DEVELOPMENT OF SELF BALANCING PLATFORM ON MOBILE ROBOT USING PID CONTROLLER

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ABSTRACT

This thesis presents a development self-balancing platform mobile robot using PID controller. The platform has been designed using mobile robot kits including IMU and two servos, and controlled by an open source microcontroller with PID. An Arduino microcontroller, hobby grade servos, and a two-degree of freedom (axis) accelerometer and gyroscope have been used to create the controlled platform. The controller has been designed to maintain the platform at an initially selected angle when the support structure orientation changes. By using Matlab, the value of PID parameters i.e , Kp, Ki and Kd have been obtained and applied to the arduino. The software has been written with logic to convert the digital data from the accelerometer to an acceleration magnitude vector. The magnitude is then compared to a predetermined mathematical function to infer the angle of tilt of the platform. The angle of tilt is then converted to angle of rotation for the servos to act on. Experiment shows that the platform performed as expected. Overall, the platform design is validated based on the positional accuracy of the platform given the relatively low quality components used to create it.

ABSTRAK

Tesis ini membentangkan mengenai pembangunan mobil robot yang mempunyai platform keseimbangan diri menggunakan pengawal PID . Platform ini telah direka dengan menggunakan kit robot mudah alih termasuk IMU dan dua servo serta dikawal oleh mikro pengawal sumber terbuka dengan PID. Mikro pengawal Arduino, servo gred hobi dan dua darjah kebebasan (paksi) pecutan dan giroskop telah digunakan untuk mewujudkan satu platform yang terkawal. Pengawal ini telah direka untuk mengekalkan platform pada sokongan pilihan sudut asalnya apabila orientasi struktur berubah. Dengan menggunakan Matlab, nilai parameter PID iaitu, Kp, Ki dan Kd telah diperolehi dan digunakan untuk Arduino . Perisian telah ditulis dengan logik untuk menukar data digital dari pecutan ke vektor magnitud pecutan. Magnitud ini kemudiannya dibandingkan dengan fungsi persamaan matematik yang telah ditetapkan untuk membuat kesimpulan sudut kecondongan platform. Sudut kecondongan kemudiannya ditukar kepada sudut putaran bagi servo untuk bertindak. Eksperimen menunjukkan bahawa platform melaksanakan tugas seperti yang diharapkan. Secara keseluruhan, reka bentuk platform disahkan berdasarkan ketepatan kedudukan platform memandangkan komponen kualiti yang relatif rendah diguna untuk menghasilkannya.

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LIST OF SYMBOL

G	-	Gravity
θ	-	Angle
t	-	Time
J	-	Moment of Inertia
e(t)	-	Back Electromotive Force
τ	-	Torque
I	-	Current
R	-	Electric Resistance
L	-	Electric inductance
Ke	-	Back electromotive Force Co-efficient
B	-	Damping Ratio Of The Mechanical System
V	-	Voltage
ms	-	Millisecond

LIST OF ABBREVIATIONS

Xmeas	-	Measurement of axis–X
Ymeas	-	Measurement of axis-Y
IMU	-	Inertial Measurement Unit
Vref	-	ADC reference voltage
Vzero rate	-	Zero rate Voltage

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CHAPTER 1

INTRODUCTION

1.1 Project Background

Designing a mobile robot with special capabilities has become a trend these days for a variety of universal human consumption. It also fits well with the needs and nature of the human lifestyle. Different forms and uses, mobile robots have been designed and are now in the market worldwide.

A mobile robot comprises of three main parts including sensors, logical processing unit and actuator. In this project, a robot that can maintain an upright and balanced position on a platform is designed and developed. The robot consists of Inertial Measurement Units (IMU) sensors, microprocessor and motors. The design is designed with Matlab and the resulting parameters are used and burned into Arduino UNO controller. The main purpose of the controller is to fuse the wheel encoder, gyroscope and accelerometer sensors to estimate the attitude of the platform and then to use this information to drive there action wheel in the direction to maintain an upright and balanced position platform.

If the platform system itself is not balanced, which means it keeps falling off away from the vertical axis, then a gyro chip is needed to provide the angle position of the inverted pendulum or robot base and input into the controller, which the program itself is a balancing algorithm. The PID controller will then provide a type of feedback signal through PWM control to turn the motor servo clockwise or anticlockwise, thus balancing the platform. These two measurements are summed and fed-back to the actuator which produces the counter torque required to balance the platform robot.

In this project, the PID will be used because it is relatively easy to implement yet practical. Besides that, PID controller has only three adjustable parameters that can be determined from several techniques. Previous research has shown that PID controller has shown good results in terms of response time and accuracy when the parameters i.e, Kp , Ki and Kd, are properly tuned.

1.2 Problem Statements

Control systems are often designed to improve stability, speed of response, steady-state error, or prevent oscillations. Many researchers wants to produce a mathematical equation that is able to determine the position of a very accurate motor position, thus the steady state error should be zero. DC motor systems have played an important role in the improvement and development of the industrial revolution. Therefore, the development of a more efficient control strategy that can be used for the control of a DC servomotor system and a well defined mathematical model that can be used for off line simulation are essential for this type of systems. Servomotor systems are known to have nonlinear parameters and dynamic factors, so to make the systems easy to control, conventional control methods such as PID controllers are very convenient. Also, the dynamics of the servomotor and outside factors add more complexity to the analysis of the system, for example when the load attached to the control system changes.

