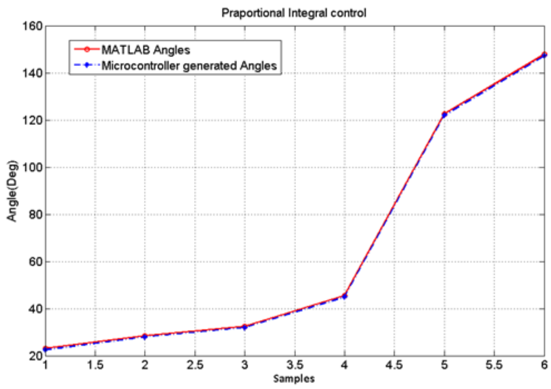

Figure 5: MATLAB Angle versus Attained for P-I Controller

3.3 Proportional - Differential Controller

The closed loop 8051 based Proportional - Differential controller is implemented for ship rudder angle generation. Figure 6 illustrates the step response of the Proportional - Differential controller.

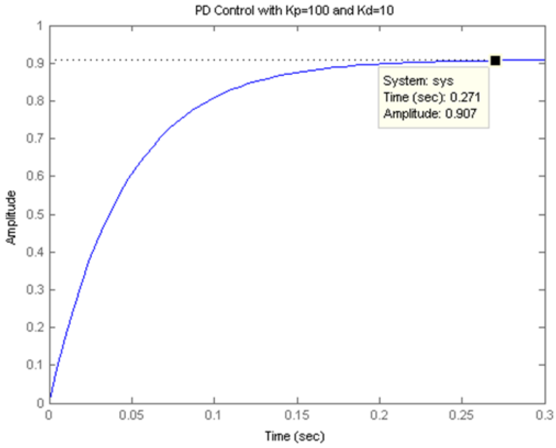

Figure 6: Step Response of PID Control

Table 3 indicates the obtained MATLAB rudder angles in accordance with triangulation formulae and compares the same with the practically obtained rudder angle along with the time taken by controller to attain the desired angle.

Table 3: PD control simulated vs generated angles

MATLAB calculated angle	Controller attained angle	Error	Time (s) required
122.57	120.77	1.8	2.94
147.83	146.03	1.8	3.69
28.52	26.72	1.8	0.12
32.53	30.73	1.8	0.24
23.11	21.31	1.8	0.03
45.50	43.70	1.8	0.63

Figure 7 illustrates that an angle deviation of 1.8^0 exists, when compared with the MATLAB generated angle and the time taken to attain the set angle is relatively less (3.69 second is required to attain 147.83 degrees). Thus Proportional-Differential based controller is not suitable for rudder actuation system, (even though the time required is less, error is more)

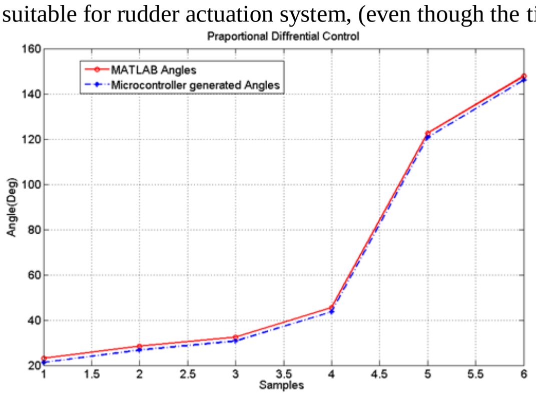

Figure 7: Set angle versus Attained Angle

3.4 PID Controller

The closed loop 8051 based Proportional – Integral - Differential controller is implemented for ship rudder angle generation. Figure 8 illustrates the step response of the Proportional – Integral - Differential controller.

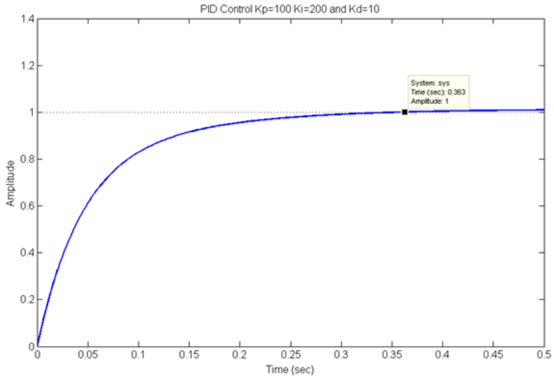

Figure 8: PID Controller

Table 4 indicates the obtained MATLAB rudder angles in accordance with triangulation formulae and compares the same with the practically obtained rudder angle along with the time taken by controller to attain the desired angle.

