Stabilization of an Inverted Pendulum on a Mobile Robot

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Abstract

The inverted pendulum stabilization problem is commonly studied in control theory since it clearly demonstrates how a nonlinear system can be locally stabilized while visually observing the performance. Implementation of previous inverted pendulum experiments required large power supplies and a geared track. The system sensors and motors were previously hard-wired to a nearby PC which performed the necessary calculations. The objective of this project is to implement an embedded control system on a mobile robot, with all sensors, actuators, and other required components to be contained in a small, lightweight package, without compromising the power required to stabilize the pendulum. The implementation of such a system demonstrates the ability to create other fully autonomous robotic systems which use a comprehensive embedded control system, while having powerful and lightweight physical characteristics. Although there are no direct applications for the inverted pendulum, this project is a demonstration of how autonomous robotic applications can be implemented in various fields, for example lightweight autonomous aircraft.

Sommaire

Le problème de stabilisation d'un pendule inversé est couramment étudié en théorie du contrôle car il démontre clairement comment un système non-linéaire peut être stabilisé localement tout en observant visuellement son comportement. Les implantations précédentes de pendules inversés exigeaient de gros blocs d'alimentation et une piste dentée. Les senseurs et moteurs étaient branchés à un micro-ordinateur qui exécutait les calculs nécessaires. L'objectif de ce projet était d'implanter un système embarqué de contrôle sur un robot mobile avec tous les senseurs, actuateurs, et autres composantes requises contenues dans un ensemble léger, sans compromettre le courant nécessaire pour stabiliser le pendule. L'implantation d'un tel système démontre la possibilité de créer d'autres systèmes robotisés entièrement autonomes qui utilisent un système de contrôle embarqué complet, tout en étant puissants et légers. Quoiqu'il n'existe aucune application immédiate pour un pendule inversé, ce projet démontre comment des applications robotiques autonomes peuvent être implantées dans plusieurs domaines, par exemple les aéronefs autonomes légers.

1.0 Introduction

The problem of stabilizing an inverted pendulum is very challenging and requires a system which can react quickly and predictably. In the past, systems of this type have been mounted on geared tracks, giving perfect traction while also being controlled and powered by third party machines such as computers and power supplies [C]. This makes for a system that is predictable and effective, yet limited in its range of motion by physical connections.

The objective of this project was to design and implement a mobile platform, free of physical constraints imposed by third party devices, on which all control, motive force, and power could be enclosed in one unit. Not only was our mobile platform to maintain the vertical position of the pendulum, but to also maintain a wirelessly inputted, user defined cart position.

In order to implement a stand-alone inverted pendulum system, or any robotic platform, significant consideration must be given to the physical construction of the system. For this system, powerful actuators or motors were required to achieve the desired acceleration of the platform in order to stabilize the pendulum. This requirement places a large demand on the battery or power source which is often the heaviest component in a robotic system.

The proposed control system for this experiment is model-based, which requires a dynamic model for the physical system. A control law was formulated using the linear quadratic regulator (LQR) method. In order to develop the controller, a linear approximation to the nonlinear system model must be made.

2. Physical System

The components housed inside the enclosure include 2 drive-train assemblies, 2 motors, 2 batteries, 2 optical encoders, and 2 electronic speed controls. Every moving part has a ball bearing in order to reduce friction as much as possible to ensure reliability and consistency.

Two independent drive trains were implemented for future development of the system to allow for the cart to move in two dimensions, rather than a straight line. Future work could also involve remove the 'training wheels', thus creating a double inverted pendulum system.

To gain as much traction as possible, every consideration was taken to maintain a low center of gravity and a large contact patch with the ground. To maintain a low center of gravity, the largest masses (motors and batteries) were mounted as low in the cart as possible and centered around the main axle line. This low center of gravity allows the car to change direction quickly while minimizing the tendency for the momentum to lift the wheels off the ground. To gain as much grip as possible, the softest rubber tires available were chosen.

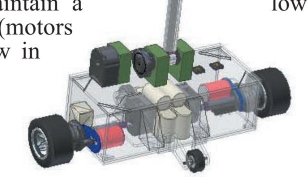

Fig. 1: Mobile Robot Chassis with Pendulum

2.1 Power Train Electronics

The power train components of the vehicle consist of 2 motors, 2 electronic speed controllers, and two 5-cell battery packs. All of the parts were designed for specific use in 1/18th scale model cars, and thus, are small, efficient, and reliable. Selecting quality parts ensures that predictable operation remains uniform over the course of the experiment.

