DEVELOPMENT OF CONTROL SYSTEM FOR A TWO WHEELED SELF-BALANCING TRANSPORTER

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ABSTRACT

Personal balancing transporter now be operating widely in every country and closely interacting with human environments. There were a lot of challenges in the development of personal balancing transporter especially on their operation, navigation and interaction. In other words the development of balancing transporter had two commitments that is to increasing efficiency of urban transportation for short distance travel and helping conserving the environment. The system architecture comprises an Arduino microcontroller board, a single-axis gyroscope and a single-axis accelerometer was employed for attitude determination. In addition, a complementary filter was implemented to compensate the gyro drifts and eliminate accelerometer distortion signal cause by disturbance. The PID controller was used in sensor fusion to reduce an error reading and stabilize the final angle measurement. The 350 Watt DC motor drive by 2x60 Amp Roboclaw motor driver with Serial Protocol to define the proportional speed control. There were many research had been done on balancing transporter development. However the robustness of the system is not fully tested and more experiment needs to be performed to evaluate the robustness of the system by transferred the signal conditioning to Matlab GUI and fine tuning of the control algorithm for better performance.

ABSTRAK

Kenderaan pengimbang kini beroperasi secara meluas di setiap negara dan berkait rapat dalam berinteraksi dengan persekitaran manusia. Terdapat banyak cabaran dalam pembangunan kenderaan pengimbang ini terutamanya berkaitan operasi, pelayaran dan interaksi. Dalam erti kata lain pembangunan kenderaan pengimbangan ini mempunyai dua komitmen iaitu untuk meningkatkan kecekapan pengangkutan bandar bagi perjalanan jarak dekat dan membantu memelihara alam sekitar. Seni bina sistem terdiri daripada papan mikropengawal Arduino, giroskop paksi-tunggal dan pecutan paksi-tunggal yang bekerja untuk menentukan pergerakan. Selain itu, penapis jenis pelengkap telah dilaksanakan untuk mengelakkan seretan giro dan menghapuskan ganguan pecutan berpunca daripada gegaran. Pengawal PID telah digunakan dalam pengesan IMU untuk mengurangkan kesilapan bacaan sudut dan menstabilkan pengukuran sudut akhir. DC motor yang berkuasa 350 Watt digunakan dengan 2x60 ampere pengawal motor Roboclaw melalui protokol sesiri untuk menentukan perkadaran kawalan kelajuan. Terdapat banyak kajian yang dilakukan ke atas kenderaan pengimbang ini. Walau bagaimanapun keteguhan sistem ini tidak diuji sepenuhnya dan lebih banyak eksperimen perlu dilakukan untuk menilai kemantapan sistem dengan menganalisa isyarat dengan menggunakan pengantaramuka Matlab GUI dalam melakukan penalaan halus algoritma kawalan untuk prestasi yang lebih baik.

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LIST OF SYMBOLS AND ABBREVIATIONS

θ - Accelerometer Angle

$\dot{\theta}$ - Gyro Angle

∂ - Speed serial variable

$\hat{\theta}$ - Angle variable

α_{inmin} - Angle min value

α_{inmax} - Angle max value

β_{outmin} - Gain min value

β_{outmax} - Gain max value

PID - Proportional, Integral, Derivative

PWM - Pulse Width Modulation

UTHM - Universiti Tun Hussein Onn Malaysia

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CHAPTER 1

INTRODUCTION

1.1 Project Background

The field of robotics has grown significantly over the last few decades and it still be improvise from time to time but when it comes for personal robotic, it is still in its infancy. There are a lot of challenges in the development of personal robots especially on their operation like intelligence, navigation and interaction. Segway TM [1] is a self-balancing transporter was invented by Dean Kamen in 1999. It was first self-balancing transporter and was an electric-powered transportation machine. It transforms a person into a "power walker", allowing rider to go farther, move more quickly and carry more load [1]. This product innovation was design to improve the travel constrains in urban transportation such as workshop, closed offices, campuses, golf courses, etc. Conventionally, the robotic mobile platforms are three or four-wheeled platforms that are stable stand still [2] but the device platform with parallel wheels need a control system to balanced. The work presented in this thesis addresses some of the challenges in operating of balancing electric vehicle on human passenger. In particular, this work focuses on developing a control system for two wheeled self-balancing transporter.

1.2 Problem Statement

The need of electric vehicle (EV) is to reduce the CO2 by zero emissions is the perfect solution. An electric vehicle like Segway / balancing transporter is suitable transportation but because of the power consumption its only can be used for short distance travel. The balancing transporter is a new way of travel device, its maneuverability is similar to a bicycle but still in highly cost of production. In other words the development of balancing transporter had two commitments that is to increasing efficiency of urban transportation for short distance travel and helping conserving the environment. There are many research done on this balancing transporter development. However the robustness of the system is not fully tested and more experiment needs to be performed to evaluate the robustness of the system and fine tuning of the control algorithm is required for better performance.

1.3 Aim and Objective

The aims was to design an electronic control system for two wheeled self-balancing transporter. The objective are as follows:

1.3.1 To investigate the characteristic of gyroscope and accelerometer sensor on Inertia Measurement Unit (IMU).
1.3.2 To develop a balancing control system of human transporter.
1.3.3 To analyse the system performance via real time plotting User Interface (UI).

1.4 Scope and Limitation

The design of balancing transporter has many approach that have been done by other researcher, for the project to be achievable in the given time, the scope of following constraints have been set.

This project focuses on investigation of the Sparkfun 5DOF Inertia Measurement Unit (IMU) IDG500/ADXL335 based on Complementary filter. The 24V DC motor as actuator controlled by ROBOCLAW 2x60amp driver module by using serial communication protocol wirelessly. The real time system performance evaluate by designing a MATLAB Graphic User Interface (GUI) verified on frame design as experimental platform. The work presented in this thesis does not involve the detail design of the hardware components, but focusing on the design of balancing controllers.

1.5 Organization of Thesis

This thesis is organized in five chapters that explain the theoretical aspect and development process of the project. These chapters are arranged in sequence order as follows:

Chapter II: Literature Review. This chapter discusses about studies and researches conducted by other scholars related to this project. The overview of history, comparison between various types of human transport devices, and its summary of features is presented in this chapter.

Chapter III: Methodology. This chapter describes the approaches used throughout the development of this project which covers theoretical analysis about the dynamics of the system, mechanism system of the device, and software implementation to control the whole operations of the device.

