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INVERTED PENDULUM TWO-WHEEL ROBOT USINGACCELEROMETER AND GYROSCOPE FOR ITS SENSORS

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ABSTRACT

An inverted pendulum is a pendulum - a free body hung from a fix point and can swing freely in all directions – that has its center of mass above its pivot point. Unlike regular pendulum which is inherently stable, an inverted pendulum is inherently unstable and must be actively balanced in order to remain upright by applying some force at the pivot point, thus moving the pivot point horizontally as a feedback system. The pivot point is moved using a simple vehicle consisting of two wheels that moves freely in one direction. The feedback control to move the pivot point horizontally is a sensor system consisting of solid state accelerometer and gyroscope. The accelerometer will detect the angle of the inverted pendulum device and the gyroscope will detect the rate of rate of change of angle and therefore measure the angular velocity. The vehicle robot is a two-wheel vehicle which is controlled independently using two independent DC motor. The DC motors are controlled by a microprocessor which controls the speed of the motors using pulse width modulation independently for each motor and the feedback on how to move the robot horizontally is by the accelerometer and gyroscope system which is mounted on the top of the robot. The control system is a PID control which in which the proportional gain, differential factor and the integral factor already predetermined. A second microcontroller will obtain the result from the sensor and put it on a display for monitoring purposes. The robot has been built and programmed and shown to work to balance the robot for certain period of time using accelerometer and gyroscope as the feedback sensors and a set of microcontrollers as the control system to set the robot stay erect.

Keywords: inverted pendulum, accelerometer, gyroscope.

INTRODUCTION

An inverted pendulum is a pendulum with its center of mass located above the pivot point of the pendulum. An inverted pendulum system designed here is implemented on a cart with two wheels sharing the same axis; therefore the pivot point of the system is located at the wheels. This system is inherently unstable; therefore force must always apply to the system in order to keep the system erect. Figure-1 shows the inverted pendulum robot system with the pivot point on its wheels from the side of the robot. It is shown in the illustration that the center of mass will pivot about the point of the wheels touching the ground.

An inverted pendulum system is a classic control system in the field of control engineering s essential in the evaluating and comparing of various control theories. This system is a non-linear system which can be treated as a liner control system without too much error in the output of the system. As illustrated in Figure-1, the system must be kept in upright position so that the robot will not fall and the compensation force is given on the servo motor to keep the system upright.

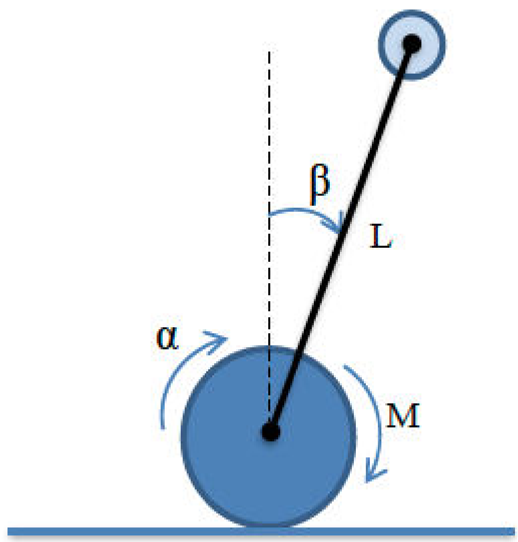

Figure-1. The inverted pendulum robot system with the pivot point on its wheels (side view).

The block diagram of the inverted pendulum robot is shown in Figure-2. This illustration shows that the system has two sensors - gyroscope and accelerometer - to detect the angle of inclination of the system. The gyroscope will provide the angular velocity of the system and the accelerometer will provide the angular acceleration. The output of both sensors - which is already in digital format - is fed to a Kalman filter for noise

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reduction and also signals averaging and other calculations to obtain the angle of the robot.

Angle of the robot obtained from the accelerometer can be obtained via equation (1) and the angle from the gyroscope is integration over time depicted via equation (2)

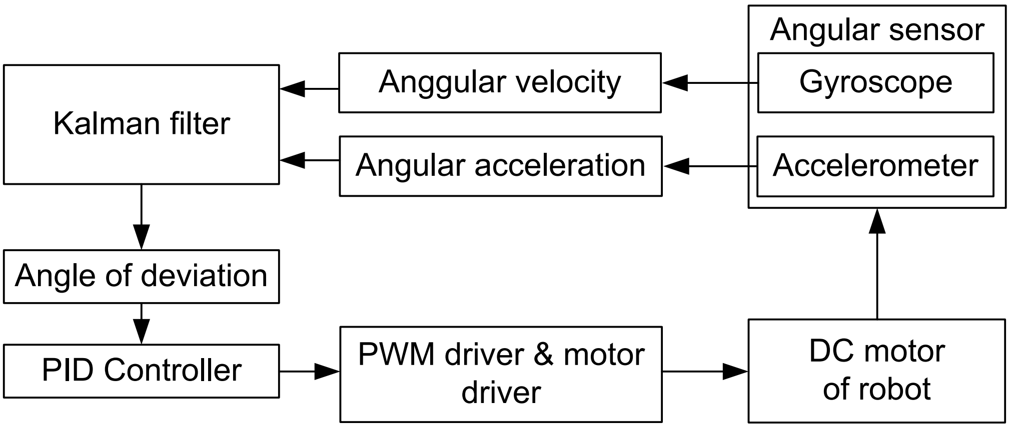

Figure-2. Block diagram of inverted pendulum robot which consists of two sensors, microprocessors and DC motors with its drivers.