Due to these parameters and factors, this study will apply the PID controller to make the steady-state error, due to continuous disturbance, to be zero. Accordingly this project will review the principles of PID that is used to control the servo movement that depends on the angle captured by the IMU. This project uses the PID to compensate the robot body inclination to stabilize the platform. Among other performance requirements are to reach the final position of the motor position very quickly without excessive overshoot. In this case, focusing on systems that have a finish time of 10 ms and the overshoot is smaller than 25%.

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1.3 Project Objectives

The aim of this project is to implement PID controller to a mobile robot to maintain its flatness on a moving platform. The objectives of this project are as follows:

a) To design and develop a mobile robot and a flat platform.

b) To design a PID controller to maintain the robot flatness

c) To simulate the controller using Matlab and analyse its performance.

d) To integrate the controller into the mobile robot.

1.4 Project Scopes

The scopes of study are as follows:

a) Using mobile platform kits available in the market.

b) Using sensor fusion to measure the tilts in the X-axis and Y-axis.

c) Using PID as the flatness controller.

d) Using arduino Uno as the mainboard of the mobile robot.

1.5 Organization of Report

As an overview, the structure of this report is organized as follows :

Chapter 1 describes a general introduction of the project, problem statement project aims and project scope.

Chapter 2 provides details literature review that includes an introduction to some basic concepts and a survey of existing works in the areas of developing an algorithm for solving PID controller to maintain flatness platform. This chapter explains in detail all the researches, studies, theories and gathering that have been make throughout the project.

Chapter 3 discusses the methodology of the project which provides a detailed description of the design to develop a mobile robot using PID controller to maintain the platform flatness. It also discusses about the hardware which has been used in the project.

Chapter 4 discusses about the result and analysis. It also includes the design of a mobile robot with a flat platform.

Chapter 5 concludes the project and gives suggestions for future work.

CHAPTER 2

LITERATURE REVIEW

2.1 Previous Case Study

Conducting initial review research is very critical in understanding self balancing platform control techniques. The review of research about related literature conducted in this project summarizes some of topics related to the techniques used for the balancing of platform based on Dc motor position. Comparisons between the present project and the related topics of existing information will also be discussed. The methodologies and the techniques used by other researchers around the globe on the balancing platform topic will also be reviewed.

Meena et al. (2011) proposed a design for a servo motor controller in discrete-time system to obtain the transfer function of the PID controller design. MATLAB / Simulink has been used to confirm the effectiveness of this new design method, which provides a simple and powerful way to design a speed controller for servo motor.

It also extracted a DC servo motor mathematical model and equations and there were three different motion controllers that were designed and simulated to control the velocity of the motor.

Popescu et al. (2011) did a comparison between PID and Fuzzy controllers used in mobile robot control. There is a significant problem for fuzzy controllers in which computing time is longer than the PID because a lot of complex operations such as requiring fuzzification, inference, and defuzzification.

Masakazu et al. (2005) proposed a tuning method for PID controller that considers changes in system characteristics. It is about the concept of using the optimization of PID controller tuning, depending on the obstacles on the control input derivatives and considering model uncertainties caused by changes in the system dynamics. Partial model matching method was used to evaluate performance and control while the reference referred to interference and repression compared to the tracking properties.

Arpit et al. (2012) proposed a performance comparison of PID and Fuzzy logic controller using different defuzzification techniques for positioning control of dc motors. The result of the fine-tuned PID controller gives relatively less overshoot and settling time with no steady state error. The fuzzy logic controller with different defuzzification techniques gives zero % overshoot and lesser settling time.

In a paper titled ‘Attitude Estimation Using Low Cost Accelerometer and Gyroscope’ written by Young Soo Suh (2003), it shows two different sensors which are the accelerometer and gyroscope that exhibit poor results when used separately to determine the attitude which is referred as the pitch angle or roll angle. However, the gyroscope can combine with accelerometer to determine the pitch or roll angle with much better result with the use of Kalman filter.

Tomislav et al (2012) proposed self-balancing mobile robot tilter. It provides a summary of work done in the field of electronic, mechanical design, software design, system characterization and control theory. Robotic system model and simulation results of various control methods required for the stabilization of the system were studied. Dynamic effects become increasingly important in assessing performance limits in robotic. The processes where the project was carried out including design and production of certain parts of the integration section, electronic, mechanical and software.

Hany Ferdinando et al. (2001) proposed a paper titled Developing Mathematical Model of DC Servo Motor Using Bond Graph. Bond graph can serve as a tool in the modeling of some plants. The plant was DC servo motor with all parameter is unity. Simulink and 20-Sim was used for the simulation procedure.

The use of plant transfer function had several performances, such as using a step response and unit impulse function, the parameters change, how to control the torque and speed using the input voltage and current.

2.2 PID Controller

This project concerns the development of a mobile robot with a platform, which can be levelled using PID controller. The main objective is to control the flatness of the platform efficiently with a low cost hardware without limiting the strength and performance of the whole system. There are various stages that have been used to stabilize the platform such as modelling the system, obtaining the data from sensors and determining how the control algorithms will be implemented.

V.J. Van Doren (2009) suggested a two wheeled robot to perform the balancing and control of mobile robots. In this project the Proportional, Integral, Derivative (PID) has been implemented to control the flatness of a mobile robot platform. PID has proven to be popular among the control engineering community.

