AC 2012-3588: A VERSATILE PLATFORM FOR TEACHING MECHATRONICS

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A Versatile Platform for Teaching Mechatronics

Abstract

Mechatronics courses typically include a project which allows the students to integrate and apply their knowledge in the design, construction and testing of a real mechatronic system. At one extreme, these projects can be free-form. The students think of an original device and then deal with all aspects of engineering development from parts procurement to final testing of the full-up system. At the other end of the spectrum students are given prebuilt systems and must program them to perform certain task(s). These often take the form of small mobile robots that are run in a contest of some sort at the end of the semester. Both approaches have their merits and drawbacks. Free-form projects permit the most creativity but require more time consuming tasks such as parts procurement and detailed parts fabrication that are at the margin of the core subject matter of the course. Use of premade machines or kits removes many of the tedious and peripheral tasks and permits the students to focus more on the programming, control and testing aspects of the project. However, there is a danger that such a set-piece project becomes "cookbook" with known, well-defined outcomes and the students' experiences with fault-finding, debugging and design iteration may be minimal. This paper presents a middle-ground approach that seeks a compromise between free-form and set-piece projects to maximize exposure to core mechatronics concepts while minimizing peripheral tasks and, importantly, preserving a good measure of creativity. Students in the author's mechatronics class were given premade motorized XYZ platforms and challenged to "do something" with the machines for their final projects. While the basic platform is prebuilt it is of such general nature as to permits a wide range of original projects. The results of one semester of this new course design will be presented and compared with the author's earlier experience teaching the same course but with a required free-form final project.

Introduction

Mechatronics is most often taught with a substantial laboratory component to help students solidify in their minds the principles taught, and to let them connect theory to practice. The format of the laboratory component typically consists of both formal exercises and a project of some sort. The formal exercises are necessary to introduce students to the techniques of microcontroller programming and interfacing. Students are taught how to program their microcontrollers to read various sensors, control different actuators and how to integrate these components into simple feedback control systems. Often the last few weeks of laboratory sessions are dedicated to an independent project in which a complete mechatronic device is designed, built and tested by small teams of students. The main benefits of an independent project are that the students gain experience with:

1. The design process as applied to mechatronics.
2. Debugging and troubleshooting a multidimensional project with interacting electronic, mechanical and software components
3. Team work and communications.

The independent project presents the instructor with important challenges that, if not met can result in a poor experience for the student that will negate the positive aspects of the project and potentially turn-off the students to the field of mechatronics. A project poorly conceived that is too complicated, too large, or too advanced given the students' knowledge and resources will likely result in:

1. Confusion that could lead to uncertainty in knowledge gained from the lectures and formal lab exercises.
2. An inability to work with complex systems that cross disciplines. If the initial hands-on challenge is too hard, then skills like project planning and troubleshooting will not be properly developed.
3. Lack of confidence, especially in a student’s ability to understand areas that are not in the students' major. For example, a mechanical engineering student’s understanding of programming and/or electronics.
4. Discouraging students from either careers in mechatronics or applying for jobs with a mechatronic component. In other words, narrowing a student’s perceived career options.

The design of the independent project is, therefore critical to the success of a mechatronics course. This paper discusses the types of independent projects, their pros and cons and the results of a the author's experience with a hybrid form of independent project

In some mechatronics courses the independent projects are free-form. The students think of an original device and then deal with all aspects of engineering development from parts procurement to final testing of the full-up system. At the other end of the spectrum students are given prebuilt systems and must program them to perform certain task(s). These often take the form of small mobile robots that may be run in a contest at the end of the semester. Another project style is to use high-level tools (e.g. LabView, MATLAB, industrial I/O boards and controllers) and have the students configure them into some sort of feedback control system.

All three approaches have their merits and drawbacks. Free-form projects permit the most creativity but require more time consuming tasks such as parts procurement and detailed parts fabrication that are at the margin of the core subject matter of the course. Within the confines of a single semester the students are often left with (nearly) finished hardware that has been hastily programmed. Device performance, therefore, is often not what it could be and the (exhausted) students gain little or no hands-on experience with key mechatronics concepts related to software, control and system testing. Use of premade machines or kits removes many of the tedious and peripheral tasks and permits the students to focus more on the programming, control and testing aspects of the project. However, there is a danger that such a set-piece project becomes "cookbook" with known, well-defined outcomes and the students' experience with fault-finding, debugging and design iteration are could be minimal. The use of high-level tools has the great advantage of increasing the intellectual coupling between mechatronics and the (usually) prerequisite controls class. Modeling and simulation can readily be introduced into mechatronics projects and they are important tools in modern engineering. The drawback of high-level tools is the degree of abstraction between the program code and the hardware. For example, an analog to digital converter is simply a black box with parameters, not a physcial device that needs power, connectors and is subject to noise.