DC Motor

The permanent magnet DC motor selected for use in this experiment is the Team Orion Big Block shown in Figure 2. The Big Block design makes it ideal for use in this experiment due to its high torque abilities, high rpm, and compact form factor. Although this particular motor is widely used in the 1/18th scale model car scene, the manufacturer Team Orion has not performed physical tests yielding technical data such as torque constants and armature resistance values. Therefore, necessary experiments were performed to determine the motor physical characteristics.

Fig. 2 - Team Orion Big Block Motor

N.Ed. The article presented here stems from a project that won the first IEEE Canada Telus Innovation Award in September 2005, and the IEEE Canada Life Member Award in December 2005. We are grateful to TELUS for sponsoring this very popular activity.

N.Ed. Cet article est issu d'un projet qui a remporté le premier Prix d'Innovation Telus de l'IEEE Canada en septembre 2005, et un Prix des Membres à vie IEEE Canada en décembre 2005. Nous sommes reconnaissants envers TELUS pour sa commandite de cette activité très populaire.

Electronic Speed Controls (ESC)

Purchasing an electronic speed control offers several advantages over designing a motor controller. Firstly, the ESC is housed in a small form factor case that easily integrates into our chassis. The case measuring (28.4mm x 24.1mm x 12.1mm) is lightweight and specially suited to the Team Orion Big Block motor. Second, the device is capable of handling a peak current of 25A while maintaining a high level of efficiency and linearity. These features along with precision quality provide a high level of reliability and accuracy.

The ESC chosen for the system is the Team Novak Micro Spy ESC. This powerful ESC is capable of operating between 4.8V to 8.4V. The design for the inverted pendulum utilizes 5 cells or 6.0V in operation. Pictured below in Figure 3, the ESC is ready built with all the appropriate connections and required no modifications to be fitted to the design.

Fig. 3: Novak Spy ESC

Fig. 4: Team Losi 5-Cell Battery Pack

The ESC controls the speed and direction of the motor using a pulse-width modulated (PWM) input signal operating at a fixed frequency of 51Hz. Depending on the duty cycle of the PWM signal, the ESC will modify the direction and speed of the motor. The corresponding output signal of the ESC is also a PWM signal with a frequency of 1 kHz, duty cycle varied between 0% - 100% and a switching polarity corresponding to the desired direction. The neutral position or off position is located at 7.5% duty cycle. Since this range of operation is small, the system microcontroller must have the ability to vary the duty cycle accurately. When selecting a microcontroller for the system one must consider the minimum obtainable PWM frequency which is dependant on the crystal frequency in addition to the available pre-scale (or frequency divide) registers on the device.

Batteries

Since the vehicle is completely standalone, powerful batteries are required to supply the necessary current to the motors. Experimentation with a wide variety of batteries led to the conclusion that specially designed battery packs were required. High capacity NiMH AA batteries grouped together in parallel were initially used since they are small and lightweight. However, upon experimenting, they did not provide the high current demanded by the motors. This failure led to the use of specially designed packs for use in 1/18th scale model cars. Team Losi 5-cell sport packs (Figure 4) proved to be the best source for power. Their NiMH composition and small form factor fit perfectly into the vehicle and are easy to remove and recharge.

2.2 Digital Control Electronics

Accompanying the digital signal controller on the circuit board are a host of other purpose designed ICs. These include two 24-bit quadrature counters, remote control decoder, wireless RF receiver, 555 timer (used for filtering), and a low dropout voltage regulator. Connected to the pendulum (through gears) and each wheel are optical encoders shown below.

Fig. 5: HEDS-5500 Optical Encoder
(printed with permission of Avago Technologies)

Avago Technologies HEDS-5500-A06 Optical Encoder

The HEDS-5500-A06 is a high performance metal code-wheel incremental optical encoder. Using an infra-red LED light source and matching detector IC, the HEDS-5500 provides 500 increments per revolution. The encoder provides an accurate account of the shafts position via 2-phase differentiated square wave signals. These phase differentiated channels are transmitted to the quadrature encoder counter to increment or decrement the counter values based on the direction of shaft rotation.

US Digital LS7266 Dual-Axis Quadrature Encoder Counter

The quadrature encoder counter (QEC) is used to record the number of pulses received from the optical encoders. The quadrature encoders communicate to the counters using two phase differentiated square waves. By using the two square waves it is possible to determine the direction of rotation on the encoder. The counters convert the pulses into a quantitative value that can be retrieved by the systems processor for use in calculating the linear and angular positions. The control design for the inverted pendulum makes use of 2 dual-axis QEC ICs to accommodate for the systems 3 optical encoders.

