Table-Top Robotics for Engineering Design

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Abstract

The Mechanical Engineering Section at the U.S. Coast Guard Academy has developed a comprehensive activity based course to introduce second year students to mechanical engineering design. The culminating design activity for the course requires students to design, construct and test robotic devices that complete engineering challenges. Teams of students are provided with a standard kit of parts consisting of metal hardware and fasteners, motors, connecting wires and a programmable remote control system. The teams use these materials to design and construct robotic devices that accomplish a simulated maritime mission. The kit of parts is reusable and requires no machine-shop support to create the robotic devices, thereby making this project portable and scalable. The experience is modeled on the capstone design activity and is a useful tool for introducing engineering design to a wide audience.

Introduction

Providing engineering undergraduates with a sound introduction to the fundamental tools for success in their major continues to be a challenge for educators. Engineering educators have been reminded of the need to strengthen this aspect of the curriculum in numerous studies and by the very standards that are used to accredit our programs. For design education to be effective, design tools must be introduced early in the curriculum, reinforced in fundamentals courses, and demonstrated in capstone projects[1].

At the U.S. Coast Guard Academy a sophomore level course Introduction to Mechanical Engineering Design has been developed to provide students with an introduction to fundamental topics that will be applied in upper-division courses. These topics include the engineering design process, engineering economics, risk based decision-making, engineering ethics, and solid modeling. In addition to these topics, experience is gained in working in teams and using shop tools and equipment. The course consists of two hours of lecture and three hours of laboratory work each week of the 16-week semester. The typical class size is 24 students with lab sections of 12 students.

Three major activities are used as lab projects associated with this course. Solid modeling and an introduction to machining tools and techniques occupy two-thirds of the lab[2]. A table-top robotics project is used to practice engineering design for the last third of the semester. During the design segment of the course, lectures introduce an engineering design process consisting of establishing a need, developing a concept, refining prototypes and producing a detailed design[3]. Students in the course are challenged to apply the design process to solve a small engineering design problem: given a set of mechanical and electrical components, create a solution to accomplish a task.

In this case, the components are the Robotics Rapid Prototyping Kit produced by Innovation First, Inc. The kit includes the mechanical, electrical and control components for building remotely controlled electro-mechanical systems. This paper describes how this kit is used in a design activity in the U.S. Coast Guard Academy course Introduction to Mechanical Engineering Design.

The Challenge of Design

Theodore von Karman eloquently described the engineering profession as: "Scientists study the world as it is, engineers create the world that never has been." It is widely accepted that design education and design practice are of paramount importance in the engineering curriculum. However, incorporating design in the curriculum can be a significant challenge.

Design problems must be realistic, open-ended and have more than one solution. For design to be a successful component of the undergraduate curriculum, design problems must have an achievable solution and often must be solved in a short period of time. Many engineering educators incorporate mechanical engineering design in the curriculum and robotic applications are a popular and captivating method [4, 5, 6, 7, 8].

The U.S. Coast Guard Academy Mechanical Engineering Section has used robotics as a design application for nearly a decade. Our robotics experience ranges from designing and executing engineering outreach activities for high school seniors to capstone projects. We have been using table-top robotics in our Introduction to Mechanical Engineering Design course since 2001 and have found this method to be an effective design education tool.

Kit of Parts: System Components

Each design team is provided with a kit of parts that consists of mechanical hardware, electrical and electronics components, and the remote control system for creating and building small robotic devices. Documentation is provided for the mechanical, electrical and software components of the kit. The materials are reusable with minimum replacement parts needed each semester. Figure one illustrates a simple device constructed from the kit.

The mechanical components, displayed in figure two, consist of metal structural members such as bars, brackets, shafts, bearings, pivots, gussets, standoffs,

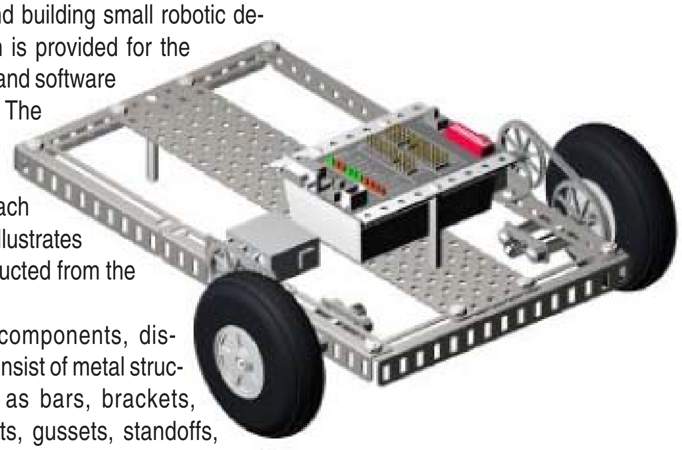


Figure One – Drive system created with the kit.

collars and fasteners. In addition to the structural members, sprockets, plastic chain, shafts, and an assortment of wheels are included in the kit.