Chapter IV: Result and Analysis. This chapter presents the findings, observation and data collections of this project in form of tables, graphical methods and data points. These results are further analyzed and commented accordingly.

Chapter V: Conclusion. This final chapter summarizes the result and analysis to obtain conclusion of this project with regards to the objectives that previously outlined. Future improvement and recommendation are presented also in this chapter as a contribution for others to acquire benefits from this study.

CHAPTER 2

BRIEF REVIEW OF SELF-BALANCING TRANSPORTER

2.1 Introduction

In the early 2000s, balancing transporter have been popular as a human transporter in the automotive field and a significantly in robotic applications until today [8]. The stability factor and design of control system as smart-electric vehicle make the system interesting in academic environments especially in research field. Lot of studies about this system are in progress of research and development on computer, electrical, electronics, mechanical and mechatronics engineering branches in the universities. This system is explained as a link interaction between robotics technologies and automotive. This chapter discusses about studies and researches conducted by other scholars related to this project including the overview of history, comparison between various types of human transport devices, and its summary of features.

2.2 Commercialize Product

The balancing transporter works based on a new technology called "dynamic stabilization"[1]. It allows the transporter to work seamlessly with the body movements. Since the wheels of the transporter are parallel, it not keep itself upright at the midpoint. When the rider stands still, it resembles an inverted pendulum concept.

2.2.1 Segway

The Segway Personal Transporter (PT) is a self-balancing electric vehicle which was invented by Dean Kamen in 2001 and produced by Segway Inc [1]. Figure 2.1 shows the general appearance of the vehicle. The Electronic Control Unit and electric motors are located at the base of the vehicle to keep the Segway in upright position.

Figure 2.1: General appearance of the Segway PT [1].

The Segway [1] can reach a speed of 20.1 km/h and can take a tour of 38 km on a single battery charge. The gyro are used to detect the inclination of the vehicle and thus indicates how much it deviates from the perfect balance point. The Segway electric motors powered by lithium ion batteries. The vehicle is balanced with the help of dual computers running an appropriate program, two tilt sensors and five gyroscopes. The Segway also has a mechanism to limit the speed called governor which is when the vehicle reaches the maximum speed allowed by the program, the device starts to intentionally lean back. The Segway also reduces the speed or stops immediately if the handlebar of the device collides with any obstacle.

2.2.2 Elektor Wheelie

The Elektor Wheelie [9] is a programmable Segway designed for control design experiments. The Elektor Wheelie kit is consist of two DC motors, two 12V lead acid batteries, two wheels of 16 inch diameter, the case of the platform, a casing control lever, and an assembled and tested control board with a sensor board installed. In appearance, the Elektor Wheelie is very similar to the Segway PT in Figure 2.2, but its mechanical and electrical structures are simpler, which makes it suitable for control experiments.

Figure 2.2: General appearance of Elektor Wheelie [9].

The electronics in the Elektor Wheelie [10] processes input signals from a control potentiometer, an acceleration sensor and a gyroscope. The ATmega32 microcontroller has two PWM output ports which are used to control two DC motors through a pair of H-Bridges (MOSFET). The second microcontroller, an ATtiny25, monitors the motor current using a Hall Effect sensor. If an excess of current occurs, due to short circuit in the system, the ATtiny25 interrupts power to the H-Bridges.

2.3 Previous Work

Abdalkarim M. Mohtasib and his group [11] has develop STEVE, is an applied research project to design, analyse, and construct an electric vehicle with two parallel wheels similar to Segway. The estimation of the tilt angle is done using Kalman filter. M. Abdullah Bin Azhar and his group [12] introduced SubukRaftar a simple self-balancing vehicles that only require a single physical input be sufficient for balancing as well as continuous movement by controlling behaviour of PID controller which has a digital filter and controller running on an AVR microcontroller. The Control variable, angle of platform is plotted using MATLAB to study response of the controller by complementary filter. H. Azizan and his team [13] introduced Fuzzy Control Based on LMI Approach and Fuzzy Interpretation of the Rider Input For Two Wheeled Balancing Human Transporter. They presents a Takagi-Sugeno fuzzy intelligent interpretation of the rider's body inclination. It provides an interface between human user and the vehicle with the aim to enhance the piloting capabilities and convenience from human user viewpoint.

Miseon Han and his group [14], introduced the implementation of Unicycle Segway Using Unscented Kalman Filter in LQR control by design a stable controller and performing simulations in MATLAB to apply to the physical model. Hau-Shiue Juang and Kai-Yew Lum [6], develop a design, construction and control of a two-wheel self-balancing robot. The system architecture comprises a pair of DC motor and an Arduino microcontroller board. A single-axis gyroscope and a 2-axis accelerometer are employed for attitude determination by implementing a complementary to compensate for gyro drifts. Electrical and kinematic parameters are determined experimentally a PID and LQR-based PI-PD control designs. Experimental results show that self-balancing can be achieved with PI-PD control in the vicinity of the upright position.

2.4 Fundamental Principles

The balancing transporter is an unstable and nonlinear system. To make the balancing by itself some kind of control strategy has to be implemented. The following subchapter will handle the theory and fundamental Principles behind candidates for balancing controller.

2.4.1 Inverted pendulum

The inverted pendulum in figure 2.3 is a classic problem in dynamics and control theory and is widely used as a benchmark for testing control algorithms such as PID controllers, state space, neural networks, fuzzy control, genetic algorithms, etc. Khalil Sultan [15] introduced by experimenting stabilization of the pendulum to shows the position of the carriage on the track is controlled quickly and accurately by the pendulum and its always maintained tightly in its inverted position during such movements.

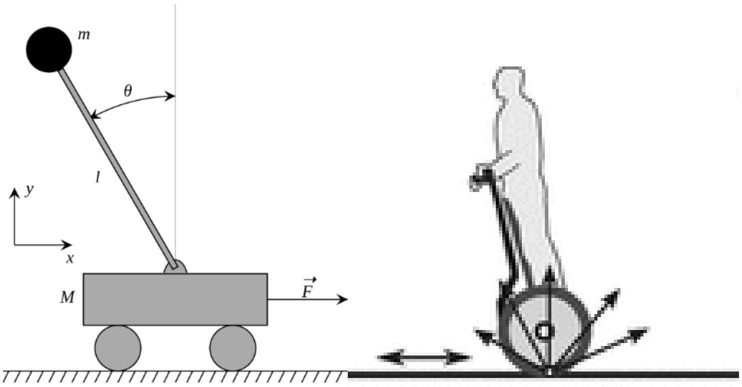

Figure 2.3: Inverted Pendulum Principle [15][16]

H.-M. Maus and his group [16] show that humans gait seem to mimic such external support by creating a virtual pivot point (VPP) above their center of mass. A highly reduced conceptual walking model based on this assumption reveals that such virtual support is sufficient for achieving and maintaining postural stability. Balancing an upturned broomstick on the end of one's finger is a simple demonstration and it is same concept apply on technology of the Segway PT, a self-balancing transportation device.