Resolution is an important concern when dealing with precision measurements. Like many QEC ICs, the LS7266 makes use of resolution multipliers. This user selectable mode allows for x1, x2, and x4 mode of operation, where x4 mode represents an effective increase of 4 times the normal operating resolution of the optical encoder by making use of all edge transitions of the square waves. This increase in digital resolution coupled with the 1:5.3 gear ratio of the pendulum gives us an effective 10615 increments per revolution and an accuracy of .03 degrees. The resolution multiplier of the linear measurement is set to x2 mode giving 1000 increments per revolution of the wheels, which translates to an accuracy of 0.17mm.

Microchip dsPIC 30F4011 Digital Signal Controller

The dsPIC30F4011 digital signal controller (DSC) is a single chip that seamlessly integrates the control attributes of an advanced microcontroller (MCU) with the computational abilities and robustness of a digital signal processor (DSP). The 30F4011 was chosen as the primary controller for several reasons. Integrated PWM control, optimization for C code, flexible re-programmability, and DSP abilities are all features that a designer might consider when developing an embedded controller.

One purpose of the DSC is to translate the data obtained from the quadrature encoder counters (QEC) into tangible values of linear and angular positions of the wheels and pendulum, respectively. Having obtained the instantaneous pendulum angle and wheel positions, the pendulum angular velocity and each wheel linear velocity must be calculated. Since the pendulum angle and wheel position are obtained using discrete devices, filtered derivatives are used to calculate system velocities. Once these values (or system states) are obtained, the corresponding state space feedback gains are applied. The DSC is also required to control the cart position through the use of integral control. The control system integration as well as the filtered derivatives are evaluated using numerical methods by the DSC.

In order for accurate control of the speed, the output of the DSC must meet the requirements of the ESC. The 30F4011 has a 3 channel PWM module, each with independent duty cycle registers.

Since the DSC communicates with a host of other ICs on the controller board, a number of inputs and outputs (I/O) were required. Port-B on the 30F4011 is a dedicated 8bit data bus interfacing the LS7266 Quadrature Encoder Counters to the DSC. In addition to the 8bit bi-directional bus, 5 control lines are used for full communication and control of the LS7266.

The programming environment supplied with the 30F4011 is Microchips MPLAB Integrated Development Environment (IDE). MPLAB (IDE) is a free, integrated toolset for the development of embedded applications using the dsPIC and other families of microcontrollers. Since many of the system control algorithms would be tedious to program in assembler, the use of a C-code compiler was used. The Hi-Tech C-compiler is designed to work with the MPLAB environment allowing the programmer to use both C and assembly languages. Programming of the 30F4011 DSC was completed onboard the vehicle via the Microchip ICD2™ through an RJ-45 modular adaptor. The ICD2 is a combination of an In-Circuit-Programmer and an In-Circuit-Debugger. Utilizing the ICD2 had many advantages including quick and easy debugging and eliminated the need to remove the 30F4011 IC. The 30F4011 can also be programmed via a separate universal adaptor.

2.3 Wireless Transmitter and Receiver

Controlling the linear position of the cart via a fixed physical connection was not an option since it would require cables to be dragging along with the cart during operation. This setback would prove to be a nuisance and would take away from the vehicles “cable-free” design. Thus, wireless functionality was added.

ABACOM AM-RT5-433 Transmitter & Holtek HT12-E Remote Encoder

A wireless link was required to start and stop the system, as well as increment or decrement the desired cart position. In order to accomplish this, a handheld transmitter and encoder were needed. The choice was made to use a Tx/Rx combination commonly used widely in robotics and remote control applications. The devices chosen for use in the remote control were the ABACOM AM-RT5-433 RF transmitter and the Holtek HT12-E remote encoder.

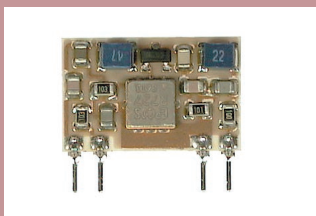

Fig. 6: AM-RT5-433 RF Transmitter

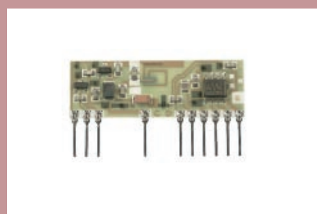

Fig. 7: AM-HRR3-433 RF Receiver

The AM-RT5-433 is an amplitude modulated 433MHz complete transmitter module. As seen in Figure 6, the RT5 is very small and has no adjustable components. A simple whip antenna measuring 16cm simplified the design by removing the need to integrate a helical or loop antenna.

Given that the transmitter will be performing multiple functions, an encoder was needed to convert the multiple push buttons into a single data stream that the RT5 could transmit. This was achieved using a parallel to serial data encoder. The HT12-E encoder is a 12bit (8bit address, 4bit data) wide encoder used for remote control applications. Its minimal external components and low standby current make it ideal for use in portable applications.