As stated by the author of article Vance J. VanDoren (2009), “For more than 60 years after the introduction of Proportional-Integral-Derivative controllers, remain the workhorse of industrial process control”.

PID controller will be extensively discussed in Chapter 3.

2.3 IMU Implementation

2.3.1 Gyroscope

A gyroscope is a device that measures angular rate around an axis. Tilt angle can be obtained by integrating angular rate over sampled time. The gyroscope modifies a servo control signal by an amount proportional to its measure of angular velocity. An estimate of angular displacement is obtained by integrating the velocity signal over time. The Inclinometer outputs an analogue signal, proportional to the angular displacement of the sensor Braun,T.,Sutherland ,and Alistair (2002). More about gyroscope can be found in Chapter 3.

2.3.2 Accelerometer

As stated by A. Warnasch, and A. Killen (2002), the tool that measures the inertial force in the opposite direction of free fall acceleration vector in terms of g-force is acceleration. So, gravity acceleration shows 0g power during free fall down constantly at 1g. It will be supported by the ground with a force equivalent of 1g, when the accelerometer is at rest on the surface of the earth. Because of that, it will show a constant downward force perpendicular to the ground 1g rest. To obtain the tilt angle using the Pythagorean Theorem can also use these features. Readers are referred to Chapter 3 for more on accelerometer.

2.4 Mathematical Modelling

Modelling is the process of identifying the principal physical dynamic effects to be considered in analysing a system, writing the differential and algebraic equations from the conservation laws and property laws of the relevant discipline, and reducing the equations to a convenient differential equation model (Robert, 1999). In order to develop the control system, mathematical model is established to predict the behaviour before applied into real system. Actually, the dynamics refer to a situation which is varying with time (Ernest, 1972). The dynamic performance of a balancing robot depends on the efficiency of the control algorithms and the dynamic model of the system. Mathematical modelling of DC motor will be discussed in Chapter 3.

2.5 The Controlled platform.

The controlled platform is a popular university level project, where many teams from various colleges and institutions as well as independent parties (tinkerers) complete designs for credit. A web search of the terms “controlled platform” or "self-leveling platform" yields a number of different platform concepts of varying complexity and sophistication. Table 1 below lists the qualities of each design and the differences between them and the concept proposed by this paper. The author selected eight completed designs for comparison. These designs were selected using their similarity in form and function to the proposed platform as the main criteria.

Note that some of the platforms do not have a complete design description or parts list. Those will be compared using the pictorial or video evidence available via the references.

Table 2.1 - List of Platform Projects

Platform Description [Reference]	**Budget**	**Electronics**	**Hardware Sophistication**	**Build Team**	**Angle Control**
Auto-level [19]	Mid-level	Arduino Digital Servos	Mid-level Two axis	St. Mary's U. single person team	none
Automotive self-leveling [20]	Mid-level	PIC18F452 micro-controller	Mid-level ~Three axis	Devry New Brunswick ~3 person team	none
Self-leveling Surface [21]	Low-level	Arduino	Low-level Single axis	Independent party	none
Self-leveling platform [22]	High-level	ezDSP	High-level Three axis	Berkeley 4 person team	none
Automotive self-leveling [23]	Mid-level	unknown	Mid-level Two axis	Unknown Institution	none
self- leveling platform [24]	Mid-level	dsPIC	Mid-level Single axis	Unknown Institution	none
Stewart Platform [25]	High-level	unknown PC Control	High-level Six axis	U of Adger, Norway	likely
Self-leveling platform [26]	High-level	PC Control via Hitachi SH2	High-level Two axis	Unknown, Germany	none

2.6 Conclusion

In this chapter, an overview of the previous research on robot control has been done, including the IMU sensors and mathematical modelling. In addition, a brief discussion on PID controller has been put forward. It is found that the research on self-levelling platform is a popular topic. As such, a number of research on the topic have been performed and published their findings. This chapter has summarised some of them in Table 2.1.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Project Methodology

This project is done in three phases. The first phase is to understand and design the mobile robot as well as to implement the theories in the real hardware. The second phase is to understand the PID controller and its characteristic and to design and implement the controller into the robot. The last phase is to analyse the controller performance using M-file in Matlab and compare it with the response of the real hardware.

Figure 3.1 shows a general procedure of the project implementation during PS1 while Figure 3.2 illustrates the procedure during PS2.

