MANTECH Publications

International Journal of Robotics and Autonomous System

Volume 3, Issue 1, January-June, 2018

Development of Self Balancing Robot

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Abstract

Two wheeled balancing robots are an area of research that may well provide the future locomotion for everyday robots. The unique stability control that is required to keep the robot upright differentiates it from traditional forms of robotics. The inverted pendulum principle provides the mathematical modelling of the naturally unstable system. This is then utilized to develop and implement a suitable stability control system that is responsive, timely and successful in achieving this objective. Completing the design and development phase of the robot requires careful consideration of all aspects including operating conditions, materials, hardware, sensors and software. This process provides the ongoing opportunity of implementing continued improvements to its perceived operation whilst also ensuring that obvious problems and potential faults are removed before construction. The construction phase entails the manufacture and assembly of the robots circuits, hardware and chassis with the software and programming aspects then implemented. The later concludes the robots production where the final maintenance considerations can be determined. These are essential for ensuring the robots continued serviceability.

Keywords: *Balancing robots, Inverted pendulum principle, PID Controller*

INTRODUCTION

Robotics has always been played an integral part of the human psyche. The dream of creating a machine that replicates human thought and physical characteristics extends throughout the existence of mankind. Developments in technology over the past fifty years have established the foundations of making these dreams come true. Robotics is now achievable through the miniaturisation of the microprocessors which performs the processing and computations. New forms of sensor devices are being developed all the time further providing machines with the ability to identify the world around them in so many different ways.

To make a self-balancing robot, it is essential to solve the inverted pendulum problem or an inverted pendulum on cart. While the calculation and expressions are very complex, the goal is quite simple: the goal of the project is to adjust the wheels' position so that the inclination angle remains stable within a pre-determined value, When the robot starts to fall in one direction, the wheels should move in the inclined direction with a speed proportional to angle and acceleration of falling to correct the inclination angle. So I get an idea that when the deviation from equilibrium is small, we should move "gently" and when the deviation is large we should move more quickly.

To simplify things a little bit, I take a simple assumption; the robot's movement should be confined on one axis (e.g. only move forward and backward) and thus both wheels will move at the same speed in the same direction. Under this assumption the mathematics become much simpler as we only need to worry about sensor readings on a single plane. If we want to allow the robot to move sidewise, then you will have to control each wheel independently. The general idea remains the same with a less complexity since the falling direction of the robot is still restricted to a single axis.

INVERTED PENDULUM THEORY

To develop a reliable and capable control system for a two wheeled balancing robot, an understanding of the parameters within the system is essential. Representation of these can be achieved through a mathematical model. Inverted pendulum theory is more traditionally known as Pole and Cart theory and although the two wheeled balancing robot does not directly compare to the Pole and Cart, the same principles are in effect. Within the system model, the cart equates to the wheels whilst the pole equates to the robot's chassis.

Friction coefficients have been neglected in this project as the robot will be expected to transverse across numerous types of terrains and surfaces. If the coefficients were to be considered during the control systems design and implementation, then additional sensors, circuitry and power consumption would be required to derive these new values whilst in operation. The time, effort and resources required to create this capability far exceed any benefits that could be expected with there inclusion.

It is necessary to generalize the effects of the left and right wheels and incorporate them together under the combined term "wheels". This simplifies the calculations as both wheels will work in unison to maintain stability. For determining specific torque (forces) requirements for each individual wheel, the wheels value can be halved for an approximate single wheel value. This approach is considered acceptable as the terrain and surface will vary between the wheels on certain terrains.

The aim of the inverted pendulum principle is to keep the wheels beneath the centre of the robot chassis mass. If the robot begins to tilt forward, then to maintain stability, the wheel will need to move forward to return beneath the chassis mass. If this is not maintained, the robot will simply fall over. The following system dynamics are associated with the mathematical problem.

EXISTING TWO WHEELED BALANCING ROBOTS

Previous two wheeled balancing robot projects include the Segway, nBot, Bender, Emiew and Emiew 2. The Emiew 2 robot is the enhanced (evolved) version of the original Emiew. They were both designed and created by Hitachi whilst the Segway was designed and developed by Dean Kamen who later formed the company Segway Inc. The remaining robots that were reviewed were created by robot enthusiasts who have continued to improve the robustness of their designs over time.

The design concepts between these robots are very similar. Each typically utilise a gyroscope to measure tilt, shaft encoders to measure distance and a microcontroller for performing the computations. These components combine to provide the basis of maintaining stability. Inclinometers or accelerometers are sometimes added to reduce the effects of gyroscope drift thus enabling a more accurate input signal for the control system.