Proposed here is a middle-ground approach that seeks to retain the best features of free-form and set-piece projects in order to maximize exposure to core mechatronics concepts while minimizing peripheral tasks and, importantly, to preserve a good measure of creativity. It also keeps the students conceptually close to the hardware with a minimum of black boxes compared to the use of high-level tools. Mechanical engineering undergraduates in the author's mechatronics class were given premade motorized XYZ platforms and challenged to "do something" with the machines for their final projects. The general nature of the XYZ platform permits a wide range of potential projects - the creativity component - while not requiring the students to design and build the bulk of their machines. In the first 2/3 of the semester the students were engaged in formal lab exercises that used the platforms to teach mechatronics concepts while at the same time building a toolkit of knowledge and techniques that was directly applicable to their projects (which happened in the final third of the semester). This resulted in a great time savings (always a precious resource in a mechatronics class) because the students essentially worked on their projects the entire semester while concurrently learning the course material.

The Platform

A stepper motor-driven XYZ platform was chosen as the core mechanical system around which the students were required to develop their projects. The platform was chosen for the following reasons:

1. It is a general purpose motion system.
2. A microcontroller is required control the platform.
3. To capitalize on the grand industrial tradition of Milwaukee, the XYZ platform mimics industrial automation systems and permits students to apply mechatronics to industrial applications.
4. XYZ platforms are at the core of 3-D printers and CNC milling machines - automated manufacturing systems that rapidly are emerging in industry and of great current interest to mechanical engineering students.
5. XYZ motion platforms are also incorporated into many electro-mechanical biomedical devices, in particular pick and place sample distribution systems for automated medical testing.

The author had considered using small mobile robot bases (e.g. two motors mounted to a platform) as the common course platform. Despite the popularity of robots they were rejected to emphasize that mechatronics is not only robotics. True, robots are mechatronic systems but the field of mechatronics encompasses many applications beyond robotics.

The particular XYZ platform chosen is the Probotix Fireball V90 (Probotix, Peoria, IL) shown in Fig. 1. Designed as a computer-controlled routing machine, this XYZ mechanism is large enough and has the carrying capacity to enable a variety of applications beyond CNC routing. It also fit within the available budget for the author's mechatronics course. The Fireball V90 is a gantry-style platform with the Y (cross) and Z (up and down) axes riding on the long X-axis. All axes consist of stepper motor-driven lead screws. A tool holder (designed for a Dremel tool) is mounted on the Z-axis and can be adapted to hold a variety of objects. The control box consists of three stepper motor controller boards and a power supply.

The computer or microcontroller interface consists of a cable terminating in a 25 pin D connector with direction and step pins for each motor along with ground connections. Thus driving the system is a simple matter of hooking the step and direction pins to digital output pins of the microcontroller. The Fireball V90 is designed to be controlled from a linux-based PC with a printer port connector. Free software is provided that can control the machine to draw patterns with a felt-tipped pen mounted in the tool holder. While this made a good demonstration at the beginning of the semester to show the students the machine's capabilities, neither the PC nor the Linux-based software was used in the course.

The author uses the Arduino Mega microcontroller board (www.arduino.cc) to teach the concepts of microcontroller programming and interfacing both in the formal lab exercises and in the project. The Arduino Mega was chosen because of its straightforward design (minimizing black boxes), good selection of I/O ports (digital, analog and serial), its simple, easy to learn programming language (the very C-like Processing language) and, of course, its low cost. A great feature of the Arduino is its vast user base that provides the students with a large pool of knowledge on interfacing to a wide variety of sensors and actuators.

Lab Structure

On the second day of class the students were introduced to the course project, rules and regulations were covered and the Fireball V90 platform was demonstrated. Past student projects and ideas for potential projects were also presented. The students were then required to form project teams of nominally four students and brainstorm ideas for projects. A draft project proposal was due in two weeks and a final proposal was due two weeks after that. The draft project proposal gave the author a chance to learn the details of the students' thinking and to help them develop their designs to make them tractable given the available time and resources. The students also presented their draft proposal to their classmates for further criticism and discussion. The final proposal was a detailed description of the project including:

1. Design goals. The students were encouraged to develop a series of increasingly more complex goals. This ensured that the students would accomplish at least the simpler, initial goals before moving on to the more advanced goals if time permitted.
2. System block diagram
3. Software flow chart

4. Development plan including a detailed GANTT chart

The students then worked on their projects throughout the semester, in parallel with the lectures and formal lab parts of the course. In the final 1/3 of the semester the laboratory periods were dedicated 100% to project work. Two progress reports were required of the groups during the course of their work. At the end of the semester each group was required to submit a written report and give a presentation of their project in which they demonstrated its capabilities.