ABACOM AM-HRR3-433 Receiver & Holtek HT12-D Remote Decoder

Incorporated into the controller board are an RF receiver and a remote control decoder. The decoder transmits data to the DSC which then actuates the corresponding pins. The devices chosen to perform these operations are the sister components of the transmitter and encoder ICs which are the AM-HRR3-433 RF Receiver and the Holtek HT12-D Remote decoder.

The AM-HRR3-433 is an AM demodulating compact hybrid RF receiver used to acquire the signal sent by the RT5 transmitter. The HRR3 operates on a single supply of 5V and requires no adjustments or tuning which often isn’t the case for stable regenerative receivers.

Only 4 connections are required on the HRR3 which are VCC, GND, ANT, and DATAout. Similar to the RT5, the HRR3 receiver utilizes a 16cm whip antenna as its means of receiving the signal.

Decoding of the signal is performed by the HT12-D decoder. The HT12-D is the complement of the HT12-E used in the handheld transmitter. Its address/data structure is identical to the HT12-E which translates to a received 4bit wide data bus. An important feature of the HT12-D is its built-in error checking. This error checking is performed for verifying the received words 3 times over ensuring that the intended signal is the one received. Once the data is verified, the 3 corresponding bits are then transmitted to the DSC so the corresponding operation may be carried out.

3. Dynamic Model

A nonlinear dynamic model of the system was formulated using the Newton-Euler method[1], and is given by equations (1) and (2). The model includes the dynamics of the motor and uses the motor voltage as the input to the system.

$$\ddot{\theta} = \left(\frac{mg\ell\sin\theta}{I+m\ell^2}\right) + \left(\frac{-m\ell\cos\theta}{I+m\ell^2}\right)\ddot{x} \qquad (1)$$

$$\ddot{x} = \left(\frac{-m\ell\cos\theta}{m+M}\right)\ddot{\theta} + \left(\frac{-k_G k_T)^2}{(m+M)r^2 R_a}\right)\dot{x} + \left(\frac{m\ell\sin\theta}{m+M}\right)\dot{\theta}^2 + \left(\frac{k_G k_T}{(m+M)rR_a}\right)V \qquad (2)$$

where,

θ = Pendulum angle
ℓ = Pendulum length
I = Pendulum moment of inertia
m = Pendulum mass
x = Cart position
M = Cart mass
k_T = Motor torque constant
k_G = Motor gear ratio

3.1 MATLAB® Non-Linear System Block

The dynamic model given by non-linear equations (1) and (2) are used to create a model file in MATLAB®. The non-linear system block is also used to specify initial conditions for x, θ, and their derivatives.

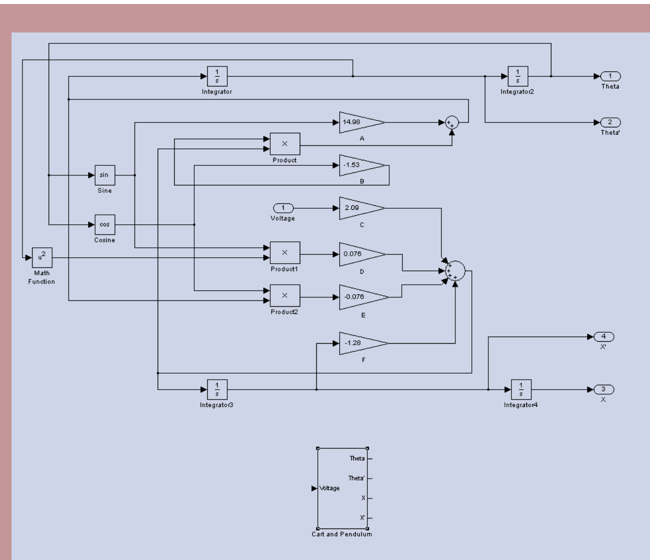

Fig. 8: Non-Linear System Model

3.2 Dynamic Model Linearization

A linear approximation to the non-linear system equations is obtained using the small angle formula. This leads to linear expressions (3) and (4) relating the linear acceleration and pendulum angular acceleration, respectively.

$$\ddot{x} = \left(\frac{-(m\ell)^2 g}{(m+M)I+mM\ell^2}\right)\theta + \left(\frac{-(k_G k_T)^2(I+m\ell)^2}{((m+M)I+mM\ell^2)r^2 R_a}\right)\dot{x} + \left(\frac{k_G k_T(I+m\ell^2)}{((m+M)I+mM\ell^2)rR_a}\right)V \qquad (3)$$

$$\ddot{\theta} = \left(\frac{mg\ell\left((m+M)I + mM\ell^2\right) + (m\ell)^3 g}{(I+m\ell^2)((m+M)I + mM\ell^2)} \right)\theta + \\ + \left(\frac{m\ell(k_G k_T)^2}{((m+M)I + mM\ell^2)r^2 R_a} \right)\dot{x} + \\ + \left(\frac{-m\ell k_G k_T}{((m+M)I + mM\ell^2)rR_a} \right)V \qquad (4)$$

4. Control Design

In order to stabilize the pendulum at its unstable equilibrium point and the cart at an adjustable linear set-point, a closed loop state feedback control was implemented. To calculate the corresponding controller gains, the Linear Quadratic Regulator (LQR) method was used [2].

