Undergraduate Mechatronics Couse Design Project

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Abstract

There is a real need to educate our engineering students in the application of electronics, controls, mechanics, and software; this multidisciplinary initiative has led to the creation of an undergraduate *Mechatronics* courses at the United States Military Academy (USMA) and many other universities around the world. The focus of these courses is to emphasize application and hands on laboratory work in general, and design projects in particular. This paper presents an example of an open-ended autonomous unmanned ground vehicle (AUGV) project that has been developed in support of the undergraduate mechatronics course at USMA. This is a one-semester course that culminates in a project that occupies the student's in class, laboratory, and at home assignments for the last five weeks of the quarter. The paper will present the design, development and pedagogy of the project.

I. Introduction

Robotics is a new track developed in the Electrical Engineering and Computer Science Department at the United States Military Academy. The track is offering a new culminating course *Mechatronics*. The course is also the foundation of the Mechanical Engineering Robotics track. The goal of this course is to produce engineers capable of successfully applying theoretical classes to the design of *Mechatronic* systems. The key element of mechatronics is the integration of electrical engineering, mechanical engineering, control theory, and computer science throughout the design process[6]. The purpose of this is to create students who can function on multidisciplinary teams developing advanced technological solutions. We accomplished this by creating an open ended project and allowing students to come up with their own solutions. The benefits of doing this are to spark creativity by designing an engineering solution to a complex real world problem, and to develop teamwork on a multidisciplinary team.

This experience is particularly important for cadets at the United States Military Academy, because in 2000 Congress ordered that a third of the ground vehicles in the military must become robotic by 2015[10]. Currently many robots are being used in Afghanistan and Iraq. In 2000, The number of robots in Afghanistan and Iraq has grown significantly from 150 in 2004 to over 4,000 in 2006. This is still far from the 2015 goal, but a better understanding of robotics will benefit future Army Officers.

II. Background

There are various universities that have offered mechatronics courses in their programs with almost all incorporating some form of design project. Some universities offering mechatronics undergraduate programs are Stanford University[5], University of Detroit Mercy[7], Drexel University[8], University of Washington[9], Georgia Tech[11] and Rensselaer Polytechnic Institute[6]. There are also some graduate only programs in mechatronics for example Brigham Young University[3]. The Stanford University project has the goal of the autonomous vehicle being able to make a basket on a 4 foot by 8 foot playing field[5]. The University of Detroit Mercy project uses a toddler robot kit with ultrasonic and bump sensors to avoid obstacles and to stay on a table top[7]. Drexel University project uses an industrial robot arm remotely controlled via the internet[8]. The University of Washington had three different projects: Shaft Dynamometer for a Human-Powered Submarine, Onboard Automotive Dynamometer, and Force Distribution Measurement of Snow Skis[9]. Georgia Tech has five different design projects: 3-axis milling machine, autonomous following vehicle, automated coffee bean sorter, an input shaper for a gantry crane and an intelligent baby monitor[11]. Rensselaer Polytechnic Institute has four different design projects: Ball on Beam Balancing System, Ball on Plate Balancing System, Inverted Pendulum Systems: Rotary and Arm-Driven, and Hydraulically-Balanced Beam System[6]. Brigham Young University AUGV has a year long graduate research project using a full Linux based microcontroller, WiFi 802.11b wireless communications, and a variety of sensors for situational awareness[3]. This added complexity makes sense for their graduate students given the amount of time available for this project.

Our project is similar given that the teams are of diverse student backgrounds using available technology. The difference is in the difficulty of the approach. Brigham Young University has a year long graduate course for the development of their autonomous vehicle verses ours using only the last five weeks of a one semester course. The complexity of the microcontroller is also a significant difference between ours and the Brigham Young University vehicle. They use a full computer microcontroller running Linux verses our BASIC Stamp 2 microcontroller which is programmed in PBASIC. This also makes programming our vehicle less complex. However, we introduce to our students how to implement analog controllers as well as using direct digital controllers, which is not implemented in any other autonomous vehicle programs.