An important aspect of the new approach is the coupling of the formal laboratory exercises and the Fireball V90 platform. By working with the platforms during the semester, the students built-up a cache of experience and tools that could then be applied to their projects. A list of the topics of the formal lab exercises is given below, in the order in which they were presented. Labs #3 and #4 used the Fireball V90.

1. Introduction to programming the Arduino, blinking lights and "Hello World".
2. Basic interfacing: digital and analog input, digital output.
3. Reacting to events: polling and interrupts. This lab used limit switches on the Fireball V90's Y-axis as the event trigger. Other topic: control of Fireball V90's stepper motors.
4. Advanced sensors and control. Using the Fireball V90 and an optical ranging sensor as a one dimensional profiling machine. This was a very involved lab that spanned 3 weeks.
5. Controlling motors: DC brush motors, stepper motors, RC servo motors.
6. Feedback control of motor speed.

Results

At the time of this writing only one complete semester of the course with the new laboratory structure has been given (the second semester is currently underway). The results of that one semester are compared to two earlier semesters of the same course that used a free-form project in which the students were responsible for building their devices from “scratch”. There were seven project groups in a class of 29 students, six groups each consisted of four students and one group had five. The seven projects were as follows:

1. Hot dog making machine. Goal: cook a hot dog, place it in bun, dispense condiment. Results: each piece of system was constructed and tested individually. The system did not work when integrated.
2. Checker playing robot. Goal: teleoperated checkers. Each player indicated a move on a touch screen and the Fireball V90 moved the piece to the appropriate location. Results: basic motion and user interface were built and successfully tested. The students did not have enough time to program the rules of the game into the microcontroller in order to prevent illegal moves (an advanced goal).
3. Cargo loading robot. Goal: simulate the unloading of containers from a ship. Results: successful.

4. CNC drilling machine. Goal: mount a Dremel with a 1/8" drill bit on the tool holder and program the microcontroller to drill the hole pattern for a cribbage board. Results: cribbage board hole pattern was automatically drilled, the students did not route the edges of the board or accommodate boards of different sizes (advanced goals).
5. Cold beer dispensing machine. Goal: test the temperature of an array of six beers located on the base of the Fireball V90. Select the coldest beer and hand it to the customer. Results: successful pick and place of beer bottle. Problems with the temperature sensor prevented coldest beer selection.
6. Sling shot robot. Goal: convert Fireball V90 into a slingshot to fire a Velcro-covered ball at a target, sense the results, reposition the projectile and try again. Results: demonstrated fixed slingshot action. Did not develop the repositioning or target sensing features (advanced goals).
7. Soda can recycling robot: Goal: pick up a soda can, determine if it contains fluid. If so then carry it to a bucket and invert to empty its contents then place can in recycle box. If there is no fluid then take can directly to recycle box. Results: successful with can in fixed initial position. Device was not able to pick-up a can placed in a random initial position (advanced goal).

Discussion

In this new approach to the final project in mechatronics, each of the student teams was able to build and test a machine that at accomplished at least some of their design goals. No group was completely unsuccessful, as was the case with a few groups in the course with free-form projects. In a discussion at the end of the semester only one student expressed a desire to have had a free-form project, the other students who expressed opinions all preferred the structure imposed on them with the common platform. Another benefit that the author observed was that a higher percentage of each group was actively engaged in the project. With the free-form projects, often the project idea originator and/or the student(s) with prior hands-on construction experience did the lion's share of the work. With the new approach, all of the students gained experience with the common platform during the formal labs and so could more actively participate in the group projects.

The future will see the further development of this idea. There will be the greater integration of the common platform into the formal lab exercises. For example, the feedback control lab (lab #6) could employ the Fireball V90 in a linear motion control task. To make the control task more challenging the stepper motors could be replaced by DC brush motors with encoders. An exciting future lab would be to web-enable the Fireball V90 and have the students control it remotely. Both wired Ethernet and WiFi interfaces (known as shields) are available for the Arduino to establish the internet connection.

