

Controlling a Two-Wheeled Self-balancing Robot (TWSBR) with Gyroscope

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Abstract—The paper presents a two-wheeled self-balancing robot (TWSBR) that is capable of performing various tasks such as walking and moving in small spaces. Primarily application of this robot is on a mobile application platform. In addition to being able to perform these tasks, the two-wheeled mobile robot also has the advantage of moving faster than legged robots. This robot is required to keep its stability by continuously moving its two wheels. If a disturbance affects the balance of the robot, it will lose its stability. In addition to affecting the stability of the robot, a disturbance can also put the safety of the device at risk. To address this issue, a gyroscope was used to expand the balance of the two-wheeled robot. When a disturbance is applied, the control moment controller takes into account the estimated disturbance and compensates it. The improved performance of the two-wheeled robot was demonstrated through simulations and experiments. The control moment module was able to maintain its stability even when the wheels moved slightly.

Index Terms— Two-wheeled self-balancing robots (TWSBR), gyroscope MPU6050, Tilt angle measurement, disturbance observer.

I. INTRODUCTION

Compared to human-like robots, wheeled robots are more agile and can move faster than legged robots. They are also useful in various applications, such as law enforcement and public transportation. Two popular self-balancing machines, the Ninebot and the Segway, have turned out to be very widespread [1,2,3]. In addition to being able to perform these tasks, the two-wheeled mobile robot also has the advantage of moving faster than legged robots. Due to the increasing popularity of these robots, advanced versions of them are also being developed. One of these is the Georgia Institute of Technology's Golem Krang, which has an anthropomorphic arm [4,5]

The two wheels of the self-balancing robot are used to maintain its balance. Its robotic arm can also perform various tasks, such as walking. A similar type of robot known as the Ballbot was created by Carnegie Mellon University. The system allows users to easily switch its orientation in robot [7]. In addition to being able to perform these tasks, the two-wheeled mobile robot also has the advantage of moving faster than legged robots. The researchers at the KAIST created a two-wheeled robot that has an upper-body that has five degrees of freedom. As the number of dissimilar kinds of TWSBR continues to increase, it is important that the devices are designed to avoid coincidences [8]. It has been recognized that the proprietor of the company known as Segway,

Jimi Heselden, deceased in an accident while equestrian a self-balancing vehicle in the year 2010.

In comparable cases, TWSBR can also lose its stability due to a disturbance. Despite the various control algorithms that have been developed to improve the stability of the robots, they are not yet able to guarantee its safety [9,10]. Although the various control algorithms are designed to improve the stability of the robots, they are not able to prevent them from losing their balance due to a disturbance. Since the characteristics of a two-wheeled machine make it difficult to continue its position while moving, it has to make various moves to maintain its balance [11]. Even if the TWSBR is placed in forward-facing of a face or a humanoid, it has to continue its balance to avoid getting hit by either the person or the vehicle. This means that even if it maintains its stability, it can still get hit by either the human or the robot [12,13]. Besides being able to improve the stability of TWSBR, it is also important that the device is equipped with the necessary hardware to ensure its safety. This can be done by adding a control module to its chassis.

II. TILT ANGLE MEASUREMENTS OF TWSBR

This section will talk about the various techniques that are utilized to govern the angle of TWSBR wheels. These methods are usually performed if the device's wheels are in a connection zone with the pounded. An absolute tilt refers to the difference between the surface and the plane, while a relative tilt refers to the difference between the object and the plane. On the other hand, absolute tilt is not as easy to measure as relative tilt due to the lack of a physical contact point between the ground plane and the virtual gravity vector. Various sensors are usually used to determine the absolute tilt angle, such as the accelerometers, gyroscopes, and electromechanical inclinometers.

One of the most important factors that can be considered when it comes to improving the stability of the two-wheeled robot is the accuracy of the measurement. Usually, an electromechanical inclinometer is cast-off in determining the total incline angle. However, due to their slow response, they can't follow the system dynamics. A device that can provide a steady-state measurement, such as an accelerometer, is also commonly hand-me-down the incline angle reading for controlling operation. A gyroscope can also be used to follow the system's fast response.

While the measurement of gravity is carried out, the relation between the measured force and the angle of the object is ruled by trigonometric variables/functions. This means that choice of the device and the mounting method for it should be based on the occupied series of the measured angle through sensor. Since the angle of movement of the two-wheel robot's wheels is determined by the plane of movement, a linear method is usually used. An external sensor is also required to provide the necessary resolution as shown in figure 1. This type of sensor can provide a resolution of up to 45 degrees with a range of 0 to 45 degrees.

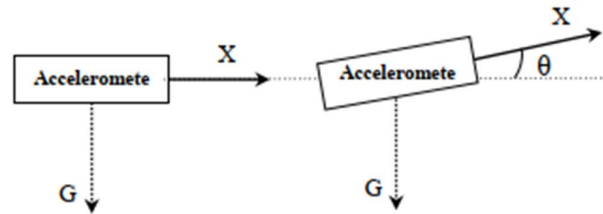


Figure 1 Tilt angle single axis sensing of accelerometer

The sensor output is a representation of the projected gravity vector on its sensing axis. This type of sensor can be used to determine the relative tilt angle of the device. The force's amplitude can be changed by the angle between the sensing and ground plane.

$$Acc_x = v_{offset} + \left(\frac{\Delta v}{\Delta g} * g * \sin(\theta) \right) \quad (1)$$

$$\theta = \sin^{-1} \left(\frac{Acc_x - v_{offset}}{\frac{\Delta v}{\Delta g}} \right) \quad (2)$$

where

Acc_x - Sensor Output (volts)

v_{offset} - Output offset Voltage

$\frac{\Delta v}{\Delta g}$ - accelerometer sensitivity

g - acceleration due to earth's gravity

θ - Tilt angle(radians)

The sensitivity of the force to the calculated tilt angle is not constant across all 360 degrees of the change due to the non-linear method used. This issue can be resolved by increasing the sensing axis' tilt angle until it is parallel to the gravitational vector as shown in figure 2.