2.4.2 Filtering (Complementary vs Kalman)

The challenge in balancing design is to determine of the real inclination angle of the platform. In comparison with the classical inverted pendulum, the angle is not directly measurable. It must be obtained indirectly after filtering the signal using one of these three options that is Accelerometer, Gyro, Combination of accelerometer and gyro. Shane Colton [17] from MIT said the inclination of the accelerometer is computed as a projection of the vector of gravity into the horizontal axis of the sensor but also the forward acceleration is projected into the measured signal and thus the angle can be computed very incorrectly. The gyro angle is obtained as the integration of the measured angular velocity. The problem is the drift of the gyro that can be eliminate by combination of accelerometer and gyro after be filtering using complementary filter.

Wasif, Ammar and his group [18] concluded that Complementary filter should be implemented due to its various advantages over Kalman Filter. The Kalman filter has a complex design compared to the design of the Complementary filter. Moreover, due to complex calculations involved in the Kalman filter it requires higher computational resources and time. Although Kalman filter has a more accurate result, but to save computational resources and time the Complimentary filter provides a good compromise.

Serv and his group [19] said that complementary filter and a basic PID controller have been successfully tested in the first prototype, verifying the correct approximation of the angle obtained. The Kalman filter takes about more times longer to execute than the complementary filter due to the more mathematical operations needed by the Kalman Filter. The Complementary Filter was selected as the main data fusion algorithm, due to the less computational resources needed and it’s an excellent choice for this application.

2.4.3 Control System

The development of the control system is essential to ensure success in balancing robot, while there are many control strategies that can be used to stabilize the robot, the main purpose is to control the system with cheap and efficient without sacrificing robustness and reliability of the controller. Differences in balance control algorithm implemented mainly depend on how the system is modelled and how the tilt information is obtained tilt. M. Abdullah Bin Azhar [12] finding method to stabilize the system by setup the control system running at 100Hz combine with complementary filter and PID control algorithm which controls the tilt angle is variable. Closed loop consists of Proportional (P), Integral (I) and derivative (D) components used in the method as shows in figure 2.4.

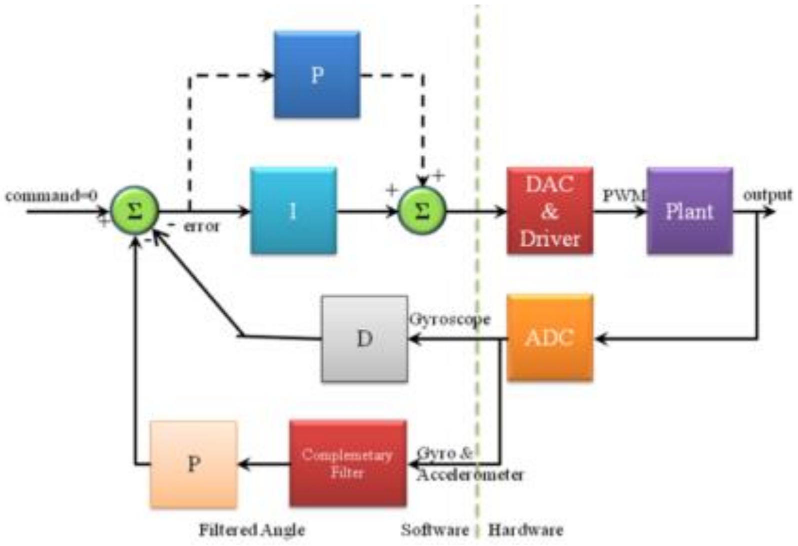

Figure 2.4: PID Control System Design [12]

2.5 Summary

This chapter discusses about the several result and finding from previous work conducted by other of researcher that related to this project including the overview of commercialized product, comparison of development method such as filtering, control system and summary of features.

CHAPTER 3

METHODOLOGY

3.1 Introduction

Balancing transporter capability is to move with speed and grace comparable to humans because of their dynamic stability. This chapter describes the approaches used throughout the development of this project which is covers a selected sensor for balancing purpose, the control system design, mechanism system and software implementation to control the whole operations of the device. It is very important to choose the most appropriate components with correct specifications in order to establish well-operated circuits.

3.2 Development Flowchart

Figure 3.1 shows the development flowchart of two wheeled self-balancing transporter as a guide line procedure on the development. The first approach need to be concern is the Inertia Measurement output angle that need to be filter using complementary filter because of unsustainable reading. The filtered angle next be transfer to PID control to reduce the error and the data will be recorded on MATLAB GUI. The electronic control system will be test on mechanical platform in real time to analyze the system performance so the corrective action can be made to optimum the system response.