Segway (Segway 2008) is the commercially available two wheeled robot that is currently in its 2nd generation of released models. It is marketed to the world as a transport alternative with the image contained within the following figure. Its advertising suggests the robot is ideal for adventure, commuting, law enforcement and transportation in general.

Figure 1: Segway HTi series two wheeled transport

EMIEW (Kageyama 2007) stands for "Excellent Mobility and Interactive Existence as Workmate". It was the first two wheeled robot produced by Hitachi and was released in March of 2005. It stood at a height of 1.3 m and weighed over 70 Kg. Emiew 2 followed in November 2007 and is approximately half the size of Emiew at 0.8 m and 13 Kg. Its design concept hoped to reduce the safety risks that were associated with Emiew larger size, incorporating reductions in height and weight.

Figure 2: Emiew 2 by Hitachi

DESIGN AND DEVELOPMENT

The design phase of a project is fundamental in evolving the ideas, requirements and objectives of the components that together, will form the completed robot. Development and careful design considerations provide the engineer with the ability of ensuring that the concept remains viable as it progresses.

CONTROL SYSTEM

The purpose of a control system is to keep a system or plant, within a specified range of elements and set variables. This could refer to numerous applications such as production, assembly and industrial plants through to computer, electrical and electronic systems. For this project, it refers to the control system charged with maintaining stability of the robot chassis. Controlling the stability of the balancing robot requires sensors to detect the direction and rate of motion as well as a decision based application that will provide the response signals to the motors.

Microcontroller:

The purpose of a microcontroller is to complete computations and process data by executing instructions or programming. They contain all the necessary components expected of a computer system in a single Integrated Chip (IC). These include the processor itself, RAM, ROM and input/outputs. Since they are small in size, they are typically implemented in embedded systems and can be found in numerous household appliances.

Ideally, a microcontroller will maintain a fast response with minimal power consumption and low susceptibility to interference. The IC should contain all the devices necessary for operational requirements such as timers, ADC, DAC, and PWM outputs. This reduces the need for additional peripherals and hardware to be incorporated which would only increase the complexity required and the power requirements needed. The microcontroller should also be reprogrammable to allow improved operation and upgrades over it intended lifespan and beyond.

The choice of microcontroller is Arduino uno

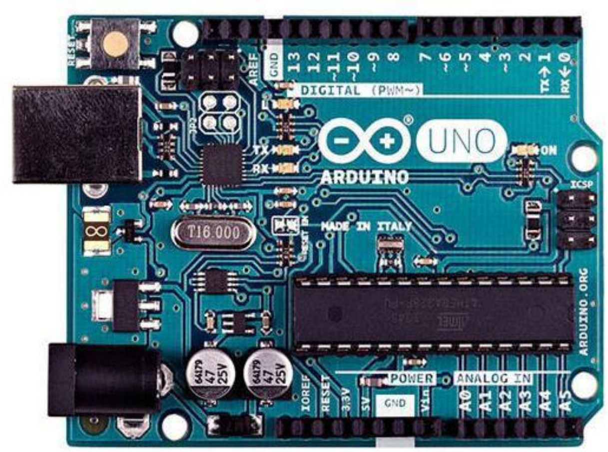

Figure 3: Arduino UNO

Wheels:

The wheels provide traction and locomotion for the robot as well as support for the robot chassis. The diameter of the wheel should be chosen to best reflect the torque requirements of the machine. The tyre used will impact on traction and the smoothness of the motion experienced by the inertial sensors and sensitive components onboard. The number of wheels to be used in a design should depend on requirements of the capabilities.

To overcome poor traction, higher levels of torque are required which is ultimately supplied by the motor. Ideally the tyre traction would have maximum contact with the ground and minimal resistance through the drive system. A width between 30-45 mm of a rubber tread was deemed acceptable as it would provide reasonable grip for most terrains and weather conditions. It would also prove ideal for turning on the spot which is a major feature of a two wheeled balancing robot.

Two plastic wheels with solid rubber tyres were chosen due to there reduced cost and lower associated weight compared to its metal counterparts

Motors:

Motors are an essential component for providing mobility. Without motors to move the machine, it would prove to be an expensive paperweight. Several types of motor are available including Alternating Current (AC) or Direct Current (DC) types. Variances of these motors include the brushless, brush, servo and permanent magnet motors. Another consideration for the motor is its Revolutions Per Minute (RPM). As most motors are rated between 2000-7000 RPM, some form of gearing is required to reduce the rate experienced at the wheel.

The idea of a motor for each side of the robot, also known as differential drive, was decided upon early to reduce the potential mechanical complication involved with implementing a single motor system. Using two motors will also allow the torque to be more effectively applied to the wheel shafts thus reducing the need for complex calculations for frictional and rotational losses.

