51st AIAA Aerospace Sciences Meeting including the New Horizons Forum and Aerospace Exposition
07 - 10 January 2013, Grapevine (Dallas/Ft. Worth Region), Texas

AIAA 2013-0981

An Inexpensive Dynamic System for Teaching Measurement and Controls

Ann M. Wright[1]
Hendrix College, Conway, AR 72032

Andrew B. Wright[2]
University of Arkansas at Little Rock, Little Rock, AR 72204

The Control and Sensor System (CASSY) was designed to use primarily off the shelf hardware and to be an inexpensive platform that allows educational institutions to teach control theory. Fabrication and assembly guides were prepared and the resulting materials proved valuable in teaching undergraduate and graduate students basic fabrication, machining, and soldering skills. The platform consists of four independently driven wheels instrumented with encoders, inertial yaw rate measurement of the body, and bluetooth telemetry. Physics students from Hendrix College, a liberal arts college, and engineering students from University of Arkansas at Little Rock (UALR), a state sponsored university, used the guides to build several prototype CASSY robots and to explore autonomous programming, integration of new sensors, and other useful research skills.

I. Introduction

Dr. Ann Wright is a professor in the physics department of Hendrix College, a private liberal arts undergraduate college. She first introduced robotics into the curriculum in a Lego Mindstorms-based robotics course for non-science majors[1]. Dr. Andrew Wright is a mechanical engineer at the University of Arkansas at Little Rock (UALR) in the department of Systems Engineering. Together, they mentored a FIRST robotics competition team during 2000-2004. Dr. Andrew Wright incorporated robotic design into a UALR course called FIRST in Engineering: Elements of Mechanical Design[2]. While the Lego Mindstorm kits and the FIRST robots certainly allowed a nice introduction to robotics, the platforms had limitations in both the classroom and in the research lab. As a result, a new robot platform was created and successfully implemented at both schools. The goal of designing the Control and Sensor System (CASSY) was to create an inexpensive, but fully featured dynamic system. Such a system would be useful for education and could support research.

Fabrication guides similar to Lego Constructapedia (available at http://education.lego.com/en-us/preschool-and-school/secondary/11plus-machines-and-mechanisms/ constructopedia/) were prepared to allow collaborators to build a CASSY. These fabrication guides are available at http://robotics.ualr.edu.

In summer and fall 2010, independent study exercises with engineering students at UALR and physics students at Hendrix were offered. These exercises proved more valuable than expected, as the student response to the fabrication exercises developed surprisingly useful skills in the students. The fabrication exercise developed a detailed understanding of the robot in a way that reading manuals could not. The students were inspired to get started because the initial exercises were not intimidating. By the end of a semester, students had built basic skills that can be used to enhance research activities. The by-product for the instructor was a fully functioning mobile robotic platform which can be used to carry on educational and research activities.

The students reported that this exercise gave them a feeling of being a real robot engineer. It augments an engineer's training (especially if the student has been theoretically trained) and helps physics students prepare for engineering graduate school. These activities are also very useful in the recruiting and retention of students.

The platform has enough expandability that it offers flexibility to explore many different types of problems that lead the student to conducting introductory research.

[1] Associate Professor, Physics Department, 1600 Washington Ave. Conway AR 72032, AIAA Member.
[2] Associate Professor, Department of Systems Engineering, 2801 S. University Ave., Little Rock, AR 72204.