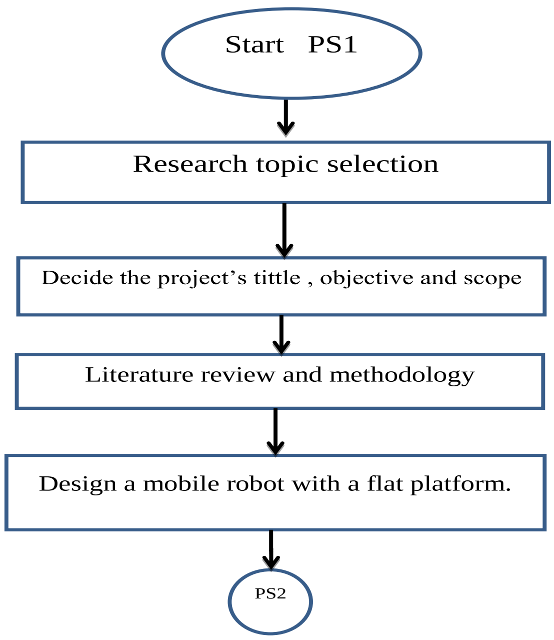

Figure 3.1 : Flow Chart of process Methodology PS1

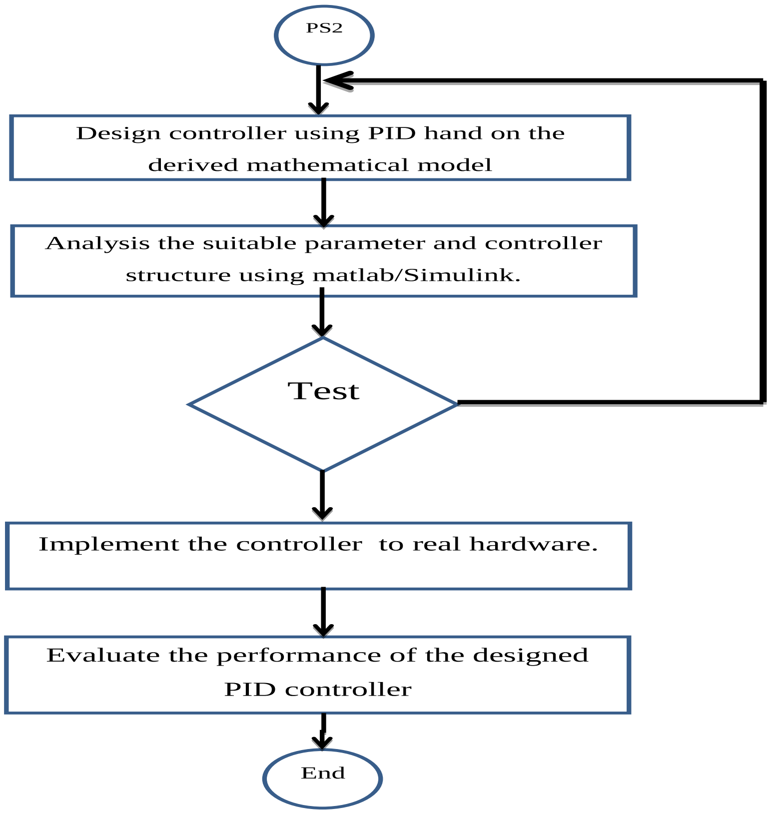

Figure 3.2 : Flow Chart of process Methodology PS2

3.2 Project Activities

The process of executing this project is quite challenging because it involves several phases which include understanding the underlying theories, designing the robot as well as the PID controller. To make the process systematic, a Gantt Chart has been formulated. Gantt Chart is very important in order to complete this project on time. It starts with discussing with supervisors on the topic for the project, objectives, scopes and related things. Study on the literature is also planned in the Gantt Chart. Before proceed the to the PID controller design phase, it is very important to learn how to use the Simulink Matlab, which is also stated in the chart. Implementation and works of the project are summarized into the Gantt chart, as shown in appendix A.

3.3 The Hardware

The self-correcting platform consists of two platforms (Figure), the “top” platform (smaller wood piece), which is autonomously controlled, based on initial user input, which is where the IMU sensor is installed and the angle of tilt is measured.

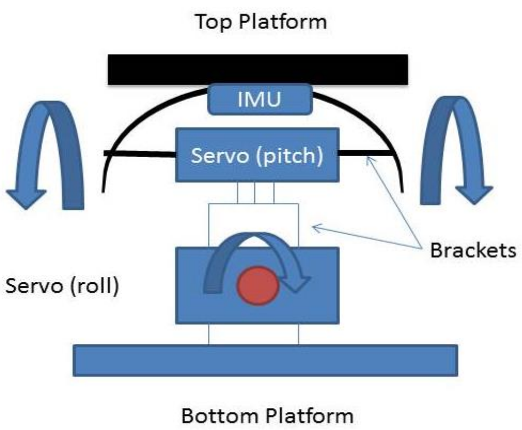

Figure 3.3 : Platform Schematic

An Arduino Uno board, ADXL325 accelerometer, ITG 3205 Gyrometer , two MMG 995 servos, and a Li Po battery control the upper platform tilt angle. The following sections describe the mechanics, electronics, and programming aspects of the platform. The Arduino board connections to the IMU sensor and servos are illustrated in

Figure 3.4. Normally, the Arduino board and other accessories can be powered from the universal serial bus (USB) connection used to program the board.