III. Approach

The AUGV project at USMA is a multidisciplinary activity with electrical engineering and mechanical engineering curriculum. Figure 1 shows the course map. This paper focuses on the Autonomous Vehicle block. The design project consists of building an autonomous vehicle which will

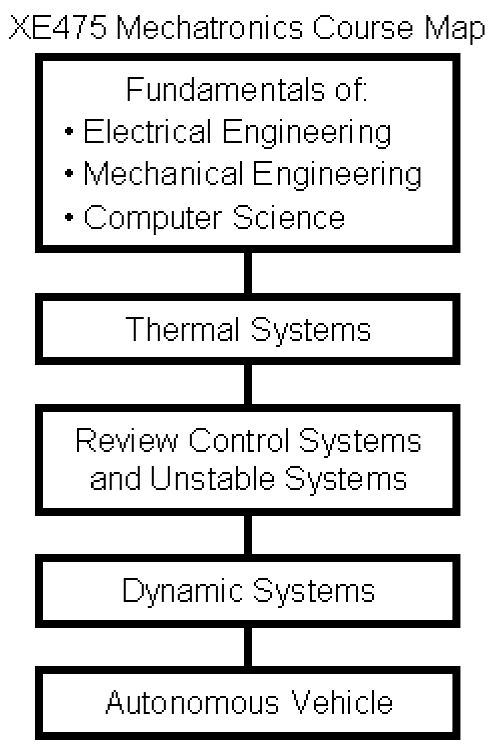

Figure 1 Course Map

incorporate applied knowledge of robotics. In an introductory mechatronics course, there needs to be a design project which allows students to apply these concepts in a meaningful way. This is done during the last five weeks of the semester by inductive learning. Inductive learning requires structure and slow withdrawal of support. In this design project, the foundation has been laid to systematically remove support, and the students are still mentored through a five phase design process: build, characterize, model, design, and test phase. The last five weeks of the course focuses on the AUGV project specifically measuring autonomous vehicle physical parameters and finally AUGV qualification. At the beginning of this block of instruction, an autonomous vehicle demonstration of the vehicle qualification is shown to the students. The autonomous vehicle uses a radio controlled truck chassis with motor and steering servos as a base, Parallax Servo Controller, BASIC Stamp 2 microcontroller, ultrasonic sensors, and Bluetooth communications.

Inductive learning is a broad term for project based learning. The project is assigned during the last five weeks and most of the course lessons are left for the students to work in their groups. There is a lesson on sensor integration during this time. The groups are responsible for task organizing their work, and students are individually held responsible for their accomplishments. The students individual accomplishments are based on their lab notebooks, homework, oral exam, presentation of their project and demonstration. The focus is on the project results. The project is an open ended autonomous vehicle project.

We constructed the autonomous vehicle using a Traxxis Emaxx remote control truck as the base with upgraded shocks to accommodate the extra platform weight, which included the motor controller, steering servo and motors. This portion is powered by two 7.2 V 3800mAH batteries. We used a Parallax BASIC Stamp 2 microcontroller, which has 13 registers capable of holding 13 word size variables with a word being 16 bits. This was on a Board of Education Development Board, which had 15 digital input and output ports. To overcome this limitation, we added a Parallax Servo Controller which would control the motor controller, gear shift, steering servo, front and back sensor servos, because the PWM signal off the original Board of Education Development Board did not activate the Traxxis Emaxx motor controller at slower speeds for example 3 mph. We used four “Parallax Ping)))” Ultrasonic Sensors to give the vehicle 360 degree feedback for situational awareness. The front and back sensors are mounted on servos allowing for scanning the front and rear of the vehicle. We also mounted a Bluetooth module for communication with a nearby laptop using hyperterminal. This communications was used for datalogging the vehicles distance from all four ultrasonic sensors which were accurate up to 1.8m. A picture of the constructed vehicle is in figure 2.

