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LOW COST MOBILE INVERTED PENDULUM USING KALMAN FILTER WITH FUZZY BASED PID CONTROLLER

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ABSTRACT: In the "Mobile Inverted Pendulum (MIP)," the robot with two-wheels can move front and back in a horizontal path and take the role of the cart in the basic inverted pendulum system. The usage of expensive sensors, like the SCC2130-D08-05 Murata, is a flaw in the current system. Our work includes modeling the MIP's State Space equation and utilizing MATLAB to examine the system's observability and controllability. To estimate the angular position of the MIP, a combination gyro sensor, accelerometer sensor along with Kalman filter is developed thereby reducing the cost of the model. PID controllers with FUZZY tuning are used in the proposed system. The MIP is stabilized using the PID. The PID gain settings in this case are tuned using a fuzzy method.

Keywords: ***Mobile inverted pendulum, Kalman filter, PID Controllers and Fuzzy Algorithms***

I . INTRODUCTION

An inverted pendulum (IP) is unsteady and will go over if not supported. A benchmark for evaluating control strategies is the inverted pendulum, a famous problem in dynamics and control theory. The Inverted Pendulum is made up of a cart and a pole that are moved back and forth by an actuator to keep the pole balanced in an upright position. The application for rocket landing is also essentially a balance issue with an inverted pendulum. It is possible to conceptualize both animal and human locomotion as inverted pendulum balancing issues.

The Mobile Inverted Pendulum (MIP), which substitutes a two-wheeled robotic system that swings back and forth in the horizontal direction for the cart, is a comparable inverted pendulum balance problem.The MIP also includes a more complicated balancing algorithm that takes into account unknown loads. Segway, which is used to transport people from one location to another, is its application. It is an essential component of the mobile inverted pendulum system, but it also has a third dimension that enables its users to rotate around its axis. Accurate sensing of the system's current state becomes increasingly crucial and must be completed before control in order for the mobile inverted pendulum robot system to function properly.

II. PROCESS DESCRIPTION

In this study, low-cost sensors like gyros are used in place of more expensive ones. Gyro sensors' drift issues must be addressed with the aid of accelerometers. Although the gyro sensor responds quickly, it drifts as a result of cumulative mistakes from the integration process used to derive angle information from acceleration.The accelerometer and gyro sensor are combined to determine the angle based on sensor data. The Mobile Inverted Pendulum was then brought into balance using a PID control system. Using fuzzy logic, the PID controller has been tuned.

2.1 ROOT LOCUS TECHNIQUES

In the root locus technique, the control system will evaluate the roots' position, their locus of movement, and associated data. These specifics will be utilized to assess the system's efficacy.

$$G(s) = k \times \frac{numerator\ of\ s}{denominator\ of\ s}$$

2.2 CONTROLLABILITY

The dynamic system must be controlled in order for us to have complete freedom in how we use it.

$$\begin{bmatrix} \mathbf{y}(0) \\ \mathbf{y}(1) \\ \mathbf{y}(2) \\ \vdots \\ \mathbf{y}(n-1) \end{bmatrix}^{(np)\times 1} = \begin{bmatrix} \mathbf{C}_d \\ \mathbf{C}_d\mathbf{A}_d \\ \mathbf{C}_d\mathbf{A}_d^2 \\ \vdots \\ \mathbf{C}_d\mathbf{A}_d^{n-1} \end{bmatrix}^{(np)\times n} \times \mathbf{x}(0)$$

2.3 OBSERVABILITY:

To be able to perceive what is occurring inside the system under observation, it must be observable. A matrix has been created from the observability:

$$\begin{bmatrix} \mathbf{y}(t_0) \\ \dot{\mathbf{y}}(t_0) \\ \ddot{\mathbf{y}}(t_0) \\ \vdots \\ \mathbf{y}^{(n-1)}(t_0) \end{bmatrix}^{(np)\times 1} = \begin{bmatrix} \mathrm{C} \\ \mathrm{CA} \\ \mathrm{CA}^2 \\ \vdots \\ \mathrm{CA}^{n-1} \end{bmatrix}^{(np)\times n} \times \mathbf{x}(t_0) = \mathcal{O}\mathbf{x}(t_0) = \mathrm{Y}(t_0)$$

The observability and controllability tests will be combined with the rank tests of particular matrices, including the controllability and observability matrices.

Stability is the most important element of every system. The controllability (observability) of unstable system modes is referred to as stabilization (detectability) notions. We also show that controllability and observability are both invariant under nonsingular transformations. The study of observability has a close relationship with observer (estimator) design, a simple but essential technique for creating a dynamic system known as an observer (estimator), which produces estimates of the system state variables using knowledge of the system inputs and outputs.