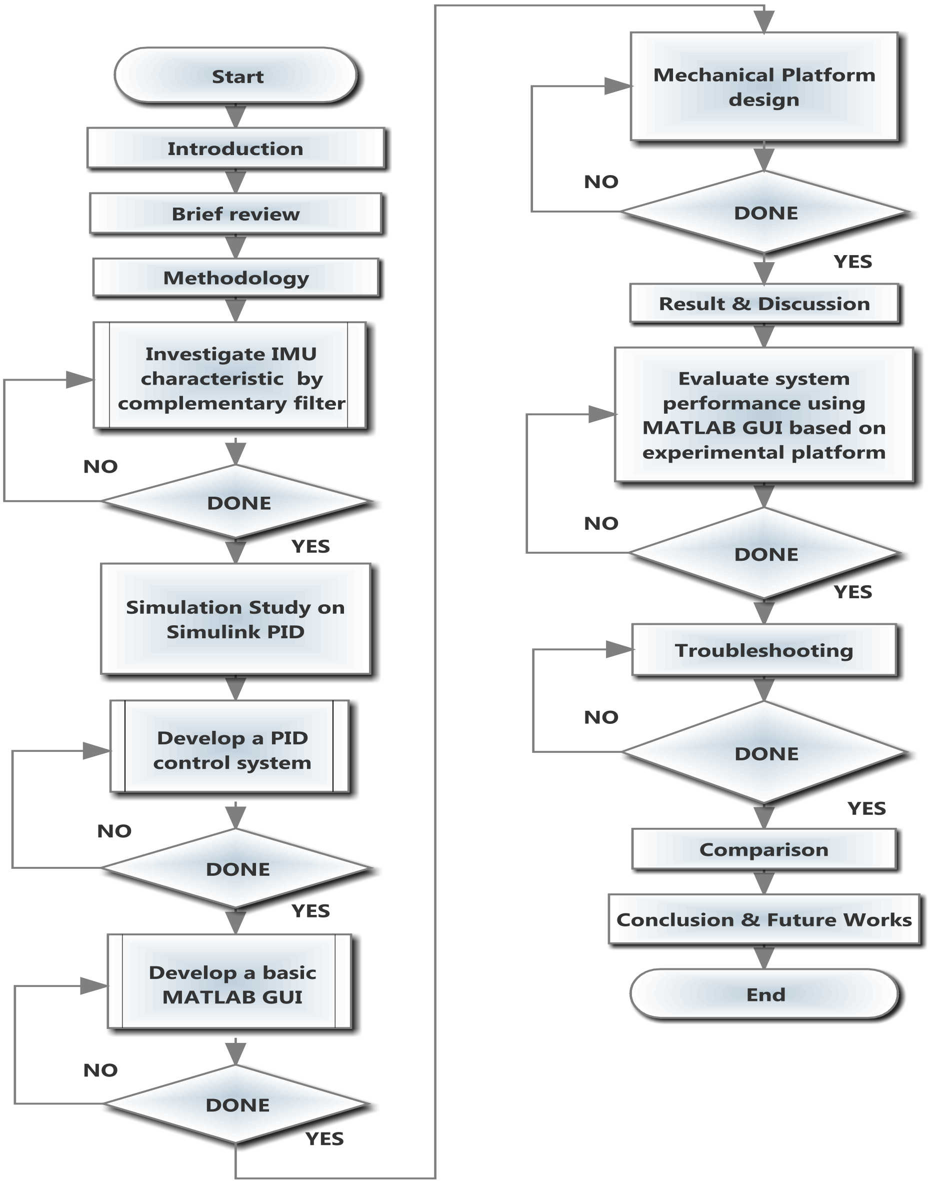

Figure 3.1: Development Flowchart

3.3 System Design Block Diagram

A balancing transporter is a platform attached to a set of two independent wheels that is controlled by a DC motor. The platform attached to the wheel to make the system behave as inverted pendulum. Figure 3.2 shows the design layout block diagram to these features which is a common problem in engineering controls and processes to test a different control systems. Tilt angle measurement is implemented by inertial measurement unit (IMU) that consisting of gyroscope and accelerometer. Variable used to control steering motion steer either left or right. Gain variable is used to tune the signal response between the controller and the motor driver. Board controller process the input signal with a complementary filter and converting to speed PWM depending on an angle measurement. The angle manipulated by the controller to estimate the correct speed to compensate the platform and send it to the motor driver module by serial communication protocol. At the same time, the data from the controller processed and transmitted via wireless communication to Matlab GUI for performance analysis. The main goal of this process is to move the wheel in a certain position while keeping the center of mass of the system in an upright position.

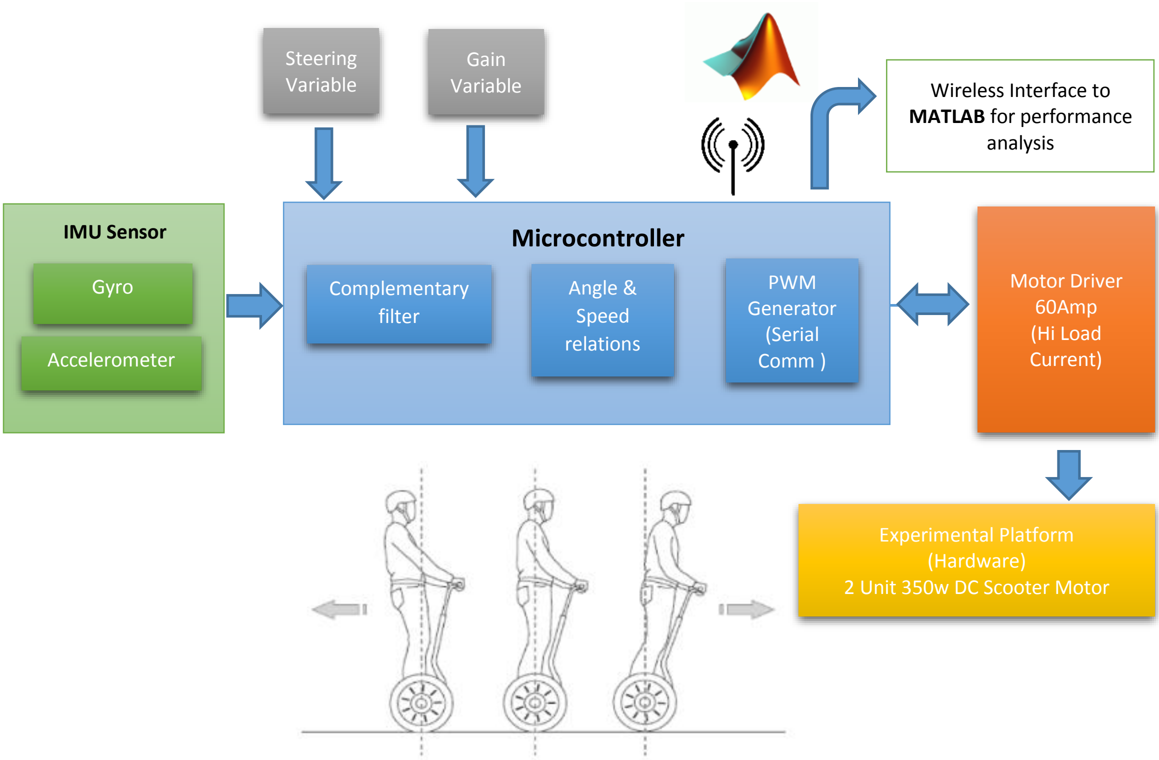

Figure 3.2: System Design Block Diagram

3.4 Electronic System

3.4.1 Inertia Measurement Unit (IMU)

The Sparkfun Inertia Measurement Unit Combo Board incorporates a dual-axis gyroscope IDG500 and Analogue Devices ADXL335 three-axis accelerometer in a tight footprint that enables unheard of 5 axis of sensing (Roll, Pitch, X, Y, Z). Figure 3.3 shows the physical board IMU in less than an inch board size for small PCB board installed. The board operated with 3.3V supply voltage that can be taken from the LM1117 voltage regulator at the controller. There are 3 output from the accelerometer that is X, Y, and Z axis are used to track the movements from three different directions (left-right, forward-backward and up-down). The roll and pitch of gyros has 4.5 gain value and detect the same direction as the accelerometer but without axis Z (up-down). For a sense of balance for balancing transporter platform, only two axes were included in the design for the YR axis of gyro and X-axis of accelerometer. These two types of analog output is connected to the analog input of the controller to process and get the angle represents the angle of the platform. There is a comparison between several type of IMU with different manufactured will be conducted for next experimental works to find the best response of balancing system.