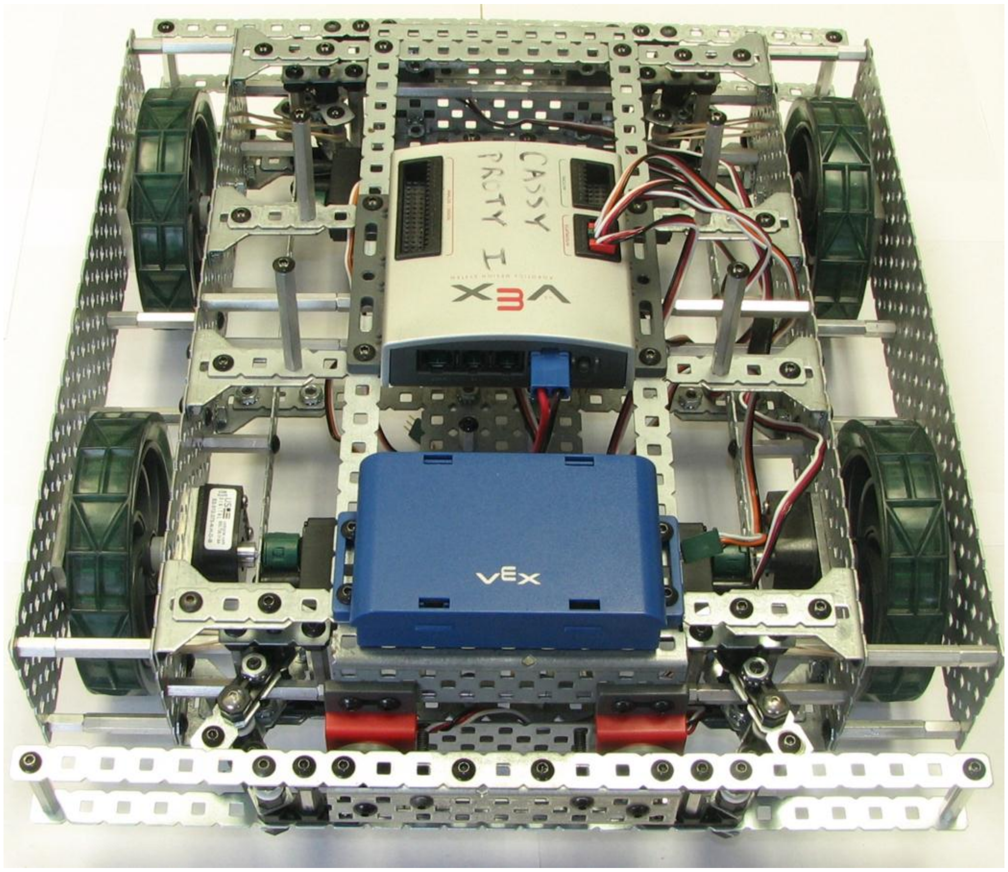

Figure 1. Assembled CASSY platform.

II. Control and Sensor System (CASSY) Platform

The basic mobility platform (see Figure 1) is made from Vex mechanical parts[3] and the Vex PIC18F8520 microcontroller, running a 55 Hz real time control loop. The finished dimensions are 33 cm (13 in.) wide by 41 cm (16 in.) long by 10 cm (4 in.) tall. CASSY has four independently driven wheels, the front two of which are instrumented with HEDS 100 counts per revolution quadrature encoders[4]. A custom-designed timing measurement algorithm combines the two signals to give a velocity signal in the direction of travel. Currently, the cost of all materials to build a complete CASSY is approximately $1500, which is far less than most commercially available robots or robot kits. In fact, it is inexpensive enough that most schools could afford to build more than one, which would open up programming opportunities to include cooperative behaviors or allow for student competitions or use in student lab classes.

A novel six-bar bumper design allows the right and left bumper switches to be independently toggled, when the bumper contacts a rigid obstacle on either the right or left of the CASSY. The bumper sensor outputs can give an indication as to the location of contact which can inform an autonomous algorithm to resolve the collision.

A custom circuit board (see Figure 2), mounted on a Radio Shack printed circuit board, uses a layout that is identical to standard solder-less bread-board, which allows bread-boarded prototype circuits to be directly transferred to soldered connections. The circuit board contains an Analog Devices ADXRS613 inertial yaw rate sensor[5] aligned with the turning axis. A Roving Networks-based Bluetooth serial port on the custom circuit board gives wireless telemetry to the host computer with a Bluetooth connection.

The chassis has room for a second custom circuit board and there is resource expansion for at least one additional mechanical module or sensor module containing perhaps one additional motor and encoder.