As the right motor moves forward and the left motor moves backwards, the robot chassis will be turned to the left. If equal torque is applied to each of the motors, the robot will turn on the spot. The same principle applies if both of the motor directions are reversed.

Motor Control: Motor controllers control the motors rate of turn and its direction by varying the output voltage signal and setting its polarity respectively. There a several forms of motor control with the application dependant on the role and the motor in use. Direct, Relay, transistor or H-bridge (motor bridge) controllers are all common types available. The later provides the facility for a pulse width modulation (PWM) signal output for varying the motor speed.

PWM provides an output voltage that is varied by a duty cycle. This duty cycle is a percentage of voltage time high compared to voltage output and specifies the 'pulse width'. The speed of the motor is altered by altering this duty cycle percentage.

A benefit of this approach is that there is no digital to analogue conversion necessary so there is no potential for induced noise or interference on the signal. It is recommended (McComb & Predko 2006) that PWM is run at frequencies over 18 KHz, higher than the maximum human hearing frequency, to avoid hum noise generation within the motors.

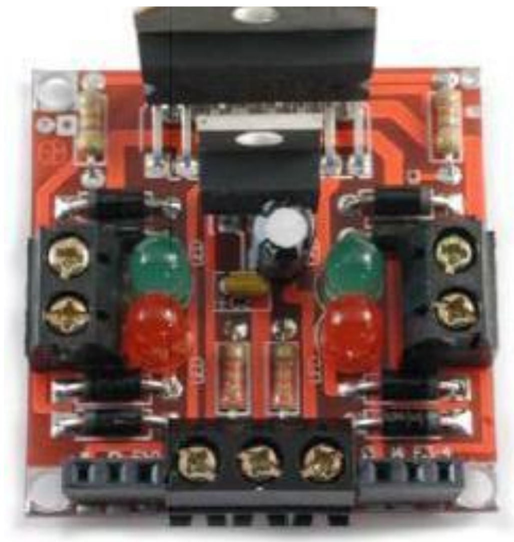

Figure 4: Motor Driver

The H-bridge circuit also offers LED indication of the direction each motor is driven as well as an additional regulated 5V power supply output. This proved beneficial for isolating the gyroscope circuitry from the main 5V distribution and reducing the gyroscopes EMI impact on the system. The control inputs to the driver allow forward or reverse rotation as well as braking of the motors. Another benefit of the motor driver is the thermal shutdown protection incorporated into the PCB.

Sensors:

Sensors provide the robot with the ability to interpret the environment around them. Without sensors, the robot would blindly execute a series of instructions without the capacity to re-evaluate its progress and make adjustments. Sensors are available in two forms, analogue and digital. Analogue sensors provide a range of values in response to its sensitivity which have the benefits of measuring rates or volumes. Digital sensors only provide an on or off value and are ideal for an absolute indication. Sensors may be connected by parallel or serial connections to the microcontroller or Analogue to Digital Converters (ADC) depending on the actual sensor used.

Accelerometers, gyroscopes are the most common types of sensors utilised in robots and machines that require stability control. They provide a means of measuring acceleration, velocity and direction. If multiple axes were to be measured with certain type of sensor then a sensor would be required for each particular axis.

By combining different sensors through a process known as sensor fusion, certain sensor problems such as gyroscope drift and noise can be overcome and kept within the required accuracy. Commonly, a gyroscope and inclinometer are combined.

PID Control System:

The control algorithm that was used to maintain it balance on the autonomous self-balancing two wheel robot was the PID controller. The proportional, integral, and derivative (PID) controller, is well known as a three term controller.

The input to the controller is the error from the system. The Kp, Ki, and Kd are referred as the proportional, integral, and derivative constants (the three terms get multiplied by these constants respectively). The closed loop control system is also referred to as a negative feedback system. The basic idea of a negative feedback system is that it measures the process output y from a sensor.

The measured process output gets subtracted from the reference set-point value to produce an error. The error is then fed into the PID controller, where the error gets managed in three ways. The error will be used on the PID controller to execute the proportional term, integral term for reduction of steady state errors, and the derivative term to handle overshoots. After the PID algorithm processes the error, the controller produces a control signal u. The PID control signal then gets fed into the process under control

Power Source:

A power source is essential for providing energy to a machine. Without energy, a machine would simply not operate. If an insufficient power source was implemented, a machine would not function correctly nor would it perform adequately. Power sources may be AC through electrical main supplies or generators. They may also be DC from devices such as batteries. Batteries are rated by voltage output and ampere hours (AH). AH refers to the current that they can supply per hour.

Batteries will be an essential component in allowing the robot to maintain autonomous operation. Otherwise a direct connection between the robot and a power source would need to be maintained at all times. Ideally, the best practise is to minimise the total power consumption during this design phase so a smaller power system may be implemented. This is an important factor as power systems are typically the heaviest element of a robot or device.