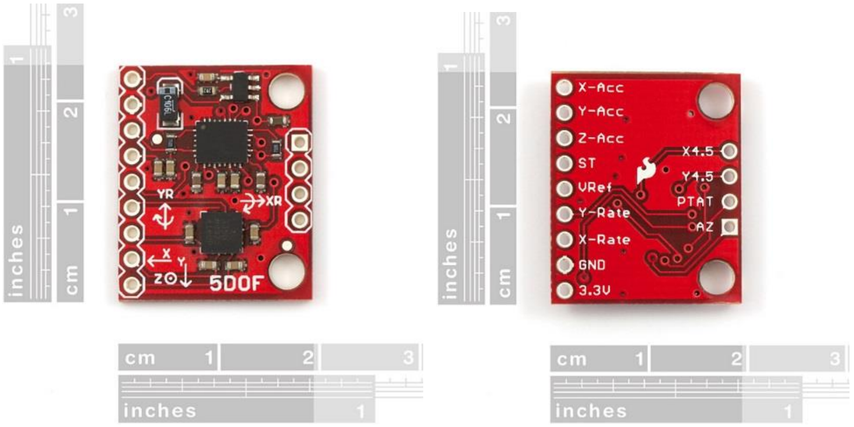

Figure 3.3: 5DOF IMU [Courtesy by Sparkfun]

3.4.2 Controller Board

Arduino in figure 3.4 is an open-source single-board microcontroller, the hardware consists of a simple open hardware design for the Arduino board with an Atmel AVR processor and on-board input/output support. For the UNO model, there is six analog input which is enough to support two analog signal from the IMU and two input variable for steering and gain respectively. The 3.3v power pin used to power up the IMU module and it has a plenty of digital I/O that can be used as output indicator. There also have a serial communication pin at pin 0 and pin 1. This pin is the same pin used for interface the Arduino board USB bootloader programming and to communicate between the controller and the motor driver module using simple serial communication protocol. Also, there is experimental works will be conducted using Arduino Mega which is provided with more analog input to process two unit of IMU simultaneously.

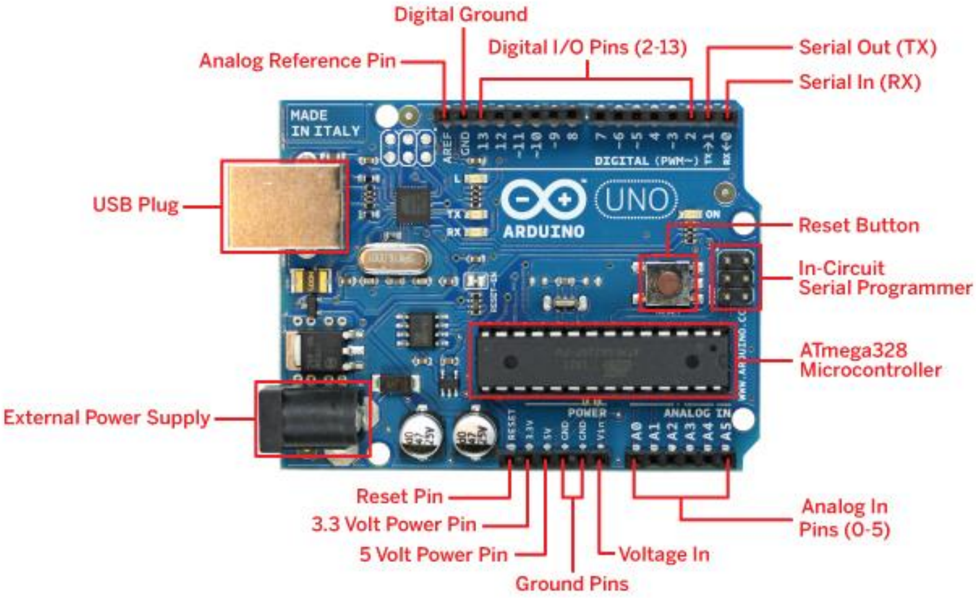

Figure 3.4: Arduino Controller Board

3.4.3 Motor Driver

The RoboClaw 2x60 Amp motor controllers in figure 3.5 is a dual channel motor controllers. It can supply two DC motors push with 60 Amps continuous and 120 Amps peak. The RoboClaw also includes a 3 Amp switch mode BEC that can power up any device from RoboClaw. To be able to control the speed and direction of the motor specific motor driver are be used. Motor driver is a small circuit board with a microprocessor itself that have a serial communication protocol. It can independently and simultaneously control two motors in different speeds and directions by receiving a control data in serial bit format. The board is fed with 24 Volt from the power supply to the motor and the internal circuit was regulated by 5 Volt operations that suitable with internal microcontroller embedded at the motor driver. Each motor can be controlled with a resolution of 8 bits. By submitting a value between 1 and 127 of the first motor is controlled 1 full reverse, 64 is stop and 127 correspond to full speed ahead. The second motor is controlled in the same way, but the numbering bit is in between of 128 and 255, where 128 is full reverse , 192 is stop and 255 is full speed ahead . One of the serial port on the controller board that is used for this communication physically.

