2006-1124: BRUSHLESS DC MOTOR PROJECT IN AN INTRODUCTION TO ELECTRICAL ENGINEERING COURSE

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Brushless DC Motor Project in an Introduction to Electrical Engineering Course

Abstract—*Brushless dc motor project kits are used in teaching an introduction to electrical engineering course. The simple-to-construct motor kits provide exposure to elementary circuits, magnetics, electronics, and feedback systems. Students purchase individual kits along with assembly instructions for building a device that demonstrates elementary feedback operation. Feedback signals are generated using magnetic and optical sensors. The feedback signal causes an electromechanical switch or a power transistor to actuate an electromagnetic coil. Additional benefits are a personally-built class memento; an animated, physical manifestation of electrical engineering; and a recruiting tool for future students. Assessment results are included that indicate a high degree of student satisfaction with the project.*

Introduction

A new brushless dc motor project has been developed for a two-week assignment in a first-year electrical engineering course (EE-100 Introduction to Electrical Engineering) offered by the Department of Electrical Engineering and Computer Science at the Milwaukee School of Engineering (MSOE). In this new project, students build and test a brushless dc motor that utilizes a variety of feedback sensor and power switching technologies. Students assemble and modify individual kits to create their own systems with active sensor controlled switching.

Our main goal is to provide a platform for introducing fundamental electrical engineering concepts such as voltage, current, magnetic flux, motor operation, amplification, and transistor switching which will capture student interest and allow for further exploration. In this paper, the project is placed within the context of the EE-100 course[1]; the basic brushless dc motor kit is described; and student experiences and assessment results are summarized.

Motivation for the Course

At MSOE, first-year electrical engineering students are required to take a course, EE-100, to acquaint them with the field of electrical engineering, to excite them about the profession, and to improve retention[2]. In support of these goals, several criteria were developed:

• *Introduce the EE field with the intent of career choice affirmation*[3]. A possible outcome is that the student may decide to change programs. However, it is believed that the majority of students find their decision to be the correct one, and have added enthusiasm for the program.

• *Acquaint the students with key EE faculty*. The course is team-taught by the four EE faculty who are the academic advisors.

• *Provide a sense of community within the EE program*. The new students meet the other EE freshmen, making them feel more welcome, comfortable, and part of a team during their first quarter on campus.

• *Reduce first-quarter stress*. The pass/fail type grading system reduces the pressure of grades while encouraging the emerging engineers to experiment, with little chance of criticism or fear of failure. That is, show them that *electrical engineering is fun!*

Structure of the Course

At MSOE, the academic year is broken into three quarters, each of which includes 10 weeks of classes, plus a final exam week. The course is structured to include both a one-hour lecture and a two-hour lab each week, in weeks one through nine. In Fall 2005, the four class sections included four professors and 62 students. The students select a partner and join one of four teams (one team per section): *AMPS, OHMS, VOLTS,* and *WATTS*.

Each of the four professors develop two week experiments and teach two relevant lectures. Each student team (AMPS, etc.) spends two weeks with each professor, performing that professor's experiments. Students worked with their partner at lab stations, although the experiment performance is sometimes individual (communications, microprocessors, brushless dc motor). The experiments include:

- **Instrumentation** – all students performed this in week one to familiarize them with the signal generator, multimeter, power supply and oscilloscope in the lab
- **Communications** – students build an AM radio from a kit. Each student takes home the completed radio.
- **Robotics** – students build a logic and sensing circuit to detect what a simple moving robot is doing and adjust the motion of the robotic vehicle.
- **Microprocessors** – A Parallax® Basic Stamp® system is programmed to interface with LED's and pushbuttons.
- **Digital Audio** – Laptop software provided the platform for experiments in sampling audio, aliasing, filtering, special effects, MP3, etc.
- **Brushless DC Motor** – A kit serves as the basis for this experiment where students build and test their own motor. Each student takes home a completed motor. Student ownership of the project is critical to engaging student interest[4,5].