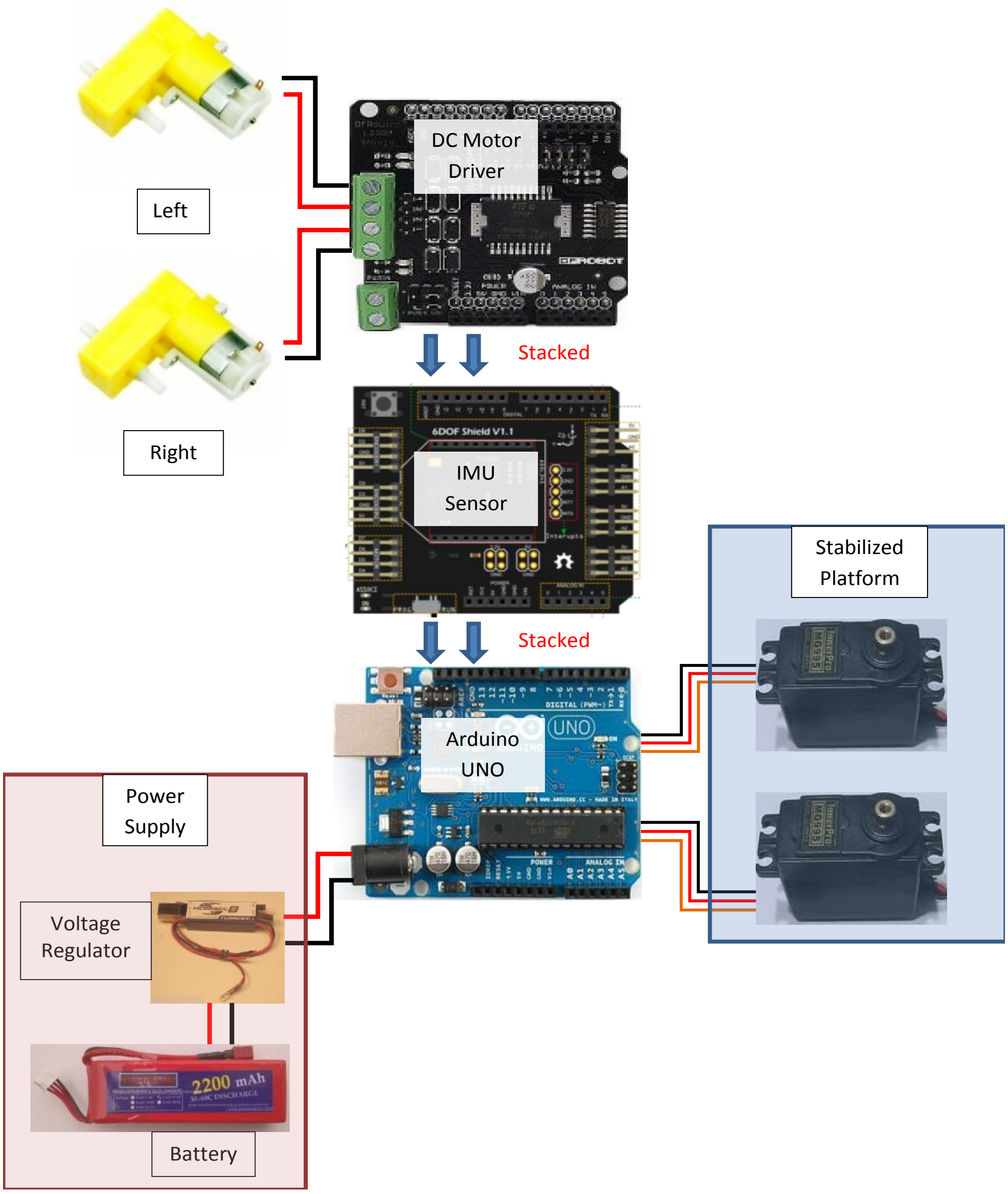

Figure 3.4 : External installation Components

However, the servos used for this board require more power than the Arduino board can supply from the 5V power pin. Because of this, the servos are powered using an external power source, a 9V battery.

According to the MMG 995 servo data , the servos are rated to 6V max, so the 9 volts from the battery are converted to 5 volts via a 5V, 1A power regulator. The regulator has enough power capacity to drive both servos at once with low load.

The servomotor used to manually control the platform are supplied with 5V from the Arduino board. It is the reduction in voltage supply to the analog pins which signals the board to send an angle signal to the servos. The accelerometer is powered by the Arduino board's on-board 3.3V power. The ADXL325 accelerometer will send different signals through the analog pins depending on the supply voltage.

3.3.1 Sensor IMU Board

To address the issue of measurement noises and the limitations of measurements by either the accelerometer or gyroscope alone, we will need to combine the readings from both the accelerometer and the gyroscope in a meaningful way so that we could use the strengths from both sensors to obtain a more accurate result than either measurement alone could provide.

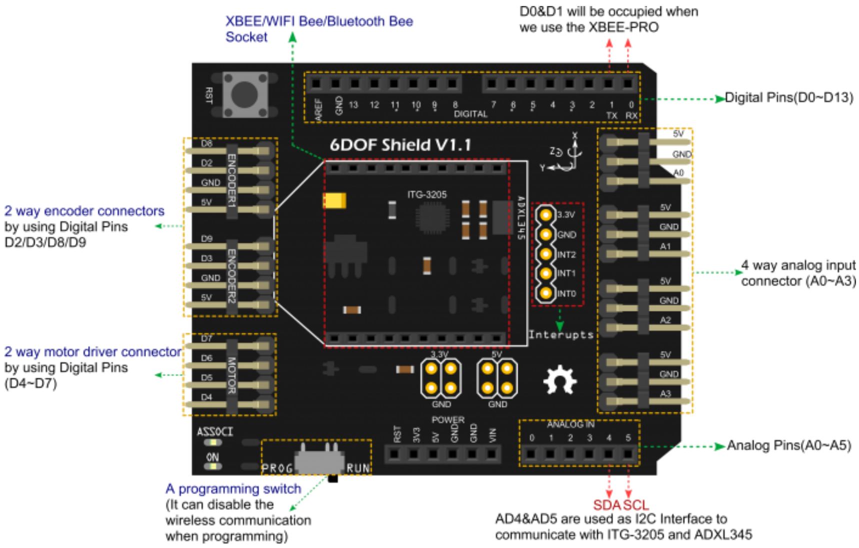

Figure 3.5 : IMU sensor 6 DOF

Young (2003) states that the factor that contributes to the deviation of the desired result of the gyroscope is the drift term. Since the drift increases with time error in output data will also increase.