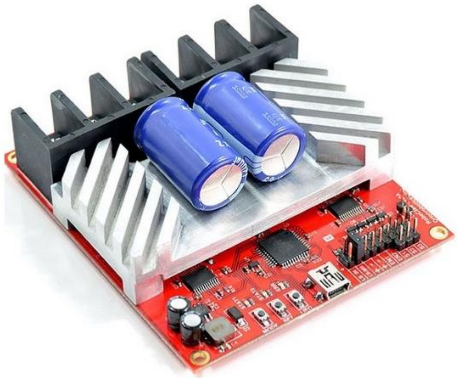

Figure 3.5: Roboclaw Motor Driver [Courtesy by Orion Robotic]

3.4.4 Motors

The motors driving the platform are mounted on the structure and the wheels are placed by gear chain socket ratio of 27:11 on the outgoing shaft of the motor. This is a powerful 24V DC brush motor that is used in electric scooter that comes with no gear reduction, maximum power 350 W and 2600 RPM maximum speed. The motor comes with an 11 teeth sprocket. An image of scooter motor is shown in figure 3.6.

Figure 3.6: 24V DC brush motor

3.4.5 Power Unit

Power for balancing transporter is provided by two common 12 V lead acid batteries. The batteries are in series to get a 24V power supply. 24V is applied to the Roboclaw motor driver directly and it is also regulated into 5V and 12V to supply the control circuit and driver circuits. These two lead-acid batteries are heavy (about 1.2 kg each), but they can provide plenty of current for two driving motors, especially when motors are working in overload.

3.4.6 Wireless Communication

The balancing transporter is equipped with a wireless module for wireless communication between computers. The module which is used is type known as “serial cable replacement”. There are two suggestion type of communication which is either RF Module or Bluetooth module. The RF module operates at Radio Frequency and the corresponding frequency range varies between 30 kHz & 300 GHz. In this RF system it’s operated with 315 MHz frequency signal up to 100 meters depending on the antenna design, working environment and supply voltage impact the effective distance. Meanwhile the Bluetooth module has built-in Bluetooth stack which makes the connection and use with the computer board easy by automatic serial pipeline data transfer. When the device is opened, sending and receiving is done in the same way as write and read to a file or a COM port. By using Arduino UNO as a controller the communication pin must be create as an imaginary or virtual comport either one from the digital pin because the physical serial communication TX RX pin used by motor driver module to communicate as shows in figure 3.7.

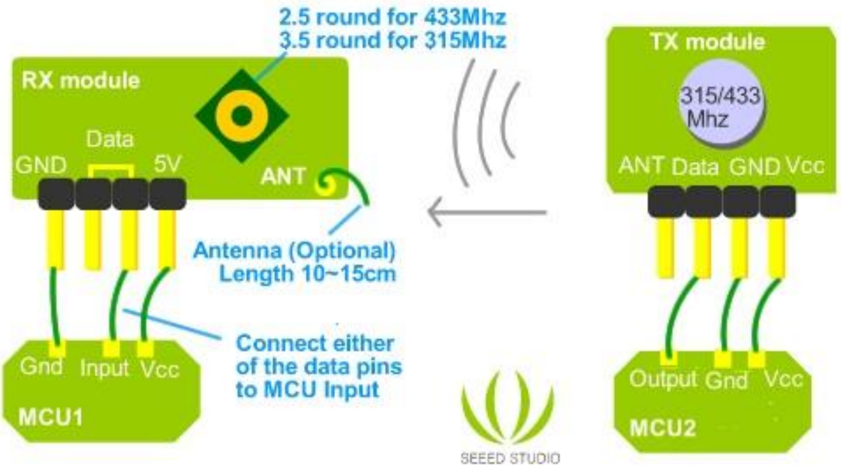

Figure 3.7: Wireless RF Module Interface [Courtesy by Seeed Studio]

3.5 Software Implementation

The software controlling the balancing transporter is developed in regular C, and for more specific it run on open source platform which is an Arduino C compiler that run on Arduino UNO controller board. One feature added in this case is the real-time performance analysis by Matlab GUI interfacing via imaginary serial port. To give the software a good structure, it is divided into a number of separate files or subroutine.

3.5.1 Accelerometer and Gyroscopes

The normal range for Arduino 10-bit Analog to Digital Converters (pin A0-A5) is 0-1023, where 0V input produces a value of 0, and 5V input value, 1023. By using 3.3V Arduino analog input, the maximum value of the Arduino can read from the sensor is approximately 675 by (3.3V / 5V * 1023). To get the full range of 3.3V device, the desired reference voltage 3.3V should connected to the analog reference (Aref) of Arduino pin and add a coding to initialize the Arduino, to use an analog reference. This method will change only the analog reference voltage input pins (A0-A5) and not change any other input or output pin which is still produces a 5V signal.

The accelerometer measures the gravitational force of the IMU relative to the horizon. To equal 0 degrees the IMU must be parallel to the horizon. If the IMU board is tilted left or right in figure 3.8, the angle measurement yields a proportional value in either direction. The code is set to shut down the motors in the event that the IMU measures an angle above the limit.

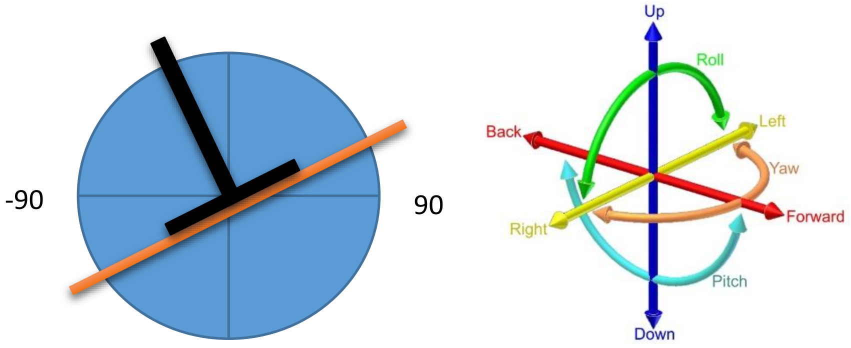

Figure 3.8: The IMU rotating along X-axis

Seemingly the function of accelerometer can used to detect the angle of the IMU board. The reason it’s not suitable to use only to detect angular acceleration is that it severely affected by gravity. Any sudden change in gravity or vibration can affect the angle of the accelerometer output, although the point has not changed. This can drastically change the output readings, the signal becomes useless by distortion signal and need to apply some filtering to prevent false readings. Unfortunately, vibrations and bumps are unavoidable when riding a balancing transporter, this is where a gyroscope sensor comes in handy to solve the problem.

Gyroscope measures how many degrees per second. The measurement of gyroscope value angle is difficult to be measured because it can measure only the rate of change. Gyroscope sensor indicates the current changes while moving along the axis and when stop moving, the voltage drops back to the state capital. Gyroscope drift which refers to the tendency to deviate from the starting point, although it’s not move. These errors make it difficult to get the right angle without accelerometer to use as a reference point for point.