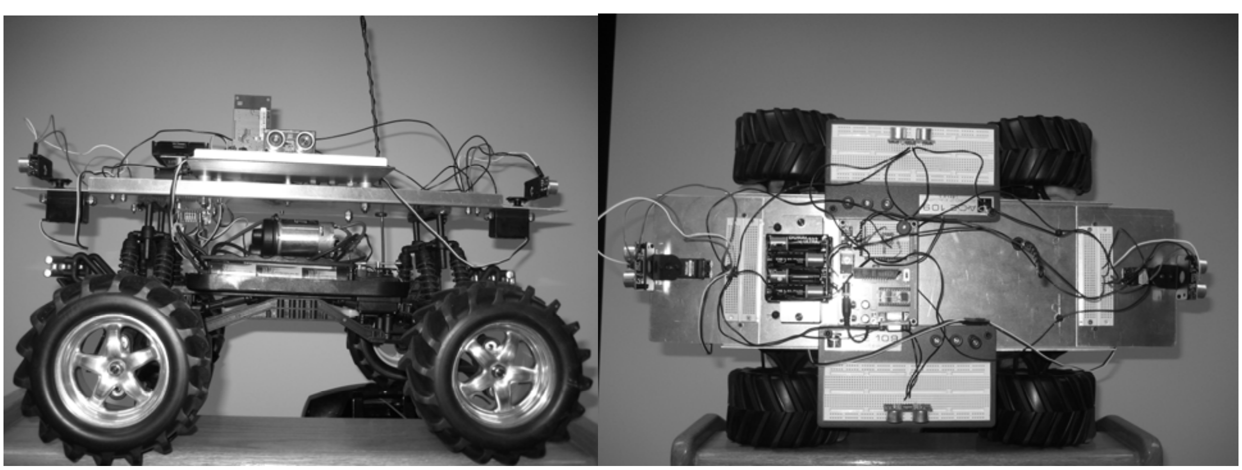

Figure 2 side and top view of autonomous vehicle.

The ultrasonic sensors work by sending a 40 kHz sound wave and measuring the time that it takes to return to the sensor. This time is converted into distance by calculating the speed of sound which is temperature dependant. The sensors and Board of Education Development Board are powered by four AA batteries, and the Parallax Servo Controller are powered by another four AA batteries. The microcontroller is programmed in PBASIC which determines the vehicles actions based on distances from the vehicle.

A step input is used along the wall to trigger the vehicle to respond to the change in terrain. This response will be used to create a second order response curve to be used to characterize and build a mathematical model for the system. After cadets build a math model of the system they will design a controller to reduce settling time of the system and they will simulate their designs in Matlab and test it on the actual platform. This can be greatly improved by incorporating a controller to improve transient response. The cadets will use the five step design process: build, characterize, model, design, and test to design the controller.

IV. Results and Discussion

The autonomous vehicle performed as expected to a settling time of approximately 60 seconds. Figure 3 below shows the sensor reading from the vehicle in cm from the wall verses time. The dashed thin gray line is the raw sensor data. The thick blue curve shows curve-fitted ultrasonic sensor feedback. This was done to remove sensor noise and distortion.