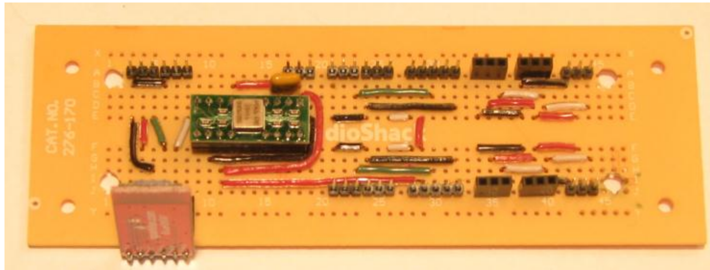

Figure 2. Custom circuit board.

The encoder interface requires custom parts to be machined to adapt between the Vex component constraints and the encoder constraints (see Figure 3). It was discovered that the Vex Delrin bearings provided too much nonlinearity and a custom roller-bearing design was developed to occupy the same foot-print as the Delrin bearings.

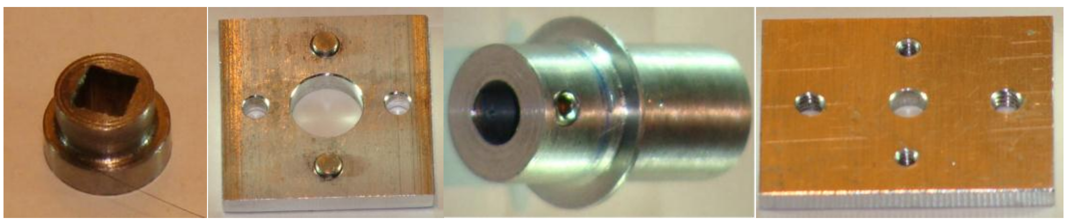

Figure 3. Custom machined parts for CASSY.

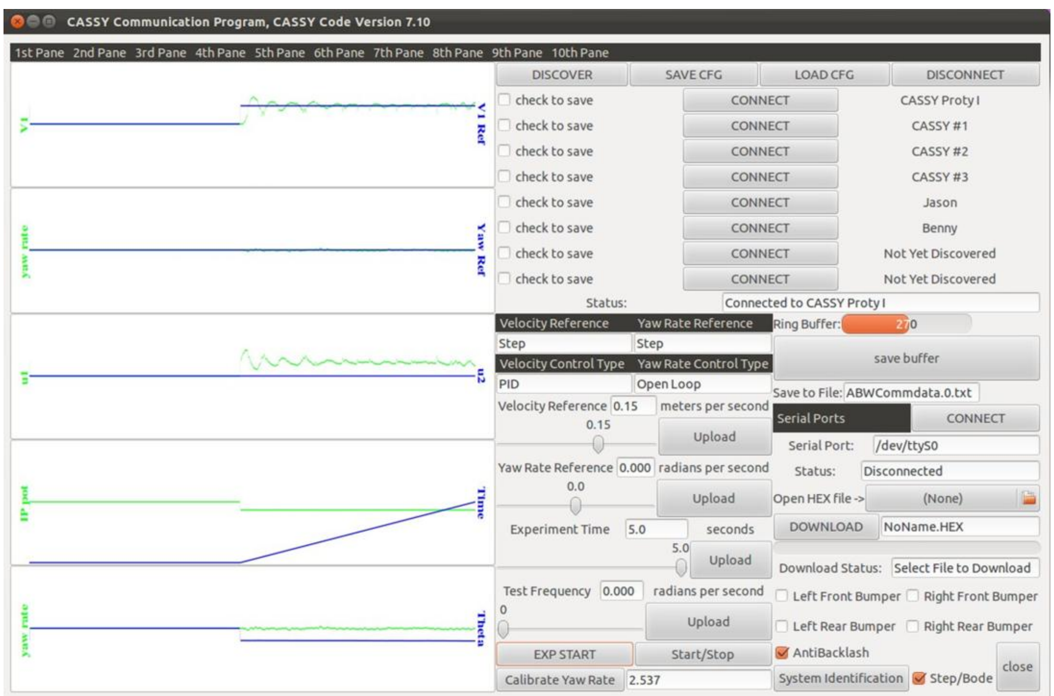

Figure 4. Custom GUI (ABWComm4) to communicate with CASSY over Bluetooth.