One of the disadvantages of using accelerometer individually is that the device is sensitive to vibration since vibration contains lot of acceleration components. One solution that Young suggested is that a low pass filter is required to limit the high frequency.

a) Sensor Gyroscope

Gyroscope can measure the rate at which the rotation is taking place and the rotation angle for a given time interval is governed by:

$$(t)=\int t1t2G(t)dt \qquad (3.1)$$

where *G(t)* is the gyroscope reading with respect to the rotation direction. When the time interval is small, the gyroscope reading can be treated as a constant and can be approximated as a above equation:

$$\theta(t)\approx\theta(t1)+G(t)(t2-t1)=\theta(t1)+G(t)\Delta t... \qquad (3.2)$$

Gyroscope measurement is largely immune to none angular movement and thus far less susceptible to vibrations and lateral accelerations mentioned previously. Drifting effect will happen if the angular measurement is cumulative, any minute error in measurements will manifest over time. Thus gyroscope alone cannot be used to reliably measure the inclination angle either.

Orientation errors of the gyroscope mounted to the printed circuit board can cause cross-axis sensitivity in which one gyro responds to rotation about another axis, for example, the X-axis gyroscope responding to rotation about the Y or Z axes. The orientation mounting errors are illustrated in Figure 3.6.

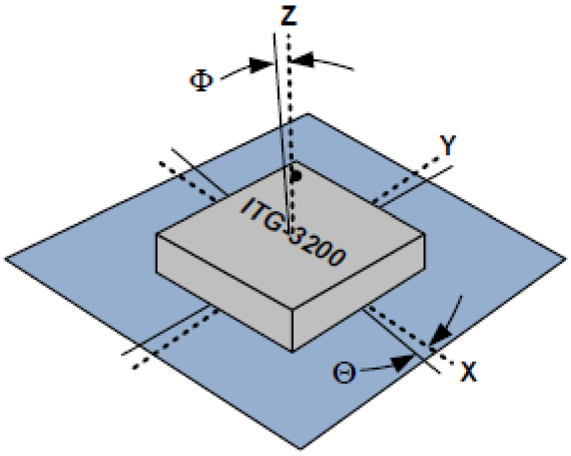

Figure 3.6 : Gyro Axes (θ) Relative to PCB Axes (θ) with Orientation Errors (θ and Φ)

Orientation

Figure 3.7 shows the orientation of the axes of sensitivity and the polarity of rotation.

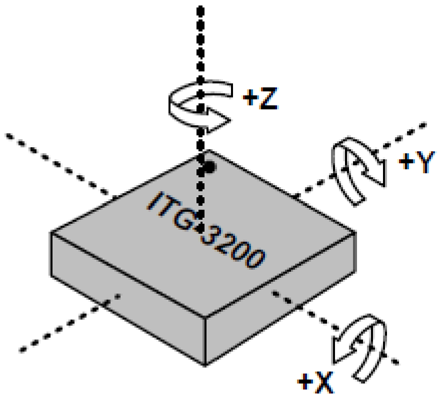

Figure 3.7 : Orientation of Axes of Sensitivity and Polarity of Rotation +Z +X +Y

b) Sensor accelerometer

Accelerometers are mechanical structures containing elements that are free to move. These moving parts can be very sensitive to mechanical stresses, much more so than solid-state electronics. The 0 g bias or offset is an important accelerometer metric because it defines the baseline for measuring acceleration. Additional stresses can be applied during assembly of a system containing an accelerometer. These stresses can come from, but are not limited to, component soldering, board stress during mounting, and application of any compounds on or over the component. If calibration is deemed necessary, it is recommended that calibration be performed after system assembly to compensate for these effects.

For the need to get a good measurement of the current inclination angle in order to control the platform's movements. Inclination Angle Calculation can can be calculate as:

$$\theta = tan{-}1AyAx = sin{-}1Ax\sqrt{A2x + A2y} = sin{-}1gAx \qquad (3.3)$$

In the equations above, *Ax* is the accelerometer reading along its *x* axis and *Ay* is the accelerometer reading on its *y* axis. When the robot is stationary, *g* is the gravitational constant (which translates into the accelerometer reading on the *y* axis when the accelerometer is lying flat). In this studies, are interested in getting a calculation in which the tilt angle is small because our goal is to ensure that the deviation from equilibrium (usually equilibrium is reached when the inclination angle close to 0 depending on the weight distribution of the robot) is as small as possible. So that can further simply the above equation for small inclination angles:

$$\theta \approx sin(\theta) = gAx... \qquad (3.4)$$

By only measuring the *x* axis reading of the accelerometer, we can get a rough estimate of the inclination angle. Of course, this is under the assumption that the robot is standing still. At the same time, the *y* axis reading will be slightly less than the reading in standstill condition (*Ay*). As a result, the combined vector will deviate from *g*. But when the accelerometer is placed near the center of gravity of the platform, the acceleration along the *x* axis is small in near-equilibrium conditions. Accelerometer tends to be very sensitive to the accelerations introduced due to movement or vibration and thus the sensor readings will contain some level of noise, which cannot be removed easily.