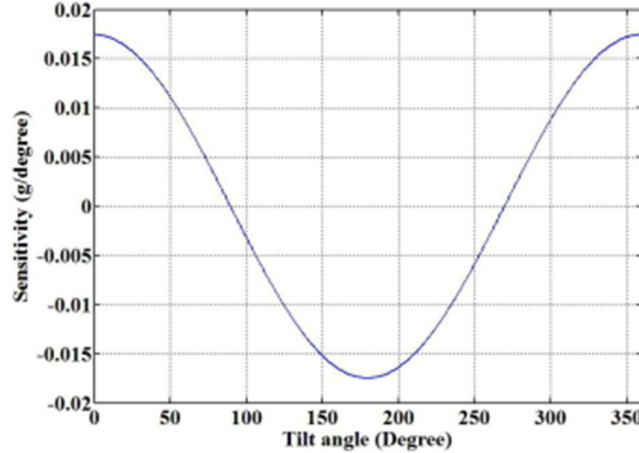


Figure 2 Single-axis accelerometer measuring tilt angle and sensitivity

III. GYROSCOPE BASED TILT AND ACCELEROMETER MEASUREMENT

A machine-driven maneuver that can be used to maintain or measure the orientation of a moving object is known as a gyroscope. Usually, it consists of a disc or spinning wheel, which can be allowed to accept somewhat alignment. Due to the expansion of micro-electromechanical systems (MEMS), the design of these devices has changed. They are now manufactured in small and lightweight sizes, and can involve SoC(System on Chip) with a variety of extent configurations. A type of device that can be used to determine the orientation of an object is known as a gyroscope. It can be used to measure the rate of change in the rotation axis.

For this purpose, a calibrated version of the MPU6050 gyroscope was used. This type of device was able to calculate the tilt angle using its internal measurement. The MPU6050 sensor is a single package that features a 3 axis and a 2-axis gyroscope. It can be interfaced with an I2C connection to allow a direct connection between the device and a control. The MPU6050 and the MPU-6000 family of components are the first and only 6-axis motion tracking devices that are designed for use in smartphones, tablets, and wearable sensors. They feature low power consumption and are ideal for various applications. The 6 Degree of Freedom sensor, which is a part of the MPU6050 family, can also be interfaced with the I2C bus. The output of the device is associated to ADC network of the controller, and it can be digitally calibrated. The device is mounted in the mid side of the chassis of a TWSBR. The sensitive axis of the device is parallel to the control axis of the system robot. This allows the user to determine the tilt angle of the moving object. The results of the test revealed that the measurement of the tilt angle with the device is not always accurate. This issue can be caused by an error in the integrational process as indicated in figure 3.

IV. RESULTS & DISCUSSION

A process known as sensor fusion is a technique that involves combining data from various sources. It can provide a vigorous and inclusive analysis of the process. It is very important for any project that requires high-quality information to be made decisions. Several types of data fusion techniques are commonly used in various industries, such as defense and aerospace, industrial control, and civilian surveillance. They allow the combined data to provide a vigorous and inclusive analysis to robot. In principle, data fusion techniques can help provide a more accurate and timely analysis of an issue. One of the most important factors that a two-wheeled robot needs to consider when it comes to maintaining its upright balance is the accuracy of its tilt angle. Usually, the measurement of this angle can be performed using an IMU. Though, substituting this component with a economical MEMS sensor can cause a fault in the quantity. In addition, the measurement of this angle can be performed with an unreliable and deafening device, such as an inclinometer. An accurate and steady-state device

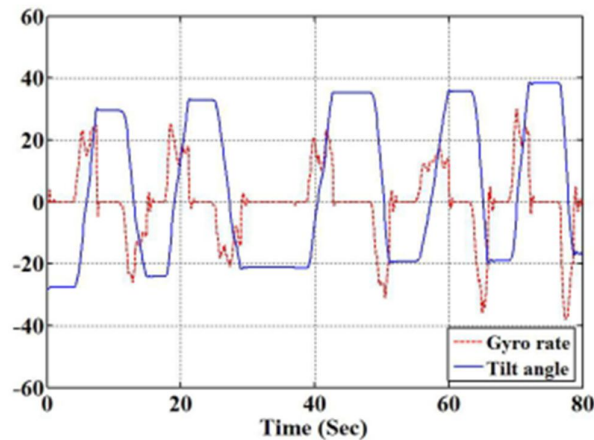


Figure 3 Gyroscope MPU6050 used for record the Tilt angle

such as an accelerometer can provide the same measurement accuracy, but it will be deafening owing to the moving object movement. Compared to this, a reckless response device such as a gyroscope can provide the same accuracy and reliability.

V. CONCLUSION

When an external force is applied to a TWSBR, it has to move forward to maintain its stability. However, if the movement caused by the force is restricted in a certain area, this can create a real issue. To address this issue, a two-wheeled robot was developed, which features a fast response device called a gyroscope. Through the tests, it was confirmed that the device's ability to generate sufficient power to reduce the impact of the force on the robot was successful. However, its performance was not perfect. Although the device was able to decrease the movement of the robot, its performance still wasn't perfect.

A simulation was performed to evaluate the effects of a higher-quality gyroscope module on the performance of the TWSBR. After the results of the study were analyzed, the researchers decided to develop and test the better-quality module in order to demonstrate its capabilities.

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