The robot can be programmed using Microchip's proprietary MPLAB integrated development environment; however, that can be superseded by the open-source Small Device Compiler (sdcc). A custom linux-based GUI program (see Figure 4) was designed to communicate with CASSY. This program includes a downloader to load user code onto CASSY. This program can stream up to ten channels of data in real-time from the CASSY over the Bluetooth connection.

III. Results

A. Independent Study Courses

1. Hendrix College (4 year liberal arts undergraduate physics program)

Dr. Ann Wright used the CASSY fabrication materials in five independent study courses from Spring 2010 through Fall 2012. The first group of three students assembled Hendrix's first CASSY and provided clarifications to the guides. In the second offering, one student disassembled the CASSY, squared the frame using fixtures, supplied data on mass of subassembly parts (to ensure identical physical properties among several CASSY robots working together for future projects) and machined a set of custom parts (see Figure 3) under direction of Hendrix's lab manager. The third course involved two students who adapted the Vexlabs default program to function with the different motor configuration on CASSY and added remote control functions. The fourth independent study involved one student who programmed response to the bump sensors, light sensors, and added basic autonomous functions. In the Fall of 2012, two students machined parts in preparation for construction of a second CASSY and continued adding sensor control algorithms. Figure 5 depicts Cason Morse, a senior Hendrix physics major, working on programming the CASSY light sensor array.

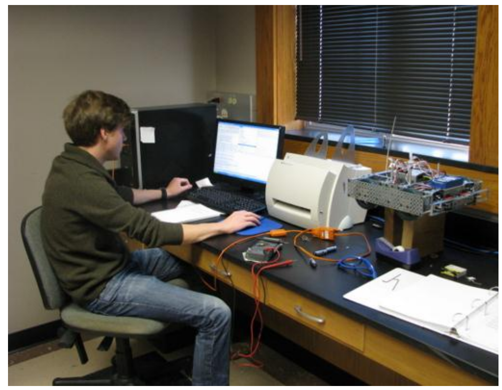

Figure 5. Hendrix student programming a CASSY.

The students at Hendrix who participated in these courses were all physics majors who were interested in graduate study in engineering. They were motivated to learn basic engineering skills such as reading and producing measured engineering drawings, basic machining skills on a mill and lathe, basic soldering skills and electronic circuit board fabrication and debugging, and basic programming skills. Some of the students were sophomores, with only General Physics I and II completed. More mature students had also completed courses in Classical Mechanics and Electronics. Each type of student learned valuable skills and research experience that helped guide their future decisions regarding career paths and future education.

2. University of Arkansas at Little Rock (state-supported doctoral engineering institution)

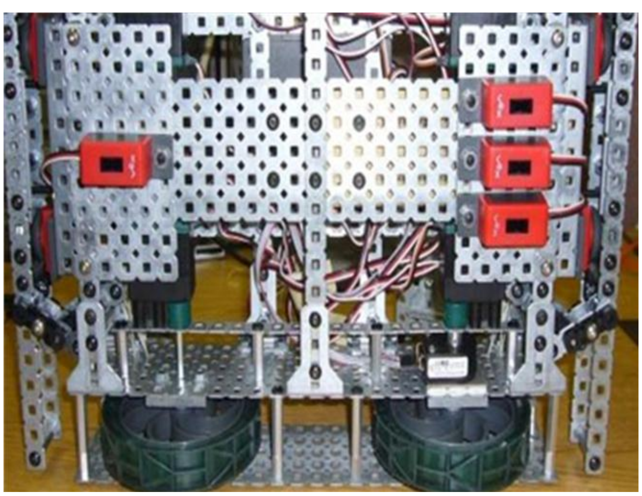

Figure 6 Placement of light sensors.

In summer 2010, under Dr. Andrew Wright's supervision, a first year graduate student fabricated a CASSY and helped to debug the fabrication manuals. He manufactured all custom parts, made all cuts and measurements, and assembled the CASSY, custom circuit board, in about three full man-weeks. The graduate student used the prototype in his research to develop an acoustic range-and-identity detection circuit.