The values measured for X0*g* and Y0*g* correspond to the x- and y-axis offset, and compensation is done by subtracting those values from the output of the accelerometer to obtain the actual acceleration:

$XACTUAL = XMEAS - X0\mathrm{g}$
$YACTUAL = YMEAS - Y0\mathrm{g}$

The ADXL345 can automatically compensate the output for offset by using the offset registers (Register 0x1E, Register 0x1F, and Register 0x20). These registers contain an 8-bit, twos complement value that is automatically added to all measured acceleration values, and the result is then placed into the DATA registers.

Because the value placed in an offset register is additive, a negative value is placed into the register to eliminate a positive offset and vice versa for a negative offset. The register has a scale factor of 15.6 m*g*/LSB and is independent of the selected *g*-range.

3.3.2 Mobile Robot

Mobile robots that are used in this project is ready made. It features two gear motors with 65mm wheels and a rear caster. The chassis plates are cut from acrylic with a wide variety of mounting holes for sensors, controllers, power, etc. Simply bolt the two pre-cut platforms together, attach the motors and caster and robotics controller. It includes all of the parts needed to assemble the chassis as well as a 4xAA battery holder with barrel jack termination.

Figure 3.8 : The Chassis of mobile robot

a) 3 Wheels Mobile Robots

The 3-wheel mobile robot has two rear wheels and an independently rotating front wheel. The robot can change direction by varying the relative rate of rotation of two separately driven rear wheels. If both wheels are driven in the same direction and speed, the robot will go straight.

The rotation center can fall anywhere in the line joining two wheels. The center of gravity in this type of robot has been put in the triangle formed by the wheel. If too heavy mass attached to the free side of the spinning wheel, the robot will tip over.

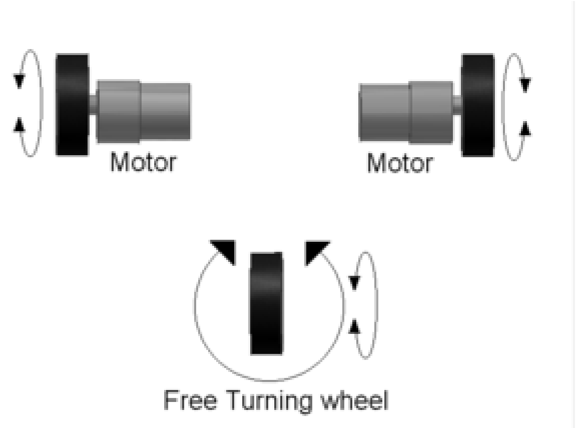

Figure 3.9 : Differentially steered 3 wheeled Mobile Robot Source [28]

3.3.3 Board Arduino Uno

The main controller for this project is Arduino Uno which uses Atmel Atmega 328 microcontroller as it combines 32KB ISP flash memory with read-while-write capabilities, 1KB EEPROM, 2KB SRAM, 23 general purpose I/O lines, 32 general purpose working registers, three flexible timer/counters with compare modes, internal and external interrupts, serial programmable USART, a byte-oriented 2-wire serial interface, SPI serial port, 6-channel 10-bit A/D converter (8-channels in TQFP and QFN/MLF packages), programmable watchdog timer with internal oscillator, and five software selectable power saving modes.

The device operates between 1.8-5.5 volts. The overview of the device as shown in figure 3.9 and figure 3.10. (Arduino.cc, 2012).

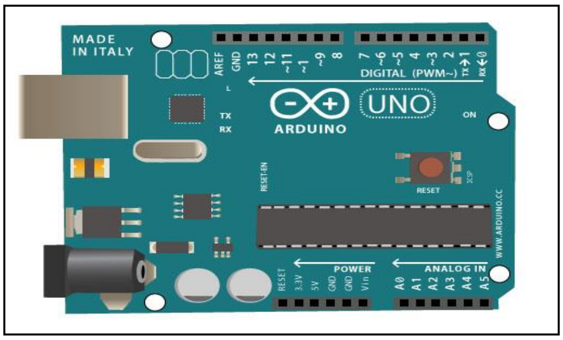

Figure 3.10: Arduino Development board

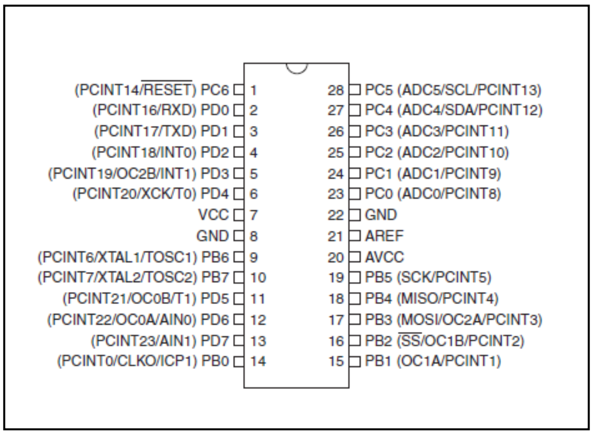

Figure 3.11: Atmel Atmega 328 microcontroller

Arduino is an open-source electronics prototyping platform based on flexible, easy-to-use hardware and software. It's intended for artists, designers, hobbyists, and anyone interested in creating interactive objects or environments.

The open-source Arduino environment as shown in Figure 3.10 makes it easy to write code and upload it to the I/O board. It runs on Windows, Mac OS X, and Linux. The environment is written in Java and based on Processing, avr-gcc, and other open source software.