In order to ensure a zero steady-state error for the linear set-point, a tracking controller was added. This tracking controller integrates the difference between the cart's position and the desired set-point over time and slowly develops an error signal which corrects any deviation.

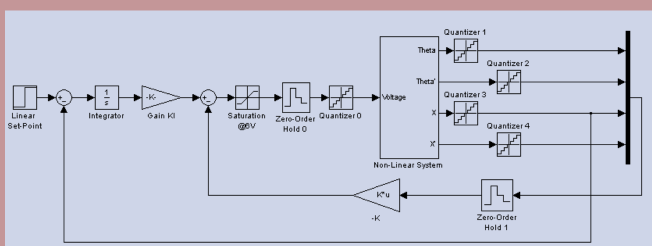

Fig. 9: MATLAB System Block Diagram

Non-Linear System Stabilization Simulations

Having obtained a control law from the LQR method based on the known system physical parameters, simulations were performed to determine the controller performance. Since the controller is based on a linearization of the system around its equilibrium point, or when the pendulum is vertical, the simulations help reveal the range of the initial pendulum angle which the controller is able to stabilize. For the given simulation, the ability of the control to respond to a pendulum angle of 10 degrees is tested while the linear position of the cart is changed to 1m.

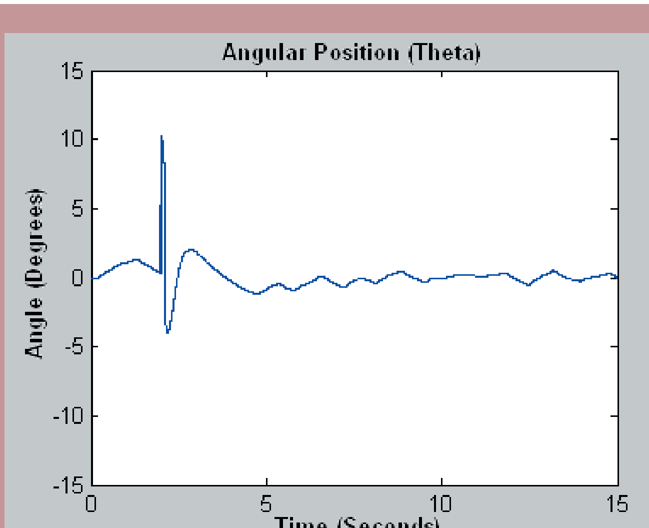

Fig 10: Angular Position with Disturbance

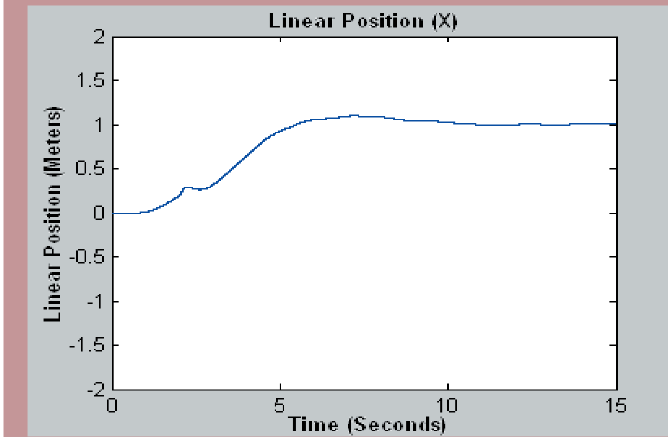

Fig. 11: Linear Position with Disturbance

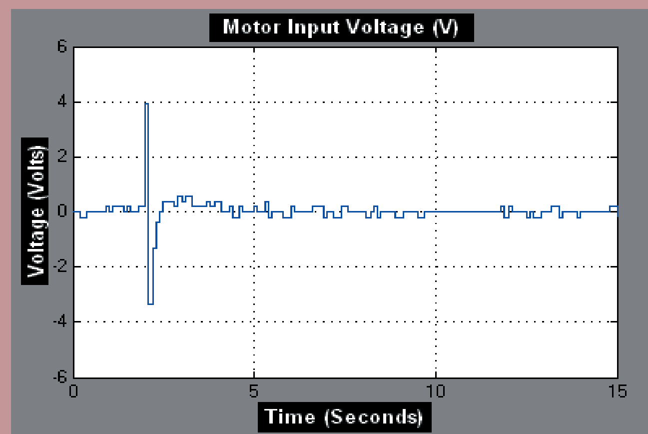

Fig. 12: Voltage Applied to Motor for Disturbance

5. Software Design

In addition to the communication with all system peripherals, the microcontroller was required to perform a number of calculations pertinent to the control system implementation. Programming these floating-point algorithms using fixed-point assembly architecture would prove to be very difficult. This was avoided through the use of the Hi-Tech C compiler which allowed for these algorithms to be programmed in C while allowing for the communication of the other electronics using assembly language.

5.1 Numerical Algorithms

Since the control design required the calculation of system velocities and the integration of an error signal, numerical representations of continuous time algorithms were obtained to be programmed in the DSC using C.

Filtered Derivatives

The equation for a filtered derivative in continuous time is given in (5), followed by an equivalent discrete-time version given by (6). These filtered derivatives are used to calculate the pendulum angular velocity and each wheel linear velocity in discrete time.

$$\dot{X} = \frac{s}{\tau s + 1} X \qquad (5)$$

$$\dot{X}_f^{(1)} = \frac{\tau \dot{X}_f^{(0)} + X^{(1)} - X^{(0)}}{\tau + T_S} \qquad (6)$$

$\dot{X}_f^{(1)}$ = Current value for filtered derivative
$\dot{X}_f^{(0)}$ = Previous value for filtered derivative
$X^{(1)}$ = Current value of state variable