$$\theta_{accel} = \tan^{-1}\left(\frac{A_{y.out}}{A_{z.out}}\right) \quad (1)$$

$$\theta_{gyro} = \int \dot{\theta}_{gyro}\, dt \quad (2)$$

Where $\dot{\theta}_{gyro}$is the angular velocity of the gyroscope?

Angle from the above equation is fed into the Kalman filter which is a predictor and corrector. The angle is first predicted using the matrix

$$\hat{X}_k = \hat{X}_{k-1} + K_k(Z_k - H_t\hat{X}_{k-1}) \quad (3)$$

Where
$\hat{X}_k$ = New or current predicted value obtained from the Kalman filter processing
$\hat{X}_{k-1}$= Previous predicted value obtained before
Z_k = Angle measurement from the two sensors
H_t = Matrix to obtain the new predicted value
K_k =Kalman filter gain and gathered from trial and error from the system and can be found from equation (4) and (5)
R = Correlation matrix obtained by updating the covariance matrix

$$K_k = \frac{P_{k-1}{H_t}^T}{H_t P_{k-1}{H_t}^T + R} (4)$$

$$P_k = (I - K_k H_t)P_{k+1} \quad (5)$$

The first process of the digital filter is calculate the next value of the angle based on the current position of the robot based on equation (3) and then calculate Kalman gain based on the value of equation (5) and (4). After the prediction based on the above steps, the correction processes is performed by calculating the current value of Kalman coefficient, current value of the angle.

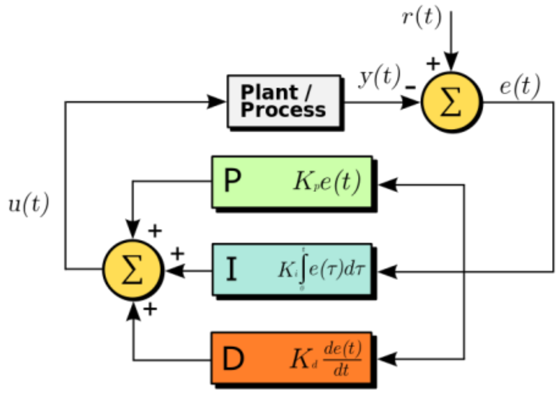

Figure-3. PID controller parameter illustration.

The value of the angle is then fed to the PID controller of the motor driver to perform the proper correction of the angle of the robot. This PID controller will perform as any other PID controller which is illustrated in Figure-3. This controller consists of three parameter for the Proportional gain, the Integration value and also the Differential value. The 'P' parameter governs the gain of the system, therefore the higher the value of P the gain will also increase. Higher gain will make the response time of the system faster and at the same time will cause overshoot and potential instability. Accumulation of errors obtained from the overshoot and undershoot of the system is the value of the 'I' parameter. The 'D' parameter determines the differentiation of the accumulated errors overtime. The system described here is illustrated in Figure-3.

IMPLEMENTATION OF SYSTEM

The system of inverted pendulum robot is implemented using microcontroller by ATMEL 164 and the system is shown in Figure-4. In this figure, the system is shown with height of 150 cm and the sensors mounted on top of the robot. In this figure, the system is clearly

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shown to be in inverted condition without any support to erect the system.

Figure-4. Inverted pendulum robot implemented in this project.

The control part of the inverted pendulum system works as predicted. Shown in Figure-5 is the error in degree (deviation of 90 degree angle perpendicular to the ground is defined as zero). In this figure the vertical axis is the error in binary unit which is when the robot is perpendicular to the ground the error is zero. The time indicated is in 10 millisecond unit. Therefore the robot will balance within six second and will stay that way for a short period of time.

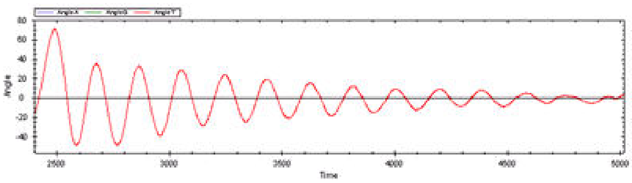

Figure-5. Error of the robot measured at e (t) in Figure-3.

CONCLUSIONS

In this project, an inverted pendulum robot has been designed and built and can stay erect for a period of time. The robot is designed using the PID controller and also digital filter to keep the robot control system robust. A gyroscope and an accelerometer are used as sensors to indicate the state of the robot.

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