The mechanical components are durable and compatible with one another. The structural members are raw material from which lengths can be cut and formed to create specific shapes. Each metal component is fabricated with connections that align with motor mounts and other kit pieces. Square stock is used for motor shafts and transfer power to the sprockets and wheels.

The electrical components include modified servomotors that can be proportionally controlled or relay operated and limit switches (figure three). The servos are capable of full and repeated rotation similar to any DC motor. The system uses a 7.2 Volt rechargeable battery and a charger provides power while bench-testing designs.

The operator interface and robot controller, illustrated in figure four, are the communication and control platforms. These units enable the completed designs to be remotely controlled with computer joysticks, push buttons and user programmed analog signals. In addition, the robot controller can be programmed to operate in autonomous mode and respond to sensor inputs on the robot controller.

The operator interface transfers input from the robot operators and relays those signals to the robot controller using a 900 MHz radio signal. Simultaneous operation of multiple systems is achieved using dipswitches on each unit to allow unique communication between the operating unit and its interface. The operator interface has 16 digital inputs (switches) and 16 analog inputs (such as potentiometers or other sensors). Information is transferred between the operator interface and the robot controller, and the operator interface displays the condition of PWM outputs, relays and battery voltage of the robot controller. The robot controller, illustrated in figure four, contains an internal antenna and a controllable microprocessor.

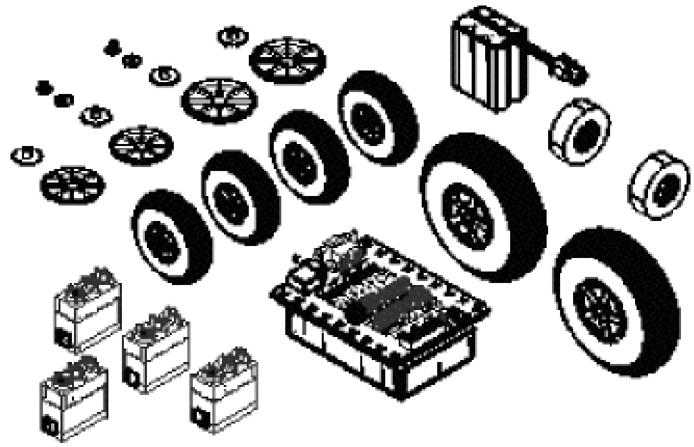


Figure Two – Mechanical components of the kit.

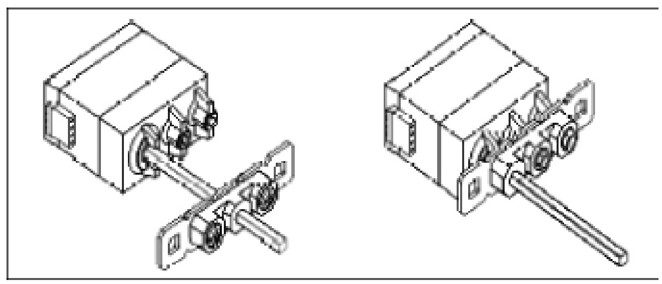
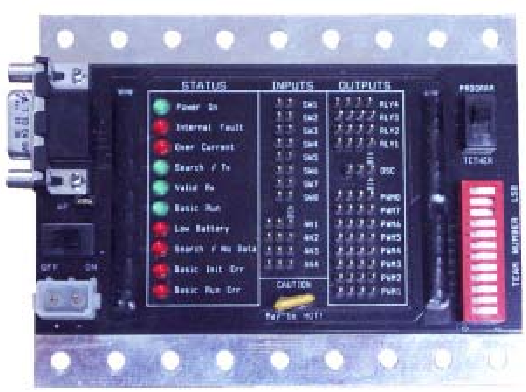


Figure Three – Compatibility of system components.



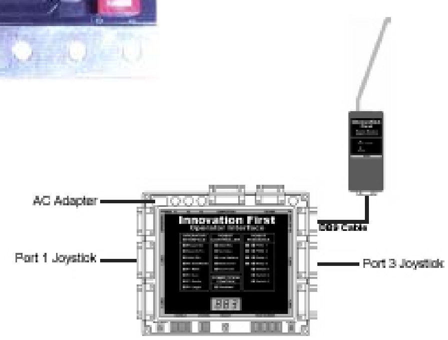


Figure Four –Robot controller and operator interface.