The sensor need to combine together to get stable angle reading. This is usually done by using Kalman filters, but several researcher found that this to be too complicated as mentioned in literature review and filtering is done by using a complementary filter, that more commonly referred to a weighted average. The weighted average represented of stable gyroscope angle without drift error and also accurate reading acceleration without spikes from bumps and vibrations.

3.5.2 Complementary Filter

Complementary filter in figure 3.9 is used to obtain an estimate of the signal from the two sources of information that is from accelerometer and gyroscopes. The Complementary filter get estimates by filtering the signal through complementary architecture, which means that if one of the signal is interrupted by high-frequency sound, then it choose a low-pass filter.

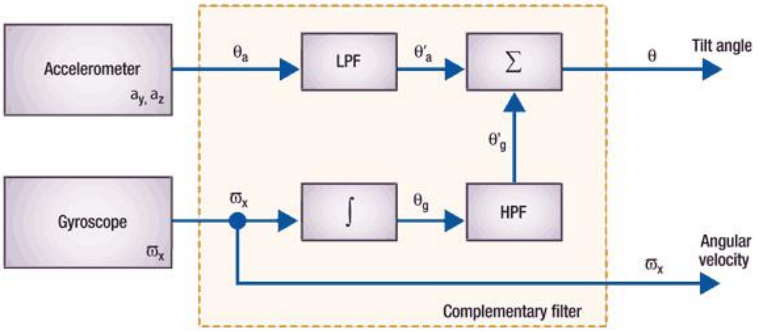

Figure 3.9: Basic block diagram of the complementary filter

3.5.3 PID Controller

The PID (Proportional Integral Derivative) controller will used in the design to reduce an error in angle measurement from the Inertia Measurement Unit (IMU). The measured tilt angle from the complementary filter will send to the input (set point) of PID algorithm in figure 3.10, meanwhile the angular velocity from the gyroscopes will send to the PID as a feedback response of close loop system.

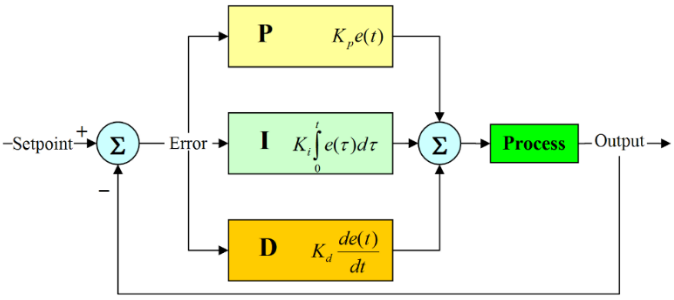

Figure 3.10: PID Block Diagram

3.5.4 Motor Controller Protocol

Motor controller is programmed to accept a simple serial protocol that allows the series forward and back to control the speed of the two motors as shows in figure 3.11. The Roboclaw accepted the value of data in between of 0 until 255 in the range of the Byte. Bytes are used to control Motor1 (1-127) and (128-255) bytes used to control Motor2. Both the range of values each split into front and back to the center position. There are 64 steps speed control in either direction for each the motor, providing enough resolution and smooth acceleration.

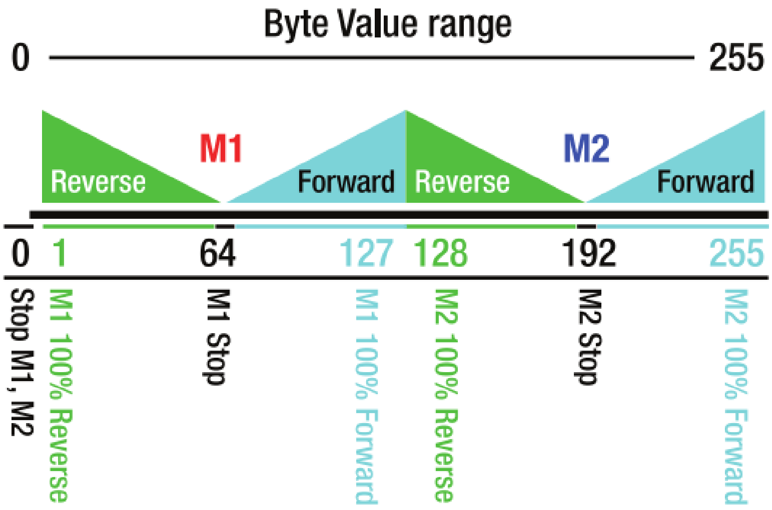

Figure 3.11: Motor Driver Serial Resolution Mapping

3.5.5 Matlab GUI Development

GUIs in figure 3.12 shows a provide point and click control of software applications build using Matlab software to evaluate the performance of balancing transporter. The GUIs plot the real time graph of accelerometer angle, gyro angle and filtered angle. The RAW analog data of IMU signal, Steering Signal and Gain Signal also be display as a reference for wiring evaluation and analysis. The motor data transferred value can be monitored especially the response of motor value be added with the gain signal.