Table 4: PID Control simulated vs generated angles

MATLAB calculated angle	Controller attained angle	Error	Time (s) required
122.57	122.37	0.2	3.03
147.83	147.63	0.2	3.78
28.52	28.52	0.2	0.21
32.53	32.53	0.2	0.33
23.11	23.11	0.2	0.06
45.50	45.50	0.2	0.72

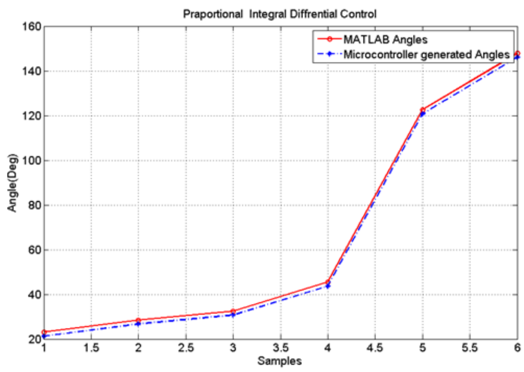

Figure 9: Set angle versus Attained Angle

Figure 9 illustrates that an angle deviation of 0.2^0 exists, when compared with the MATLAB generated angle and the time taken to attain the set angle is well within the acceptable limits (3.78 second is required to attain 147.83 degrees). Thus Proportional-integral based controller is suitable for rudder actuation system, (because both error and time is less)

IV. CONCLUSION

In this work a detailed analysis and design of GPS controlled navigation is carried out to generate accurate rudder angle in minimum time. Manual tuning of PID controller is performed using MATLAB by considering geared DC motor as load in order to determine the K_P, K_D and K_I values.

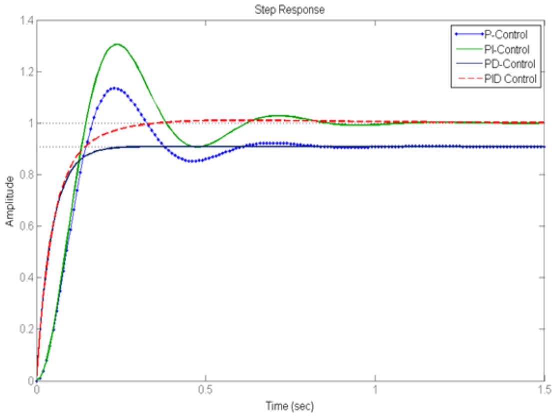

Figure 10: Comparison of P, PI, PD, PID Controller

The values obtained through simulations are used in designing the hardware (controller board).The hardware results (Figure 10, 11 and 12) obtained for various control algorithms indicates that P-I and PID controller satisfies the defined objectives, but PID controller provides better results. The P-D controller can attain steady state value in less time compared to all the other controllers, but the steady state error is more. The entire controller board is designed using low cost simple 8051 microcontroller.

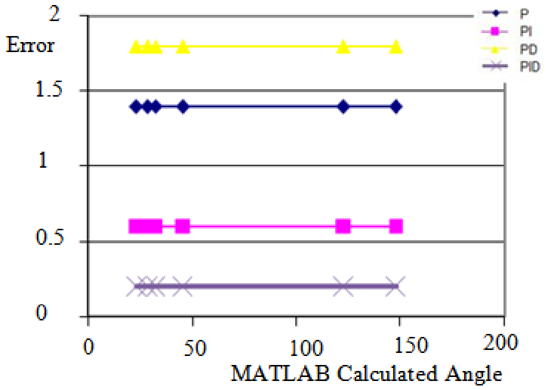

Figure 11: Comparison of Set Angle versus Attained Angle

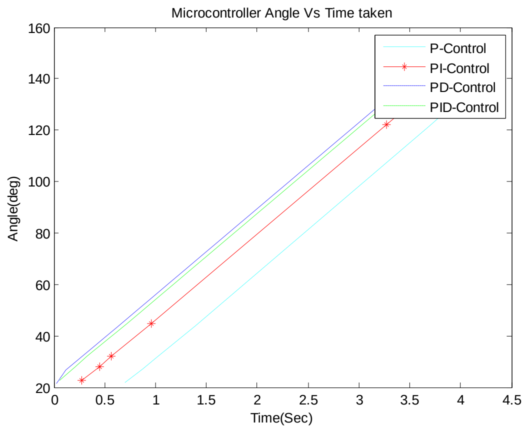

Figure 12: Comparison of Time versus Attained Angle

Sea disturbance and obstacle are not considered in this work. In case if these two are taken into consideration, implementation steps remain same, but the complexity of the program and execution time increases due to signal conditioning and processing of signals coming from sensors. The time taken can be decreased further by using high performance processor, power being an important issue, the controller chord can be designed using low power consumption processors or controllers. The accuracy of rudder angles can be further increased by using AC servomotors.

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