$X^{(0)}$ = Previous value of state variable
τ = Filter time constant (reciprocal of filter cut-off frequency)
T_S = Loop sampling time.

Set Point Integrator

The set point integrator is used to develop an error signal based on the integral of the difference between the desired set point and the actual linear position of the cart. The trapezoid method is used to calculate this integral. Similar to the filtered derivative, the trapezoid method uses previous and current values for the state variables, as well as a previous value for the integral. The expression used to approximate value of the integral is given by equation 7.

$$\int_0^{(k+1)T} (x_d - x)dt = \int_0^{kT} (x_d - x)dt + T_S\left(x_d - \frac{x^{(1)} + x^{(0)}}{2}\right) \quad (7)$$

5.2 Applying Control

Once all state variables have been calculated, the controller uses the gains to determine the required motor voltage. The required voltage is given by equation 8.

$$V_{motor} = -k_1\theta - k_2\dot{\theta} - k_3 x - k_4\dot{x} + k_I\int (x_d - x)dt \quad (8)$$

The program calculates the required motor voltage but then must convert it into a value corresponding to the correct duty-cycle. Any dead-zone associated with the ESC must also be accounted for. The program calculates the change in the duty cycle register value required to obtain the motor voltage and places it in the corresponding duty-cycle register.

5.3 Direction Control

Initially, the same signal was applied to each speed controller. Due to differences in the electronic speed controllers, motors, and/or mechanical differences, the trajectory of the robot did not follow a straight line. This problem was corrected without remodeling the system; however, it would be ideal to derive a model in 3 dimensions to account for the direction of the cart. To account for this problem the difference in position between the two wheels is calculated during every loop. When the difference in position exceeds 1cm a small effort is applied to the lagging wheel by adding or subtracting 2 increments from the corresponding duty-cycle register. Choosing which wheel is boosted depends on the direction of the cart. As shown in Figure 13 if the cart is moving in the upwards direction, the left wheel is boosted by 2 increments. If the cart is moving in the downward direction, the right wheel is boosted.

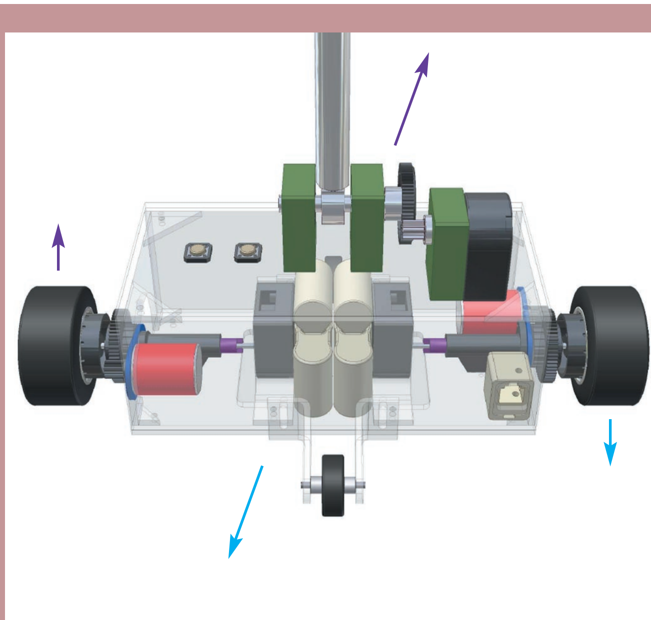

Fig. 13: Direction Control

Since the boost is not accounted for in the control system, it is important that its effect be as small as possible to avoid disturbing the desired control signal which could result in system failure.