Each week, the lecture introduces the concepts for that week's laboratory activity. As the students rotate between the four professors every two weeks, they experience the professors' specialty areas, socially connect with the professors (and EE advisors), and experience different teaching styles. The course is not set up as a prerequisite for any other course – a deliberate decision meant to allow maximum flexibility in achieving the course goals.

The era of homemade crystal radios and garage-supercharged Chevy's has disappeared and been replaced by the immediate gratification of playing video games, instant messaging, and browsing the internet[6,7]. These original hands-on activities served many purposes for burgeoning engineers. Hands-on experience with real systems yielded engineers who connected with 'real' systems. The brushless dc motor is finding increasing applications including as a motive source for hybrid vehicles. In building their own motor, students connect to a comprehensible device that is practically applied in interesting new consumer products.

Brushless DC Motor Kit

Figures 1 and 2 show an unassembled kit and an assembled Brushless DC Motor. Experience with 62 students building their kits showed that 100% were successful in making their motor operate. The kit is relatively straightforward to assemble. It is based on a low-cost design originally developed by Stan Pozmantir[8] which uses simple switching controlled by various rotor position sensors. The parts kit includes all of the parts listed in Table 1.

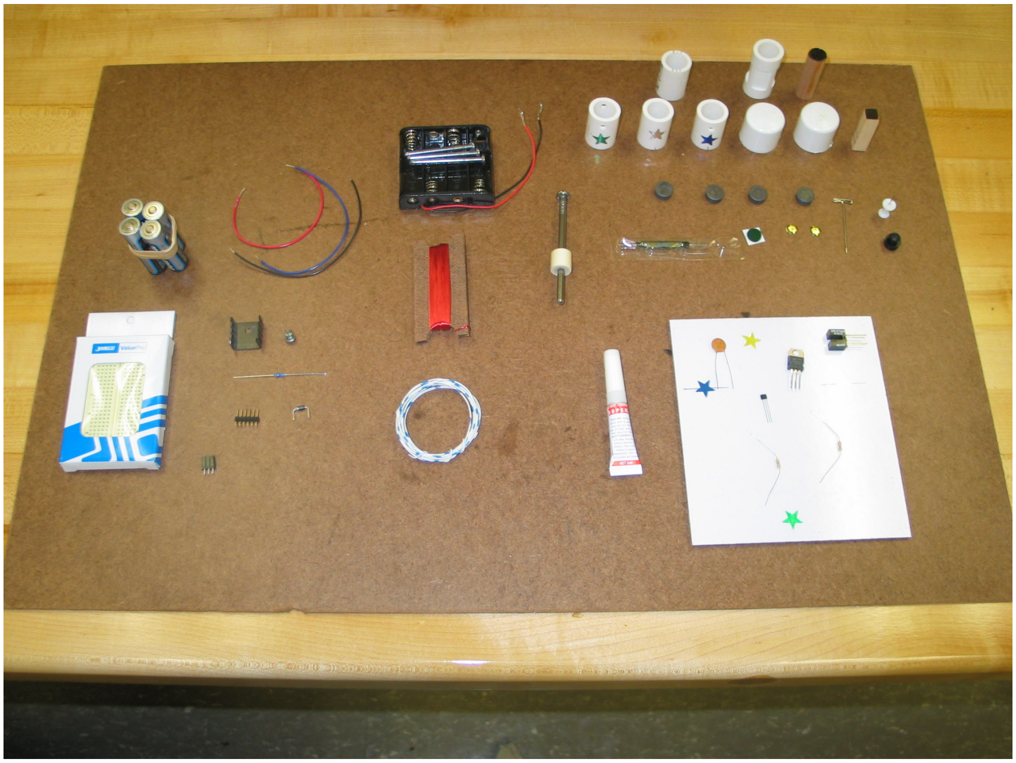

Figure 1 – Unassembled brushless DC motor kit

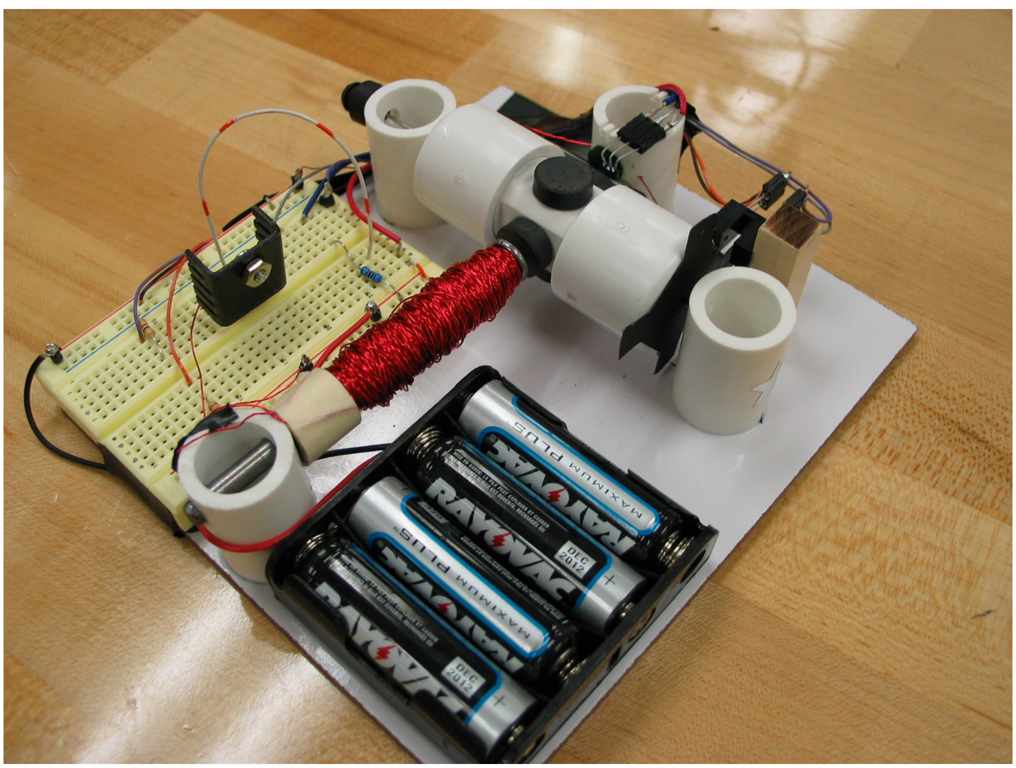

Figure 2 – Fully assembled brushless DC motor

OPB831W	Slotted optical switch
A3121E	Hall effect switch