The robot controller is electrically and mechanically compatible with the other components in the kit, as illustrated in figure one where the controller is an integral part of the design. The robot controller receives information from the operator interface, collects on-board sensors data, and processes the signals to determine robot functions. The robot controller uses Parallax microprocessors and is programed using a derivative of the BASIC programming language. Default code allows the system to be used without programming (figure five).

The robot controller has 8 PWM outputs for proportional control and 4 relay outputs for on-off control. There are 8 digital inputs and 4 analog inputs on the robot controller. Limit switches can be used (digital input) to prevent motor operation when interference is detected and the default program contains coding to enable this function. Sensors such as rotational potentiometers can be used to measure wheel rotations, with the coding developed to enact specific functions when ranges are reached.

Design Application

At the U.S. Coast Guard Academy these kits are used a competition based design activity modeled after the FIRST Robotics Competition where teams of students and engineers build sophisticated robots to play mechanical sports (www.usfirst.org). In the Academy's Introduction to Mechanical Engineering Design course, teams of five students are tasked with building a robotic device to solve a series of missions.

The game scenario, executed on an 8'x8' playing surface, is based on restoring operations for a shipping channel following a hurricane. In this scenario each team designs a vehicle (i.e. a Coast Guard Buoy Tender) to rescue passengers from a sinking ship, remove debris from a channel, place a containment boom around a sinking ship leaking oil, and service channel buoys. The number of missions accomplished during four-minute matches is one measure of the team's performance for the activity.

One design solution is presented in figure six. The design uses two servomotors for direct drive propulsion. The front of the device has a flap that is controlled by the operator to deploy an oil containment boom on the playing field. This flap can also be used to retrieve objects from the playing field. A limit switch prevents damage to the servomotor when the flap contacts the robot frame. The ramp on the side of the robot is a conveyor that deposits batteries to the buoys used on the playing field.

While class lectures present the design methodology, the design sequence is applied in the lab,

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'———— Buttons to Relays————————————————————————————————————————
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'—————————————————————————————————————————————————————————————
————-
' This maps the joystick buttons to specific relay outputs.  Relays 1 and 2
' use limit switches to stop the movement in one direction.
' The &  used below is the PBASIC symbol for AND
' The &~ used below is the PBASIC symbol for AND NOT

relay1_fwd = p1_sw_trig &~ rc_sw1      'Port 1 Trigger = Relay 1 Forward, unless rc_sw1 is ON
relay1_rev = p1_sw_top  &~ rc_sw2      'Port 1 Thumb   = Relay 1 Reverse, unless rc_sw2 is ON
relay2_fwd = p2_sw_trig &~ rc_sw3      'Port 2 Trigger = Relay 2 Forward, unless rc_sw3 is ON
relay2_rev = p2_sw_top  &~ rc_sw4      'Port 2 Thumb   = Relay 2 Reverse, unless rc_sw4 is ON

relay3_fwd = p3_sw_trig                'Port 3 Trigger = Relay 3 Forward
relay3_rev = p3_sw_top                 'Port 3 Thumb   = Relay 3 Reverse
relay4_fwd = p4_sw_trig                'Port 4 Trigger = Relay 4 Forward
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Figure Five – Default code example for limit switch operations.

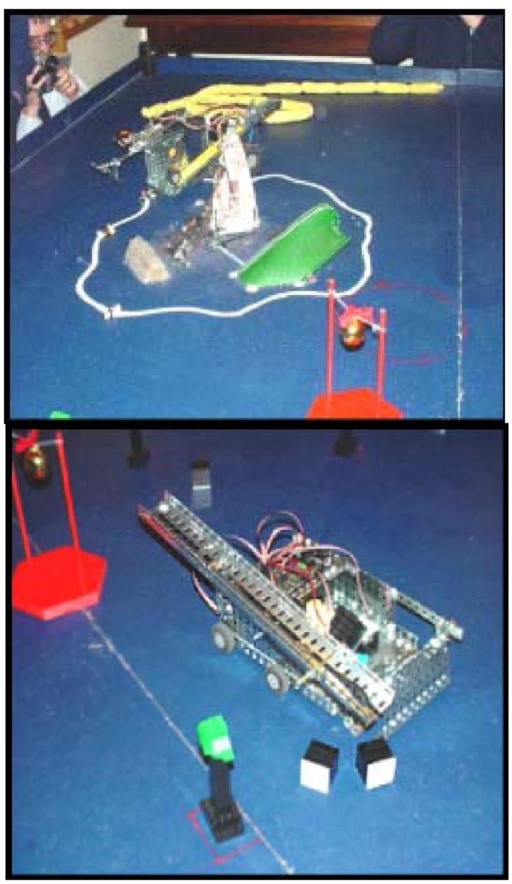

Figure Six – Playing field and robot example.

illustrated in figure seven. Three lab periods are devoted to the activity where the students learn about the kit, design, construct and test their solutions. A class period is devoted to the competition where teams demonstrate their designs.