6. Experimental Results

Although quantitative data was not available, the experimental results were observed to be similar to the simulations. The maximum capture range for the robot was observed to be approximately ±10°. For any greater disturbance, the cart can not change direction quickly enough to re-stabilize. This is due mainly, once again, to the lack of static friction required to overcome the momentum of the cart.

In practice the linear position of the cart tends to oscillate more so than in the simulations. We can see from the simulations that the linear position varies only slightly from the set-point. In practice, however, we notice that the cart will tend to oscillate about ±0.1m while stabilizing the pendulum about ±1°. When moving to a new set-point, we noticed that in practice it takes considerably longer for the cart to reach the new location, and with more oscillation. This oscillation was most likely caused by the backlash on the gears connected to the pendulum encoder. Inaccuracies in physical parameters of the dynamic model, for example changes in battery voltage, are also likely explanations for differences in simulations and experimental results.

The results obtained from the robot vary significantly depending on the value given for the time constant of the digital filters used in the filtered derivatives. A low value for the time constants would cause the robot to react faster to disturbances. This could intensify the problems with traction. If larger values were entered for the digital filters, the robot would react slower and more sluggish. This could lead to prolonged oscillation of the pendulum.

7. Conclusion

The goal of this project was to create a completely stand-alone, remote controlled, inverted pendulum balancing robot. State-space representation with a linear quadratic regulator control algorithm was used to determine the controller gains. The control system was implemented using a digital signal controller. To measure the linear positions and pendulum angle, three optical encoders with 2 dual quadrature counters were used. The drive-train utilized two programmable electronic speed controllers that powered two independent permanent magnet DC motors.

The physical model of the inverted pendulum on a cart was modeled in 2 dimensions using the Newton-Euler method. The non-linear model was used to develop a linear controller based on the linear approximated system equations. The linear control of the non-linear system was subsequently modeled and simulated using MATLAB.

The obtained model did not account for friction or non-linear performance of the electronic devices. The model only considered two dimensions which neglected turning of the robot. This could result in differences between the simulated and observed results. Due to the stand-alone nature of the robot it is difficult to send quantitative data to a computer to provide a comparison of actual and simulated results. Despite this problem, the observed system performance agreed qualitatively with the simulations. The robot is able to balance the pendulum and converge to a desired set point. The simulations also show the angle of the pendulum tends to oscillate indefinitely about its unstable equilibrium point, which is also observed in practice. The robot is able to correct for disturbances applied to the pendulum, and correct its orientation to a desired trajectory. A remote control was added to start and stop the robot, as well as increment and decrement its desired set-point.

The inverted pendulum stabilization problem has been extensively studied in control theory. As discussed, it clearly demonstrates the application of model based control on a nonlinear system, and allows the user or spectator to visualize the concept of a locally stable system, which is not always possible. Although there are no direct applications for the inverted pendulum, the motivation of this experiment was to implement a fully autonomous system that was small and lightweight. With technological improvements in batteries, motors, and embedded devices, autonomous robotics will also likely become smaller, lighter, while becoming increasingly robust and more sophisticated in its capabilities.

Acknowledgements

On behalf of all group members, we would like to extend this sincere thank you to the following people for all of their support and encouragement throughout the course of this project. Without their help this project would not have been possible.

- Dr. A. Tayebi - Project Supervisor
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- Yvon Leblanc - Mechanical drawing and Autodesk Inventor support
- Manfred Klein - Component supply and equipment support
- Bruce Misner - Component supply and equipment support

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About the Authors

Andrew Roberts, **Marc Kennedy**, and **Alex Nequest** completed the stand-alone inverted pendulum project while undergraduate students in electrical engineering at Lakehead University, located in Thunder Bay, Ontario. After completion of their degrees, the groups degree project was entered into the IEEE/Telus Innovation competition and were subsequently awarded 1st place and $10,000 CAD for their design. The group was also awarded the IEEE Life Member Award for the best student paper in Western Canada for a paper based on the project.