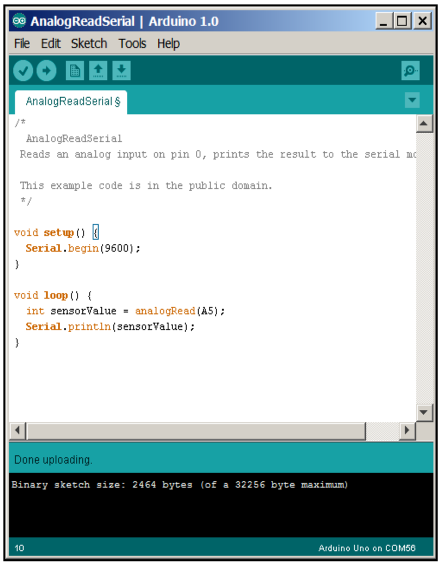

Figure 3.12: The graphical user interface (GUI) of Arduino Compiler

3.3.4 DC ServoMotor

DC servomotors are one of the main components of automatic systems; any automatic system should have an actuator module that makes the system to actually perform its function. The most common actuator used to perform this task is the R/C servomotor. A servomotor system consists of different mechanical and electrical components, the different components are integrated together to perform the function of the servomotor. Figure 3.13 above shows a typical model of a servomotor system (Nise, 2008).

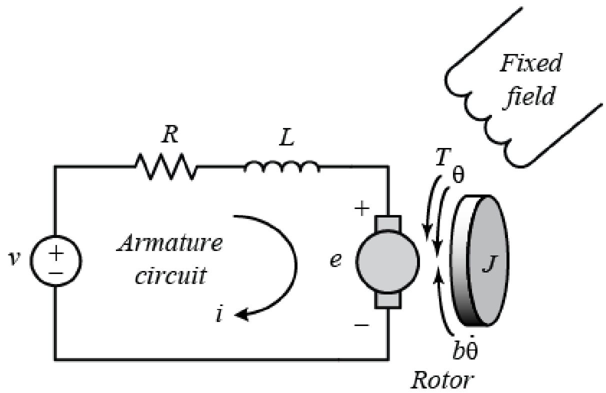

Figure 3.13: . Servomotor circuit diagram.

The servos supporting and controlling the top platform are arranged in order to control the pitch and roll. Note that pitch and roll are only subjective directions and are used to describe the motion. Since the platform has no "front" or "back" the terms pitch and roll are meaningless descriptions of the rotations about the X and Y axis. A close up view of the servo arrangement and axis' is illustrated in Figure 3.14.

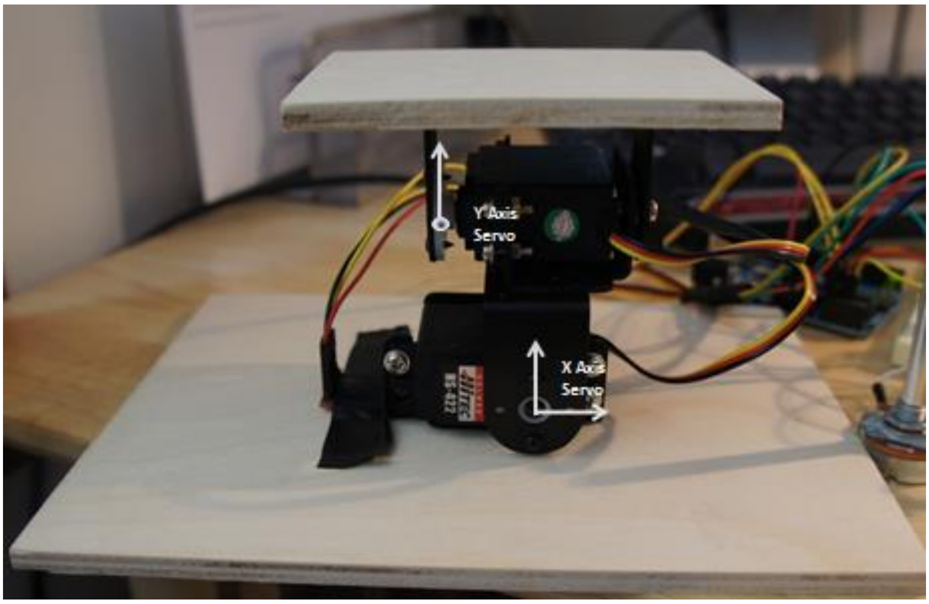

Figure 3.14 : Servo Arrangement

This servo arrangement is a more efficient use of space and limits the amount of slop compared to linkages and hinges as seen in other designs. The Y axis servo is controlled by the Y axis data stream from the accelerometer and vice versa for the X axis. Note that the X axis servo motion is in-plane with the photo while the Y axis would rotate out of plane.

The servos are installed into aluminum brackets illustrated in

Figure 3.15. These brackets allow the servo to be installed onto the bottom and top platforms. The servo "C" brackets (

Figure 3.16) are then used to attach the servo bodies, via the body brackets, to themselves and the platforms. The "C" brackets attach to the body and to the rotating servo horn.

The combination of these two brackets allows the platforms to rotate independently in two axis.

Figure 3.15 : Servo Body Brackets [19]

Figure 3.16 : Servo "C" Brackets [19]

A dual axis accelerometer was the chosen to measure the tilt of the lower platform in two axes. The data is read from two different channels and processed in the same manner regardless of direction. The two analog data streams provide the Arduino logic with the necessary information to maintain the top board level to the chosen plane.

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