	Reed switch (1A, 50V)
TIP106	PNP Darlington transistor
1N4001	Diode
270Ω, 10kΩ	¼W resistors
	50 ft, 27 ga. magnet wire
	4" nail for magnet wire coil
	4 permanent magnets
	5" x 6" press-board
	Pre-cut 7/8" round PVC pipe
	Pre-cut 5/8" square PVC pipe
	7/8" PVC endcaps
	Opaque optointerrupter disk
	Pushpins for axle
	Super glue
	24 ga. jumper wire
	4 AA battery holder
	¼" Round wooden rotor insert
	TO-220 heat sink
	2"x3" breadboard

Table 1 – Brushless DC motor kit parts list

The schematic of the basic system is shown in Figure 3. In this system, the position of the rotor may be sensed by a Hall-effect sensor switch, a slotted optical switch configured as an encoder, or a reed switch. The Hall sensor or the optical switch signal drives the base of a Darlington PNP transistor. The transistor operates as a switch to energize the coil whenever a rotor permanent magnet is facing the coil. Alternatively, the reed switch may be used to combine the sensor and coil switching functions. The diode allows the coil current to circulate during times that the coil is disconnected from the battery supply. This reduces voltage stress on the transistor and reed switch. The freewheeling diode provides opportunity for further exploration for students.

Students build the rotor and reed switch portion of the circuit during the first week laboratory. The reed switch motor is built and operated first to introduce switching in a visually active device. Students can see the reed switch mechanically open and close as the rotor position changes. Besides mechanical switching, this introduces magnetic field attraction and repulsion. Students also can see the effects of inductive switching by removing the freewheeling diode from the circuit and seeing the reed switch arc as it operates.