Currently, Alex Nequest is employed with Laipac Technologies in Richmond Hill, Ontario. Marc Kennedy is employed with Research In Motion in Waterloo, Ontario. Andrew Roberts is continuing at Lakehead University in the Master of Science in Control Engineering program, under the supervision of Dr. A. Tayebi. His current research and thesis focus are the stabilization and control of vertical take-off/landing unmanned airborne vehicles.

2005 IEEE Canada TELUS Innovation Award recipients, L-R: Andrew Roberts, Alex Nequest & Marc Kennedy, Lakehead U.; presented by Bill Kennedy, IEEE Canada Past-President & Ibrahim Gedeon, Chief Technology Officer, TELUS.

Tesla honoured with Niagara Falls monument

NIAGARA FALLS - When Nikola Tesla was a young boy in Serbia, he envisioned drawing power from Niagara Falls. Now, the inventor of alternating current has a permanent tribute overlooking the Horseshoe Falls: a monument unveiled September 3, 2006.

Members of St. George's Serbian Orthodox church have donated a bronze statue of Tesla, who has national hero status in his homeland1. They wanted to create a lasting tribute on the 150th anniversary of Tesla's July 10 birth. "He's someone the Serbian community feels has been, if not neglected, certainly overlooked throughout history," said Dushan Kolundzic, the president of St. George's church.

As a boy, Tesla saw a picture of the Horseshoe Falls in a travel book and told his uncle he wanted to put a wheel under the falls to harness the power of the moving water. The new statue stands at the same point where that photograph was taken. "Having him here at the Falls is extremely important, because it captures the complete circle," Kolundzic said.

The 2,000-pound statue shows Tesla in a long overcoat, carrying a top hat in his left hand. In his right hand, he's carrying a cane, depicting the moment he conceived of alternating current by drawing diagrams on the ground. He's standing atop an AC motor, one of the 700 inventions he patented. The motor is similar to the "Teslatron" statue in the Fallsview Casino's entrance, which also pays homage to the inventor.

The Tesla monument's total price tag could be $220,000 by the time the bills for a concrete foundation and landscaping come in, Kolundzic said. An international design competition led to more than 20 submissions; the judging committee liked one that came from Hamilton artist Les Drysdale. "The honour of being chosen to alter the landscape of the Niagara Parks is incredible. Who gets to do that?" said Drysdale.

Drysdale wore a T-shirt with Tesla's picture as "the man who powered the world," as he supervised the placement of the statue. The Niagara Parks Commission doesn't have many statues in Queen Victoria Park, but Tesla is a fitting addition, said Debbie Whitehouse, the executive director of parks. "The history of Niagara Parks and hydro-electricity are entwined together. You see that everywhere you go in the Niagara Parks."

Artist Les Drysdale, of Hamilton, created this monument to Nikola Tesla. It is in place at Queen Victoria Park. Photo courtesy of the Niagara Falls Review.

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Drysdale's statue captures Tesla's spirit, said Bill Auchterlonie, who led the church's statue committee. The inventor often appeared in photographs looking "serious, as if he was day-dreaming, look in his eye," Auchterlonie said. "He's got Tesla. You feel like your looking at Tesla. ... He may be standing on this generator. His mind is a million miles away."

Celebrating Tesla's accomplishment is a big deal not just for Serbian-Canadians, but back in his native land as well. A news crew from Serbia's national broadcaster was in Niagara Falls filming the statue's installation and its unveiling. Belgrade's airport is being renamed in Tesla's honour and the statue that finished second place in St. George's competition is being erected at the airport.

The IEEE hands out annually the IEEE Nikola Tesla Award to an individual or a team that have made outstanding contributions to the generation and utilization of electric power. Search for "Tesla" at http://www.ieee.org/ . Submission deadline is January 31st.

There have been four Tesla Awards given to Canadians in recent years: Gordon R. Slemon (U.Toronto, 1990), Thomas H. Barton (U.Calgary, 1992), Prabhashankar Kundur (Powertech Labs, Surrey, BC, 1997), Paul Dandeno (U.Toronto, 1998). The 2006 IEEE Tesla Award went to Konrad Reichert (ETH Zentrum, Zuerich, Switzerland).

To note: Nikola Tesla was awarded the IEEE Edison Medal (the AIEE Edison Medal at the time) in 1917. His acceptance of the award was surprising in view of the deep animosity between the two pioneers. The medal went missing after Tesla's death in 1943.

1 N.Ed. Nikola Tesla is claimed as a hero both by Croatia and Serbia; he was born in a minority ethnic serb village in Croatia. He is quoted has having claimed to be "equally proud of my Serb origin and my Croatian homeland". Both communities are, in return, equally proud of him.