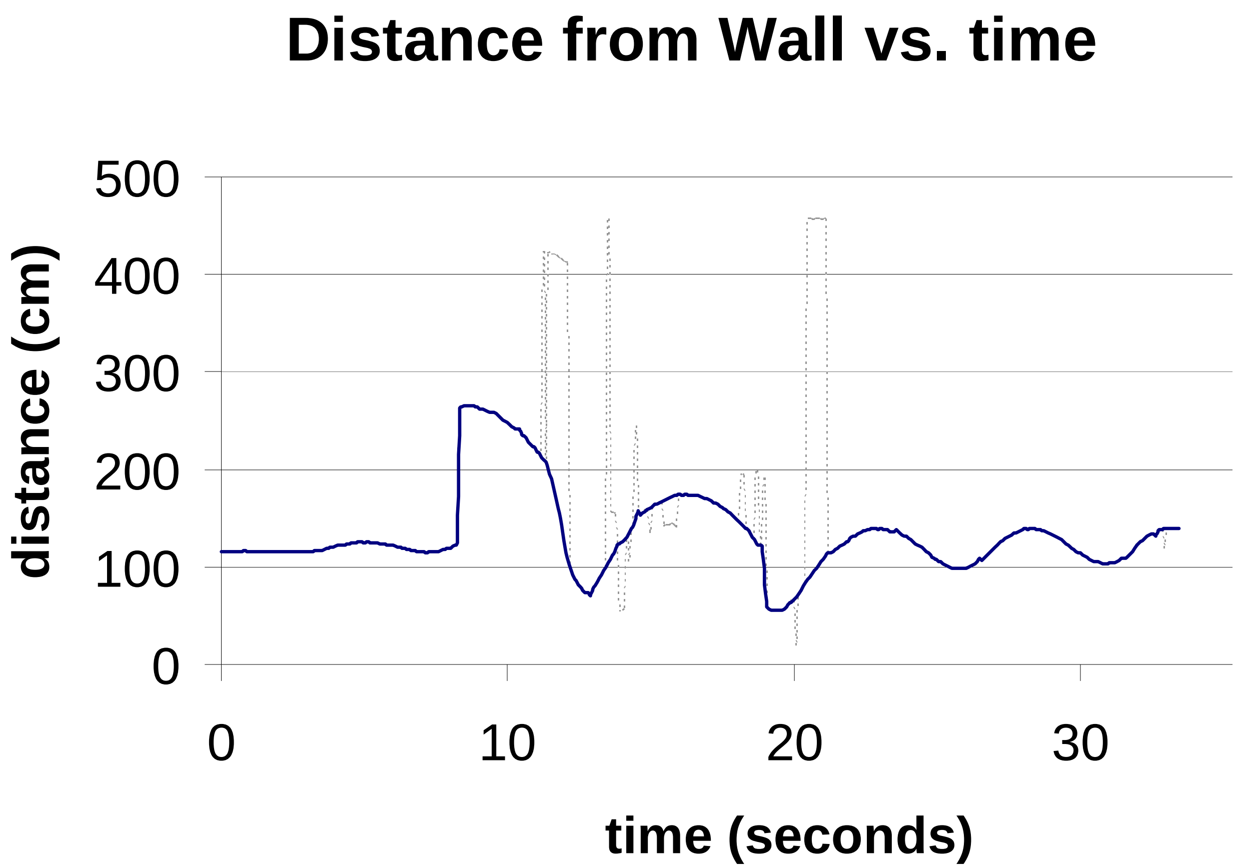

Figure 3 is a graph of vehicle distance in cm from wall verses time during Qualification Course Run

Figure 3 shows that for the first eight seconds the autonomous vehicle can hold a relatively straight line prior to the disturbance. There is a lot of noise when the autonomous vehicle makes the initial right hand turn to reacquire the wall. At 13 seconds the autonomous vehicle is again perpendicular to the wall and begins getting very accurate readings of the distance between the vehicle and the wall in cm. There is some noise in the data that could be reduced by averaging the distance results from the ultrasonic sensors. The next peak occurs at 16 seconds at 160 cm from the wall, and a minimum distance of 60cm at 19 seconds. The next peak occurs at 23 seconds at 139 cm. The oscillations continue to get smaller trying to reach steady state of 120cm from the wall. The period of oscillation typically took 7 seconds. This could be readily reproduced by the cadet teams to characterize the system and produce a mathematical model and design a controller for this system.