2.4 KALMAN FILTER

An accelerometer and a gyroscope were used in this instance as the series of readings that the Kalman filter method used. These measurements will have noise in them, which will increase the measurement inaccuracy. The Kalman filter will then attempt to estimate the state of the system using the prior and present states, which are typically more accurate than measurements alone.

When measuring gravitational acceleration when the robot is traveling back and forth, the accelerometer has the drawback of being quite noisy. The gyro sensor responds quickly, but the difficulty is that it drifts as a result of cumulative mistakes from integrating acceleration-based angle information.

III. LITERATURE SURVEY

[1]Implementing an ODIP and using the dual Takagi-Sugeno (TS) fuzzy control technique that has been suggested to control the ODIP in real-time. For ODIP system control with disturbances and uncertainties, the suggested controller integrates two fuzzy control techniques.
[2]To account for gyro drifts, a complementary filter is used. Designs for PI-PD control based on PID and LQR were implemented.
[3]A low pass filter for tilt sensors and a high pass filter for gyro sensors make up a complementary filter. Based on filtered sensor data, the Kalman filter is used to estimate the angle.
[4]Without knowing the dynamics of the system, fuzzy logic and neural network techniques have been used to demonstrate their usefulness in controlling the relevant MIP system.

Commercial Gyro Sensors, which are pricey, are utilized in the current system to sense the angular velocity of the MIP. Different control strategies have been put forth to maintain equilibrium in the MIP system, which combines conventional and intelligent controllers. The PID controller is the most crucial and fundamental controller employed, and the state feedback controller is the most fundamental conventional approach.

In this paper, inexpensive sensors are used in place of commercial ones. In order to estimate the angle based on sensor data, the gyro sensor and the accelerometer are combined. A PID control system has been used as the control element to balance the Mobile Inverted Pendulum. The PID controller has been tuned using fuzzy logic.

Table 3.1.Comparison between the existing & proposed methodology/system

EXISTING SYSTEM	PROPOSED SYSTEM
PID controller	Fuzzy Based PID Controller
Sensor fusion technique not used	Kalman Filter Based Sensor fusion technique

The table 3.1 shows the contrast between the existing & proposed methodology.

IV. HARDWARE

4.1 BLOCK DIAGRAM

The model's whole functional block diagram is displayed in figure 4.1

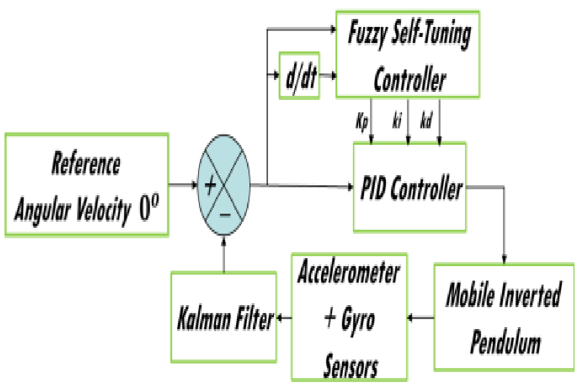

Figure 4.1. Block diagram showing the proposed system's functionality

4.2 MOTOR DRIVER L298N

The L298N is a 15-lead Multiwatt and PowerSO20 packaged integrated monolithic circuit. It is a dual full-bridge driver designed to drive inductive loads including relays, solenoids, DC motors, and stepping motors. It has a high voltage and high current.

4.3 MPU6050

The MPU6050 devices include a 3-axis gyroscope, 3-axis accelerometer, and an integrated Digital Motion Processor TM (DMTM), which manages complex 6-axis Motion Fusion algorithms. The device can link to external magnetometers or other sensors through an extra master I2C channel, allowing the devices to gather all available sensor data without the need for system processor intervention. The devices are packaged in a QFN that measures 4 mm x 4 mm x 0.9 mm.

4.4 BO MOTOR

Battery-operated DC motor. Electrical energy is transformed into mechanical energy by a dc motor. Since its gears improve torque while reducing speed, DC gear motors are employed in robot motor control circuits. RPM is used to measure motor speed. Revolutions per Minute, or RPM.

V. SOFTWARE

5.1 GENERAL

The MIP System's modeling and simulation are done using MATLAB and SIMULINK. A system can be virtually represented by modeling, and simulation aids in system behavior prediction. Particularly in the early stages of the design process when hardware may not be accessible, modeling and simulation are particularly useful for testing circumstances that may be challenging to replicate with hardware prototypes alone. By improving the quality of the system design early on, iterating between modeling and simulation helps lower the amount of errors discovered later in the design process.

5.2 DESIGN OF STATE SPACE MODEL FOR MIP IN SIMULINK

Designing a State Space Model of MIP in Simulink and response of the system without controller is obtained Figure 5.1 a,b.. Response of the System is unstable.