In Spring 2012, a senior level engineering student assembled a CASSY (custom parts were supplied) and developed a light sensor attachment (see Figure 6) and a basic measurement on detecting a line. The CASSY platform allowed the student to set a known speed in the robot and drive it over a line of known thickness. The easy integration of sensors and easy measurement of these sensors allowed the student to quickly capture the behavior of the sensors with different angular approaches to the line.

In Spring 2012, a class of senior level control systems students used the CASSY robot to study control problems. In particular, the students varied PID constants to study underdamped and overdamped behavior and to determine margins for stability. The robot platform was much more effective in getting students into the lab than previous mechanisms (e.g., spring-mass-damper). The practical implementation of control algorithms greatly enhanced the learning of the theoretical material.

In Fall 2012, Dr. Andrew Wright used the CASSY bearing adapter parts as a means of refreshing students' fabrication skills in preparation for designing their project in the course called Elements of Design. The deceptively simple parts proved to be an accessible introduction to basic mill and lathe operations. However, the tight tolerances due to bearing fits and alignment required students to take their basic skills to a new level. By the time the students completed this assignment, they had refreshed their basic machine skills, learned to read a micrometer, and were exposed to a double bearing shaft support design example. As an added bonus, a complete set of CASSY parts were machined for future research projects.

B. Student Skill Development

Several key values were observed to develop among all of the students engaged in this project. The undergraduate students had few practical skills in the beginning and could only devote about 2-4 hours per week to the project during an academic semester. However, the fabrication guides provide enough information that a student can construct a functioning robot with this work-load and this time frame. There was usually enough time left over that the student could accomplish an additional task beyond the basic fabrication.

Students develop basic soldering, measurement, and assembly skills through building and testing the custom circuit. They develop basic mechanical fabrication and assembly skills through the assembly of the CASSY platform. At each step in the mechanical fabrication, measurements, such as weighing the result and comparing against known values, give the student valuable touch points to verify success. With basic machining equipment and instruction, students can fabricate the custom parts required for the encoder and wheel bearing support, although the true novice may take an additional semester and produce a fair amount of scrap. If a basic machine shop is not available at a school, then the custom parts can be made at a professional shop for a small fee.

Students are able to implement, hone, or develop programming skills by using and modifying existing control codes. Students were very motivated to learn programming in order to make their robot perform a task. They had instant feedback on the code's accuracy because the robot would either perform the task or not. Wireless telemetry between the CASSY and the host computer familiarize students with basic data collection and analysis functions.

For the advanced student studying engineering control systems, a robot is an ideal test platform. A mobile robot has a first order velocity loop and yaw rate loop, with weak coupling between the loops if both are active simultaneously. The gear system contains back-lash and the yaw rate loop is dominated by Coulomb friction. With the addition of an inverted pendulum, the first-order velocity loop can be converted to a third-order system with an unstable pole. The yaw rate loop can be converted to a second order system by integrating the yaw rate signal and controlling angular position. Such a system gives the control system designer access to many simple and difficult control problems, allowing the development and explanation of most of the available control algorithms.

IV. Conclusion

A basic mobility platform and fabrication guides have been used in a number of independent studies and a few controls courses. This robot project brings students into the process and allows them to complete a full fabrication in a semester with minimal supervision. The CASSY robot is inexpensive enough for most schools to build a small fleet. It is small enough to make construction and testing easy and fun and does not require large amounts of space to operate. The CASSY platform has proved to be an excellent teaching tool, a robust research platform, and a fun introduction into the world of engineering.

References

[1] Wright, A. M., Ferrer, G., "A Liberal Arts Approach to Teaching Robotics," *ASEE Annual Conference Proceedings*, Nashville, TN, 2003-1236.

[2] Wright, A. B., Wright, A. M., "FIRST in Engineering: Elements of Mechanical Design," *ASEE Annual Conference Proceedings*, Nashville, TN, 2003-1604.

[3] Vex Robotics, [Online]. Available: http://vexlabs.com.

[4] US Digital, [Online]. Available: http://www.usdigital.com.

[5] Analog Devices, [Online]. Available: http://www.analog.com.