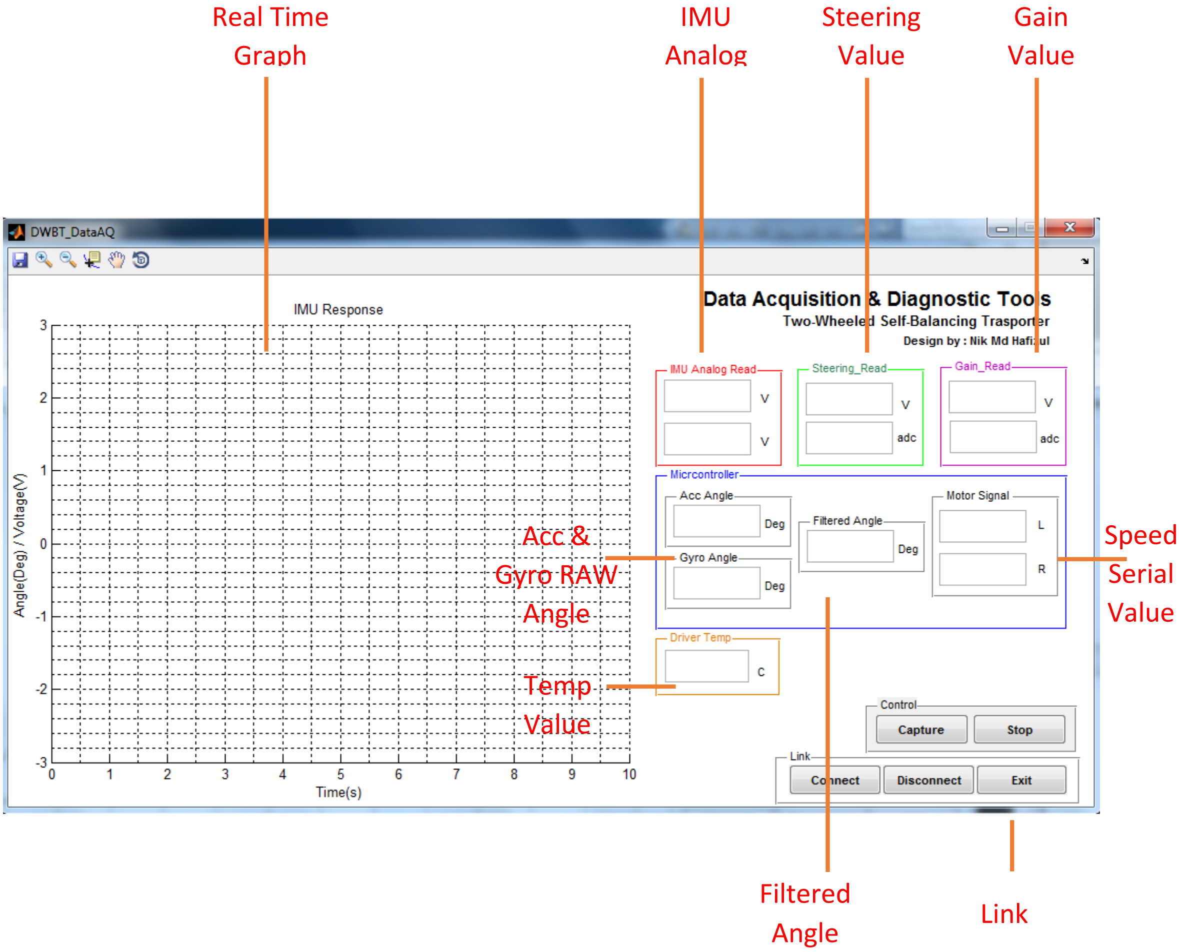

Figure 3.12: Matlab Graphic User Interface (GUI)

3.6 Frame Design

Frames provide a rough shape of the balancing transporter. Figure 3.13 shows the frame structure for balancing transporter using Solidworks sketch and the actual hardware after development. The weight of the frame is important, because it affected the dynamics of the balancing transporter. Materials selected for handlebar is aluminum profile, lightweight and easy to mount on other components, besides that the mainframe based hollow metal structure to support a heavy weight load.

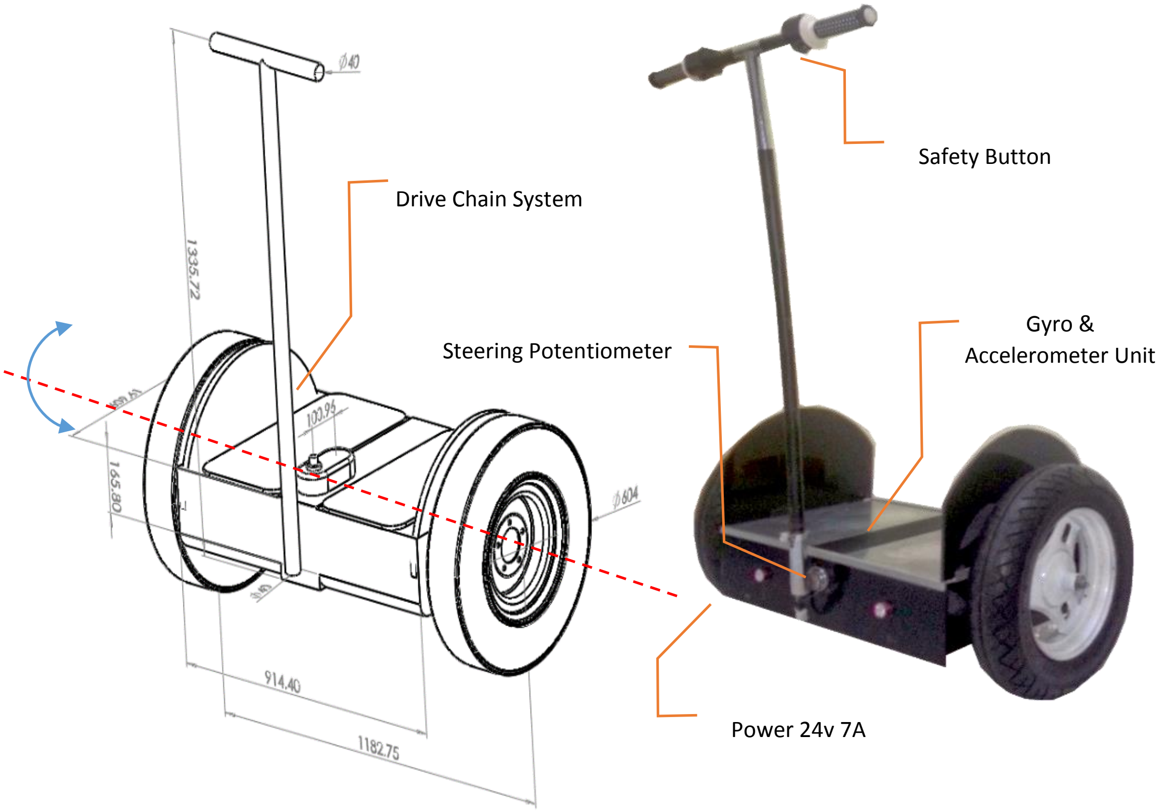

Figure 3.13: Frame Design

The frame in figure 3.14 is made by hollow metal by sized of 36 inch x 24 inch, cut into two pieces upper and lower frame. The thickness of the frame is around 6 inch, serves as the electronic part compartment. The handlebar design can be extend and retract by 48 inch length to suite the rider height. To keep the weight centre between the wheels, the batteries are housed in front of the compartment base using shows in figure 3.15. The battery cage must be larger enough to house the two SLA batteries which measure 6 inch L x 4 inch W x 3.8 inch H each. The entire frame assembly connects to each motor gear box using eight 8mm bolts.

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