V. Future Work

There are many possible future work opportunities with this unmanned ground platform. An interesting experiment is to have multidisciplinary teams design a homogeneous or heterogeneous team of autonomous robotic platforms. This would incorporate concepts of cooperative robotics, allow multiple platforms to work together, and have cadets start looking at some of the relevant current research. Another avenue of approach is to look at convoying these autonomous platforms or applying algorithms to implement simultaneous localization and mapping. These platforms could also be test beds for various non linear state space controllers or digital controllers. These concepts are more complex and it may take more effort and time to develop robust experiments in these areas. Regardless whether the cadets pursue a career in the military, graduate degree, or work in industry; mechatronic systems will be prevalent in their future.

VI. Conclusion

This lab will be implemented this semester for the first time and the cadets seem to be enthused about it. Also, it gives them the hands on edge over their peers of handling and designing a electro mechanical autonomous system controller. There are also many advantageous and classroom assessment that could be developed from this lab at a later stage. The benefits of combining applied engineering and math, designing and creative analysis, learning through hands on and interacting between different disciplines as well as enthusiasm among students and faculty alike, they sustain goals sought by the different disciplines as well as the vision of the robotics program itself. The steps profiled in this report can be mirrored elsewhere to facilitate real world collaboration between equipment manufacturers and academia. Moreover, given the increasing need for robotics in real world applications; interesting robotics projects provide: focus in robotics curricula and more interest in science and engineering.

Bibliography

[1]Detect Distance with the Ping))) Sensor.pdf available at http://www.parallax.com/Store/Sensors/ObjectDetection/tabid/176/CategoryID/51/List/0/Level/a/ProductID/92/Default.aspx?SortField=ProductName%2cProductName

[2]Lindsay, Andy, Robotics with the Boe Bot version 2.2,

[3]Hoopes, Dan, Davis, Tyler, Norman, Kelly and Helps, Richard, An Autonomous Mobile Robot Development Platform for Teaching a Graduate Level Mechatronics Course, 33rd ASEE/IEEE Frontiers in Education Conference, Boulder, CO, 5-8 November 2003

[4]Prince, Michael J. and Felder, Richard M., Inductive Teaching and Learning Methods: Definitions, Comparisons and Research Bases, Journal of Engineering Education, April 2006

[5] Carryer, J. Edward, March madness: a mechatronics project theme, Mechatronics volume 12 issue 2, p.383-391, March 2002
[6] Craig K. Mechatronics at Rensselaer: a two-course senior-elective sequence in Mechanical Engineering. In: Proceedings of the 1999 IEEE/ASME International Conference on Advanced Intelligent Mechatronics, 19–23 September 1999. Atlanta, USA.
[7] Das, S.; Krishnan, M.; Yost, S.A.; Work in progress - the outgrowth of mechatronics curriculum development efforts: an undergraduate concentration in mechatronics, Frontiers in Education, 2005. FIE '05. Proceedings 35th Annual Conference 19-22 Oct. 2005 Page(s):F3F - 7-8
[8] V. Genis, W. Rosen, R. Chiou, W. Danley, J. Milbrandt, G. Marekova, S. Racz, T. Kitchener, and B. LaVay, Laboratory- and Project-Based Courses in the Engineering Technology Curriculum, Philadelphia, PA Fall proceeding of ASEE Mid Hudson Section 2007
[9] Murray, W.R.; Garbini, J.L.; Mechatronics capstone design projects at the University of Washington, Advanced Intelligent Mechatronics, 1999. Proceedings. 1999 IEEE/ASME International Conference on 19-23 Sept. 1999 Page(s):598 - 604
[10] Weiner , Tim, New Model Army Soldier Rolls Closer to Battle, NY Times Technology, Published: February 16, 2005
[11] Charles F. Bergh, Akio Kita, I. Charles Ume, Development of Mechatronics Course in the School of Mechanical Engineering at Georgia Tech, Proceedings of the 1999 EEUASME International Conference on Advanced Intelligent Mechatronics, September 19-23, 1999 Atlanta, USA

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