Working Principle:

The IMU sensor mounted on top of the vehicle measured the acceleration and angular acceleration in three axes namely x, y and z. These values were processed by Digital Motion Processor (DMP) which transformed these values in to a more convenient set of variables i.e. yaw, pitch and roll. Here only pitch was necessary as it produced the value for tilt in the axis under consideration. This value was fed to the controller; which acted as feedback to the microcontroller. The micro controller processed the values obtained from DMP according to program specified algorithms.

The controller compared the pitch value obtained from feedback with the pre-set value, if there was a deviation then the error value was sent to the PID controller which via its algorithm produced a proportional force to be applied on the motors in order to bring it to back to the original vertical position. The control signal was produced and sent to the motor controller L298N. The motor controller derived the motor at the specified speed, torque and direction.

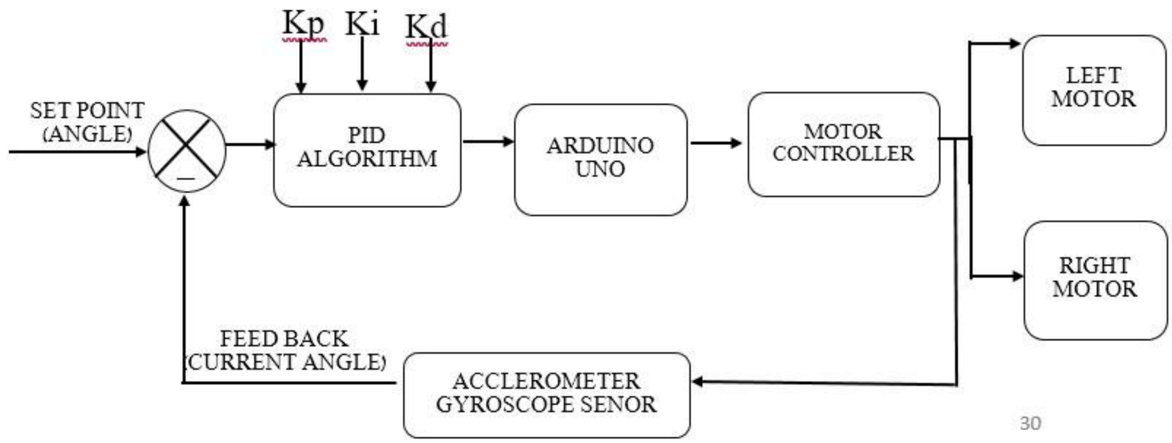

Figure 5: Block Diagram

CONCLUSION

The project utilized the classical problem of inverted pendulum and its application has been extended to realize self-balancing robot. The bot balances itself when pushed forward or backward using this principle. The requirements, functioning and connections of the components have been discussed in detail. The concept which was inspired from the functioning of the Segway can be further improved by using quadrature optical encoders for enhancing the precision of motor speed readings, which in turn would improve stability. Potentiometers can be used to tune the error constants of the PID control system. The mentioned features could not be incorporated due to the imposed time constraint but can be used as a modification to the existing system while designing a more efficient system in the future. Two wheeled balancing robots can be used in several applications with different perspectives such as intelligent gardeners in agricultural fields and autonomous trolleys in hospitals, shopping malls, offices, airports, healthcare applications, or an intelligent robot to guide

REFERENCES

I. Anderson, DP, 2007, nBot Balancing Robot, viewed 20th March 2008, http://www.geology.smu.edu/~dpa-www/robo/nbot/

II. Angeles, J 2007, Fundamentals of Robotic Mechanical Systems, Springer, New York.

III. Banks, D 2006, Microengineering MEMs and Interfacing, Taylor & Francis, London.

IV. Bates, Hellebuyck, Ibrahim, Jasio, D, Morton, Smith, D, Smith, J & Wilmshurst 2008, PIC Microcontroller, Elsevier Inc, New York.

V. Bergren, C 2003, Anatomy of a Robot, McGraw-Hill, Sydney.

VI. Bishop, R 2002, The Mechatronics Handbook, CRC Press, London.

VII. Larson, T, 2008, Balancing Robot Project - Bender, viewed 20th March 2008, http://www.tedlarson.com/robots/balancingbot.htm

VIII. Sandin, P 2003, Robot Mechanisms and Mechanical Devices Illustrated, McGraw-Hill, Sydney.

IX. Segway Inc, 2008, Simply moving, viewed 20th March 2008, http://www.segway.com/

X. Shircliff, D 2002, Build a Remote-Controlled Robot, McGraw-Hill, Sydney.