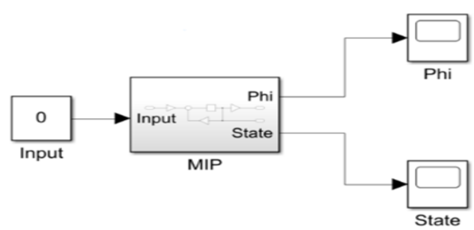

Figure 5.1 a Simulink Model - Without controller

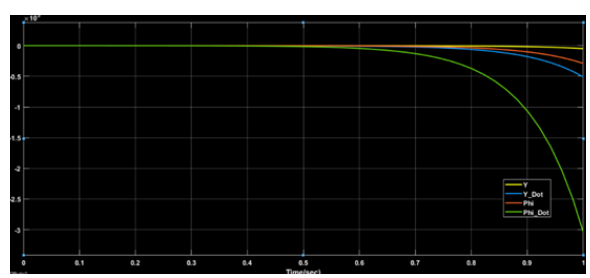

Figure 5.1 b Response of MIP without controller

5.3 DESIGN OF STATE FEEDBACK CONTROLLER IN SIMULINK

By enhancing system performance with the help of pole placement and linear quadratic regulator (LQR) approaches, a state feedback controller (SFC) is designed to stabilize the system. Gain (K) for the ideal pole is computed using LQR. as depicted in Figure 5.2a, b.

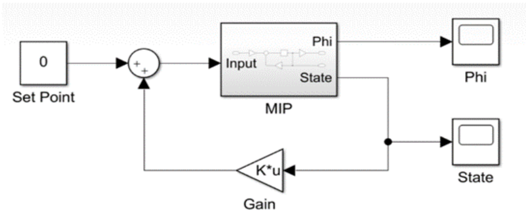

Figure 5.2 a Simulink Model –State Feedback Controller

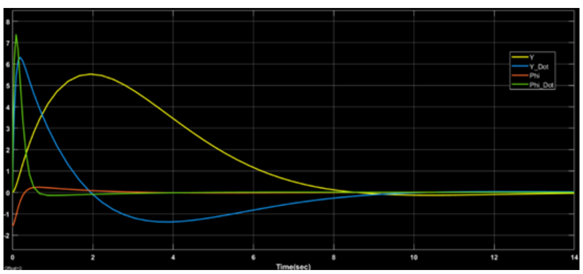

Figure 5.2 b Response of MIP using State Feedback Controller

5.4 DESIGN OF PID CONTROLLER IN SIMULINK

Figure 5.3 a, b depicts the system's response after a PID Controller for MIP was designed in Simulink. Table 5.1 contains a list of the PID parameters that were discovered through a process of trial and error for this model. PID is designed to control the angle (Phi). the PID measurements found.

Table 5.1 PID parameter using Trial and Error method

Controller	K_p	K_i	K_d
PID	100	0.1	2

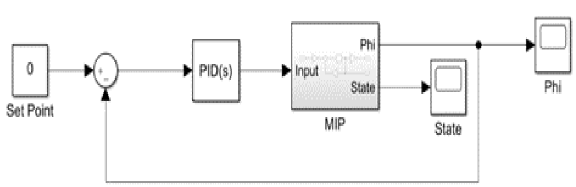

Figure 5.3 a PID Controller Simulink Model

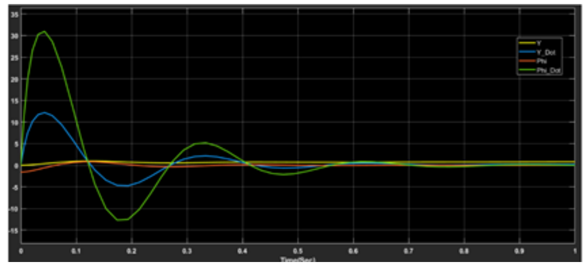

Figure 5.3 b Response of MIP using PID Controller

5.5 DESIGN OF FUZZY- PID CONTROLLER IN SIMULINK

PID controllers are tuned using fuzzy logic controllers. The closed loop feedback error (e(t)) and the derivative of error (de/dt) are inputs to the fuzzy logic controller, while PID parameters are the outputs. Figure 5.4(a,b,c) shows this.