In the second week laboratory, students build the optical encoder and Hall-effect sensor networks and the transistor coil switch network. The transition from the mechanical reed switch to the solid-state transistor switch effectively introduces the concepts of current flow and transistor switching.

Students measure the speed of their motor using both a stroboscope and an oscilloscope attached to the rotor position signal. Speed measurement proved to be a very satisfying conclusion to the laboratory. Some students modified their motors (e.g., adjusting encoder phasing, adjusting position of Hall sensor) to demonstrate the effects on motor speed.

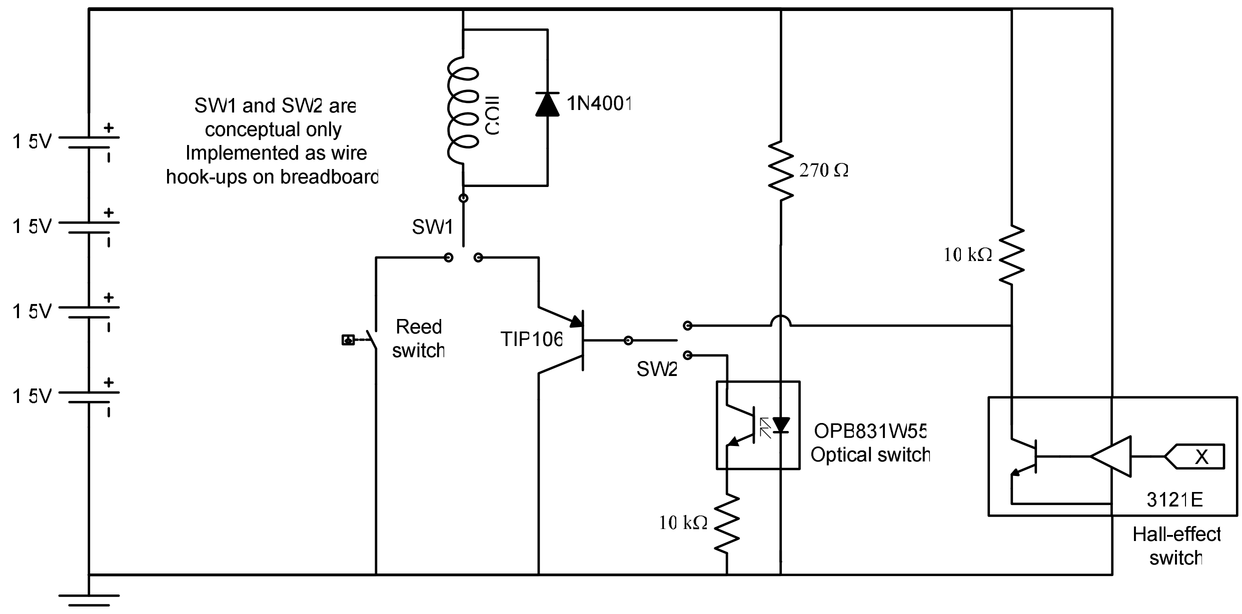

Figure 3 – Schematic of brushless DC motor

Student Feedback and Assessment Results

Following the end of the term, the students were asked to participate in a class survey. Out of 62 students enrolled in the class, 57 completed the form. Overall, student reactions were very positive. Some of the feedback students gave about the brushless dc motor project:

- "It was a cool problem and satisfying to complete."
- "It's fun and you can take it home. Unlike other EE labs, you can actually see what your circuit is doing with your eyes; you don't have to take the oscilloscope's word for it."
- "[The best part was] the 'cool' factor."
- "I got to keep it."

Follow-up discussions indicate many students have their systems on display in their dorm rooms, and some have even featured their completed system on their personal web sites.

The survey asked students which of the EE-100 laboratory sessions they found most interesting and least interesting. As stated earlier in the paper, the sessions were Instrumentation, Communications (AM radio), Robotics, Microprocessors, Digital Audio, and Brushless DC Motor**.** Results showed that students liked the motor project. The brushless dc motor project was found to be the most interesting EE-100 laboratory session by 42% of the students. This compares with the next most interesting session, robotics, which 20% of the students found most interesting. None of the students found the motor project to be least interesting. These results are shown in Figures 4 and 5.