In addition to the competition, the teams deliver a presentation on their work and prepare a report explaining how the design process led to their solution. The reports include sections on using a decision matrix and project planning software as design tools.

Project Evaluation

The goals of this project are to introduce sophomore students to the engineering design process so they are better prepared to solve open ended problems. The course and lab sequence are structured to encourage critical thinking and problem solving while working with hardware and computer tools that will be used in later classes.

The course and robotics project are evaluated using the standard review process for all engineering courses at the U.S. Coast Guard Academy. Each student evaluates all aspects of the course at the end of the term and these reviews are one component of a course review conducted by the faculty lead for the course. Students and all engineering faculty members are invited to participate in the course review.

Student evaluations give high marks to the robotics project. The activity contributes to favorable student ratings (with a score of 4.3 out of a maximum of 5) for developing an ability to design a system to meet desired needs. The students assess their ability to use techniques, skills and modern engineering tools necessary for engineering practice with equally high marks (4.2/5). Typical student comments, recorded in the archived course feedback evaluations include, "the lab (periods) were by far the most effective part of fulfilling the course objectives," and "the labs were tremendously helpful and useful in communication, construction and equipment familiarity." Students have commented that the design project should be less contrived and more closely model a real world problem.

The goals of the course and the project are met. The course and project are a defining aspect early in the mechanical engineering curriculum and provide an early sense of engineering achievement. As these students have advanced through the rest of the curriculum they have demonstrated an increased ability to deal with open-ended problem solving and are quick to move from ideas to prototyping in other design problems. The students understand that engineering design projects are iterative and often require more time than originally thought. Embedded in the experience is the professional accomplishment of designing something that never existed before.

Figure Seven – Kit of components and assembly.

Summary and Recommendations

Robotics design activities are an effective tool to introduce sophomore level mechanical engineering majors to engineering design. The rapid prototyping kits enable sophisticated electro-mechanical systems to be quickly developed and remotely controlled using wireless communications. http://www.innovationfirst.com/FIRSTRobotics/images-edu/motherboard_w650.gif This experience allows students to not only gain exposure to design, but also provides an introduction to sensors, data acquisition, control processing and computer programming.

Though created for sophomore level mechanical engineering students, the project can be adopted for use in other disciplines and curriculums. At the U.S. Coast Guard Academy the project is the middle component of three robotics applications used in the mechanical engineering major.

Engineering outreach programs are conducted using the LEGO Mindstorms robotics platform, this project is conducted during the sophomore year, and robotics projects are used as senior design projects. Students readily accept the kit described in this paper, for the construction components, electronics and software are sophisticated yet easy to use.

In the future we hope to incorporate a CAD aspect to this project using solid modeling. Here, students would first design their robot by assembling the solid models of the components and then construct the actual devices using kit components. It is felt that such an approach would reinforce the design methodology and enable students to further refine their design skills.

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References:

1. West, H, Flowers, W., Gilmore, D., "Hands-On Design in Engineering Education: Learning by Doing What?", 1990, Engineering Education, Vol. 80, Number 5, 560-564.

2. Dixon, G. W., Wilczynski, V., and Ford, E. J., "Air Engine as a Manufacturing Project in an Introductory Design Course," 2002, American Society for Engineering Education Annual Conference Proceedings.

3. Hyman, B., Fundamentals of Engineering Design, 1998. Prentice-Hall, Inc. Upper Saddle River, NJ.

4. Dufee, William, "A Hands-On Introduction of Engineering Course for Large Numbers of Students," 2001, Proceedings of the 2001 American Society for Engineering Education Annual Conference & Exposition.

5. Miner, S. M. and Tyler, T. N., "A Projects Based Introduction to Mechanical Engineering," 2001, Proceedings of the 2001 American Society for Engineering Education Annual Conference & Exposition.

6. Ahlgren, D. J. and Verner, I. M., "Integration of a Fire-Fighting Robot Contest in Multi-Level Engineering Education," 2001, Proceedings of the 2001 American Society for Engineering Education Annual Conference & Exposition.

7. Wilczynski, V., Dixon, G.W. and Kmiecik, C.G., "A Robotics Competition to Interest Minorities in Engineering," 1998, American Society for Engineering Education Annual Conference Proceedings.

8. Wilczynski, V. and Jennings, J. J., "Creating Virtual Teams for Engineering Design," 2003, International Journal of Engineering Education, Vol. 19, No. 2, pp. 316-327.

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