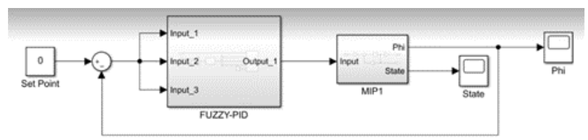

Figure 5.4 a Simulink Model – FUZZY-PID controller

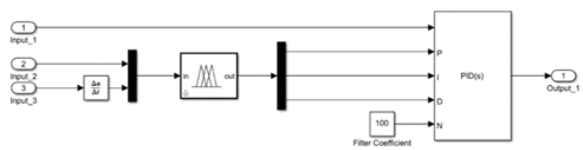

Figure 5.4 b Simulink Model – FUZZY-PID Subsystem

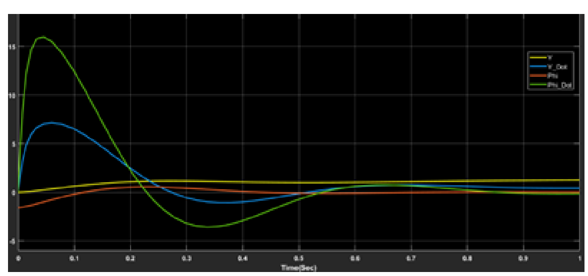

Figure 5.4 c Response of MIP using FUZZY-PID Controller

5.6 MEMBERSHIP FUNCTION

Both e and de/dt are given the following membership functions: NB (Negative Big), NS (Negative Small), Z (Zero), PS (Positive Small), PB (Positive Big), and the same for output Kp, Ki, and Kd.

VI. RESULTS

Figure 6.1 and Table 6.1 compare the outcomes of several controllers for various parameters, showing how FUZZY-PID performs significantly better than SFC and PID controllers.

Table 6.1 Comparison of SFC,MIP,FUZZY-PID

Parameter	SFC	PID	FUZZY-PID
Rise Time (sec)	0.65	0.12	0.23
Settling Time (sec)	7.5	1.0	0.7
Steady State Error	0	0	0

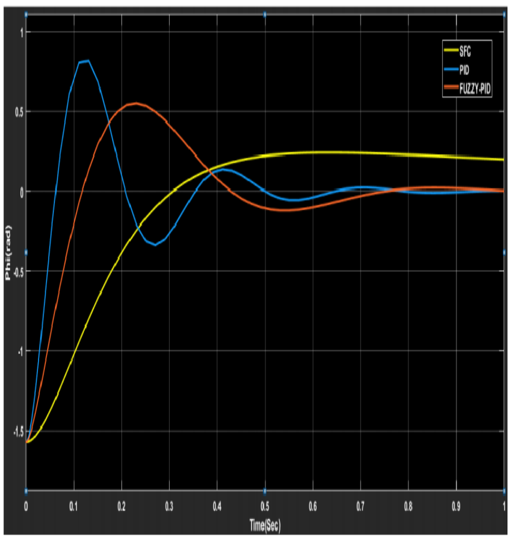

Figure 6.1 Comparison of SFC,PID,FUZZY-PID

6.1 DATA ANALYSIS OF COMPLEMENTARY AND KALMAN FILTER

Table 6.2 Data retrieved from MPU6050

Time (hh:mm:ss)	Sensor_Original Angle_Phi (deg)	Complementary_Filter Angle_Phi (deg)	Kalman_Fitler Angle_Phi (deg)
00:00:00	118.94	61.12	62.36
00:00:01	117.11	60.62	60.96
00:00:02	78.96	19.88	31.27
00:00:03	5.33	-9.68	-5.75
00:00:04	-103.55	-60.73	-57.11
00:00:05	-84.94	-35.6	-43.86
00:00:06	-1.97	12.63	2.49
00:00:07	-9.29	-22.33	-11.05
00:00:08	127.6	62.06	59.44
00:00:09	128.94	79.69	70.72
00:00:10	25.77	13.38	13.41
00:00:11	10.35	-5.76	0.56

VII. CONCLUSION

We built a mobile inverted pendulum that uses inexpensive sensors and the Kalman filter technique to estimate angle. Because we use a low-cost DC geared motor, the system can steady itself up to a tilt of 15 degrees toward the ground before the robot loses the ability to balance itself and falls over. By incorporating a high torque DC motor with a position encoder, we may also address this flaw. Furthermore, the system is quite compact, and the full robot was designed at a minimal cost. Additionally, this robot is nominally quite light in weight. We were able to achieve our highest accuracy level in a stable autonomous manner by using inexpensive sensors. By implementing a fuzzy-based PID controller, the system can self-balance in the best possible way.

VIII. FUTURE SCOPE

The MIP has only been stabilized thus far, but we can expand our vision to include position control, which opens up a new dimension. This will allow us to use this MIP as a locomotive. The carriage can be stabilized using MIP. Motion sensor technology is used in conjunction with cameras to identify and avoid large obstructions in its route. The MIP becomes more intelligent and can predict the effective path to be taken when the path is optimized by adding the shortest path algorithm, such as A*To increase the effectiveness and stabilize performance, we can employ high torque motors.

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