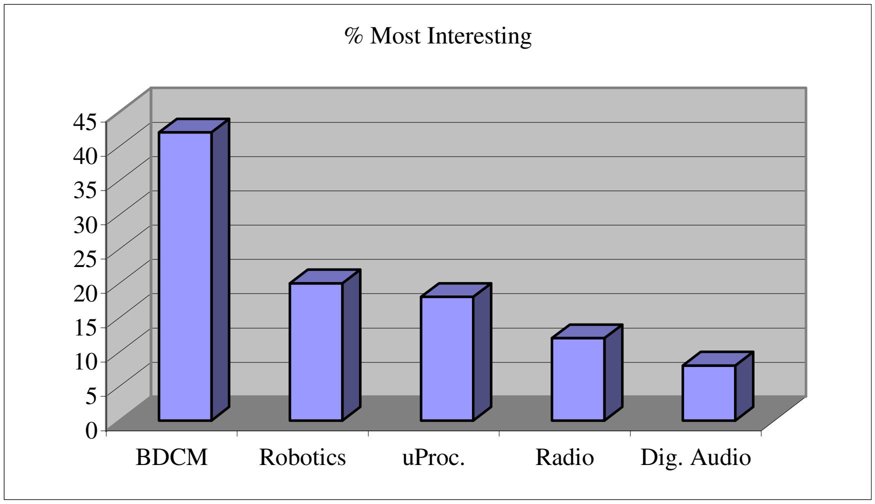

Figure 4 – Percentage of respondents (n=57) who found the experiment <u>most</u> interesting

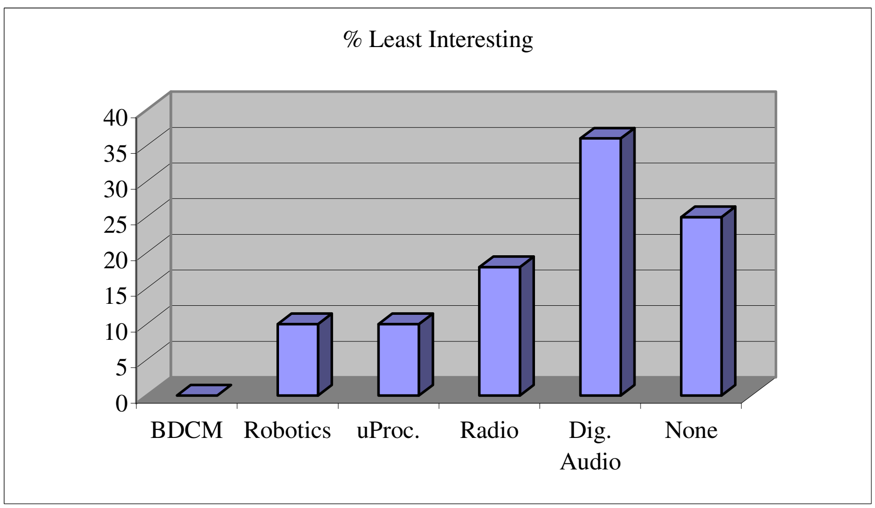

Figure 5 – Percentage of respondents (n=57) who found the experiment <u>least</u> interesting

Narrative responses to why the brushless dc motor project was most interesting included:

- "I could actually understand what was happening on the schematic."
- "Brushless motors have many new applications."
- "I got to see how it worked and put it together myself."
- "I understood how the circuit worked."

The total cost of the kit components to the students is $35. Technical staff at MSOE procured components and assembled them into the kits sold to the students. Narrative student feedback strongly correlated personal ownership with pride in their work and with heightened interest in electrical engineering.

Figure 4 – First-term students work in teams to help each other with assembly

Conclusion

The introduction of the brushless dc motor in EE-100 has increased first-year student interest in electrical engineering. It has brought the field of Electrical Engineering closer to students through a project that is comprehensible, personally built and owned, and results in a working, practical device. The use of the platform has provided ownership, contextual learning, fun, and hands-on experiences for the students in the class, making it a more worthwhile experience that they have shared with others.

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