In conclusion the common platform approach was found to be an effective way of engaging students in mechatronics design, testing and troubleshooting within the confines of the course’s time, resources and the students' skill sets. This is especially important with mechanical engineering students who often have little, or long forgotten, experience with computer programming and electronics. In addition to greater engagement, this method increased the chances of project success, with success meaning that the students demonstrated at least some of their original design goals. The greater success rate was due in large part the time savings (always a precious resource in a mechatronics class) gained by: 1) having the students work with their platforms during the semester in the formal labs, and 2) relieving the students of the need to specify and purchase all of the components required for their devices. Finally, it should be noted that the constraints on the design scope of the project caused by the use of a common platform actually increased the opportunity for the students to use and be creative with the mechatronics concepts they learned in the course because they did not have to spend time "reinventing the wheel" as they would have had to do with a de novo project.

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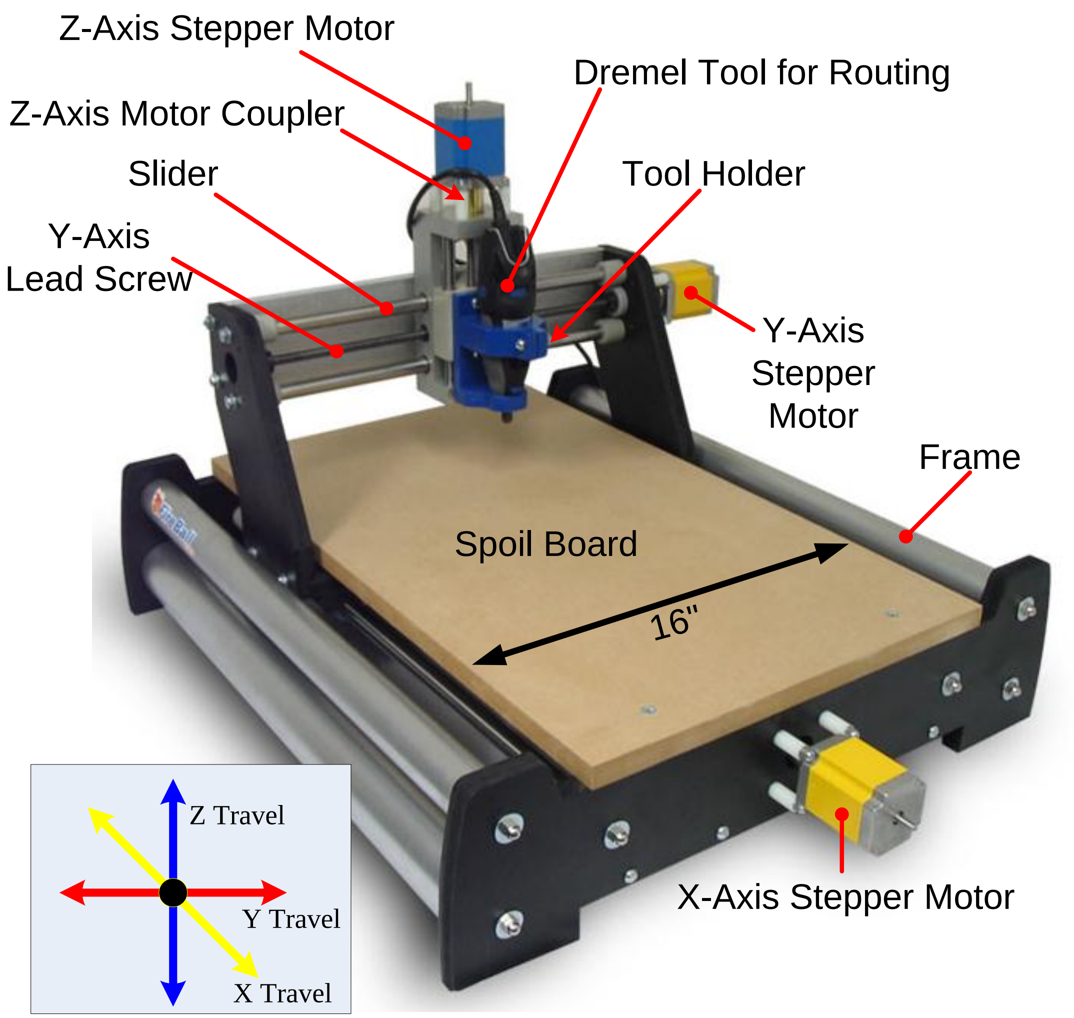

Figure 1. The Fireball V90 XYZ platform shown holding a dremel tool. Image courtesy of Probotix.