Racing to Understanding: Instrumentation Lab with Radio-Controlled Cars

By: Michael Ruane

Electrical and Computer Engineering Department

8 St. Mary's Street, Boston, MA 02215

mfr@bu.edu

Abstract

Freshmen engineering students are being introduced to electronic measurement and IEEE-488 (GPIB) instrument control using radio-controlled cars in a new Introduction to Engineering module. The seven-week module is conducted as a hands-on laboratory experience using Agilent VEE, a commercial software package for instrument control and graphical programming. Engineering content includes basic descriptions of signals, simple electronics, use of oscilloscopes, function generators, multimeters, and power supplies, open-loop control, user interface design, and the details of Agilent VEE and GPIB.

Our Radio Shack Black Wolf II cars have proportional controllers with joysticks for steering and velocity, and use pulse position modulation at 68 Hz to blank a 27 MHz carrier. Cars with four bands are available allowing students to run several cars simultaneously. The controllers were modified to access PCB signal points, allowing students to examine control signals and the carrier. They measure pulse characteristics and deduce the control scheme. Next they create their own control signals with Agilent VEE and download them to a function generator that bursts them to the transmitter. The Agilent VEE panel must be designed with an intuitive user interface. Finally they must devise a control plan to navigate a rally course in the lobby of the engineering building. The "final exam" is their rally performance.

This paper will describe the course learning objectives for our Introduction to Engineering modules, the schedule of weekly topics and software developments, the controller modifications and benchtop electronics used in the module. The use of weekly quizzes, homework, and minute papers will be described. Student evaluations and suggestions for adapting this module to another school will be discussed.

1. Introduction

Helping freshman engineers become familiar with the "real world" practice of engineering while meeting heavy first-year curriculum requirements has been a continuing challenge [1] [2]. ABET 2000 and stagnating enrollments both encourage more attention to the initial experiences of engineering students. At Boston University we address this problem with a required 4 credit course, "Introduction to Engineering", organized as two half-semester modules. The course is offered each semester to half of the freshmen class. The other half takes a required course on engineering computation. Typically 8-12 faculty from our four departments offer modules. Other recent modules have included CAD, machine design, electronic music, image processing, the human genome, and fiber optics.

Each module is intended to be a stimulating and confidence-building experience. Students are encouraged to explore their engineering interests and "tinker" with different majors as much as possible. We are not trying to create an early cognitive lesson as much as to demonstrate that engineering can be relevant, interesting and even fun! Modules usually introduce aspects of a particular engineering discipline, cover some basic engineering problem-solving skills, cultivate professional and independent learner attitudes, and bring first-year students in contact with engineering faculty. Modules operate independently, but a course coordinator administers registrations and assigns a course grade based on the two module grades. Students are given short descriptions and designate several preferred modules during preregistration. They are assigned to their two modules according to preferences, schedules, and available class openings.

The module described in this paper is called "Computer-Controlled Instrumentation and Agilent VEE". It was advertised as a laboratory-based experience using the computer to collect and generate signals that would operate a radio-controlled car. This application has generated curiosity in many students and attracted several former radio-controlled car owners. The module was fully enrolled at 28 students in its initial semester.

2. Laboratory Resources

This module was conducted in an existing undergraduate electronics laboratory having 30 stations configured for our sophomore and junior circuits, electronics, and communications courses. Each has a PC-compatible with a 100 MHz processor, 16 MB of RAM, a 1.0 GB hard drive, and a GBIB interface card. The GBIP bus connects an Agilent 33120A 15 MHz function generator, an Agilent 54600B 100 MHz digital scope, an Agilent E3631A triple DC power supply, and an Agilent 34401A multimeter. The stations are not networked, but a printer station is available for 'sneaker net' printing. Costs per station, including the PC, are under $5k. Agilent VEE 4.0 was used under Win95. License packs are less than $20/station and free evaluation and run-only versions are available on the WWW.

Figure 1. BlackWolf II radio-controlled car and controller

Six Radio Shack BlackWolf II radio-controlled cars, controllers, battery packs, and chargers were purchased. Cost per car was less than $70. The controllers have steering and velocity joysticks and each car has a two-speed motor. Their outdoor control range is 50m; indoor range depended on the building construction. Large lobby areas worked best

(and generated a lot of public attention). Since the cars are sold with only four distinct frequency bands, two cars were used as spares during the final rally competition.

The controllers were modified with 9-pin DIN connectors to supply power, measure controller signals, and insert student-generated controls from the benchtop. These additional parts were less than $5/controller and greatly improved student facility with the controllers. Rather than trying to connect to pins or traces on a PCB in the controller, important signals were available outside on simple test clips.

3. Control Operation

Steering and velocity control uses a form of pulse-position modulation. The controller first generates a local squarewave at 68 Hz. The joystick potentiometers modify this squarewave to set the cutoff levels of two amplifier stages whose outputs are inverted and added back to the original squarewave. This creates three 0.2 ms pulses separated by time delays that are dependent on the joysticks' deflections. This pulse group drives the bias point of the transmitter output amplifier to blank the carrier during the pulses' on periods. The carrier operates between 28.1 MHz and 28.5 MHz, depending on a car's band.

The receiver detects the time delays between the blanking, and generates the appropriate controls to the motor and steering mechanisms. Figure 1 shows a typical control signal from the joystick stage.
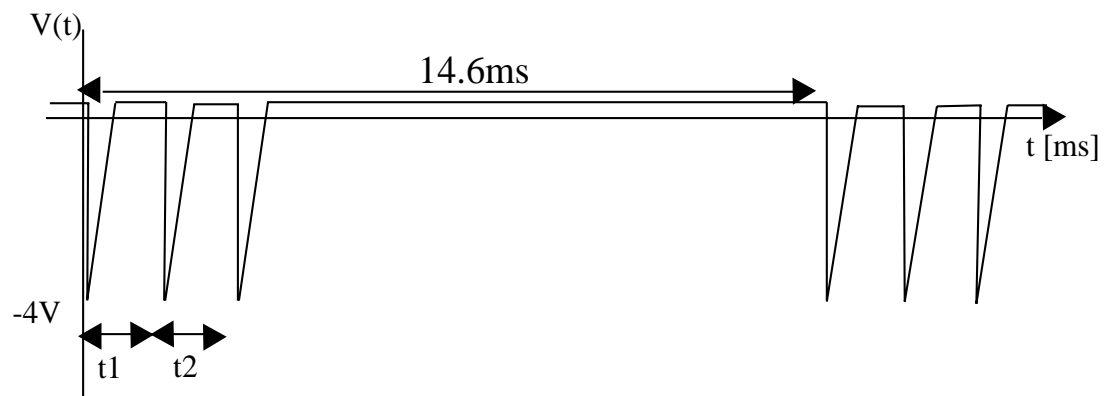
Figure 2. Schematic of controller blanking signal generated from joystick inputs. Each pulse blanks the 28 MHz transmitter carrier. Joysticks vary t1 and t2.

Each joystick can move over a range of ±20°. The steering joystick changes duration t1 between the first and second pulses while the velocity joystick changes t2 between the second and third pulses. Figure 2 shows an idealized control action plot, in terms of t1 and t2. Note that t1 = t2 =1.5 ms puts the car at rest, steering straight ahead. Ultimately, the joystick control is nonlinear. The degree of steering and velocity control at the car is nearly 100% after only 5 degrees of movement of the joystick.
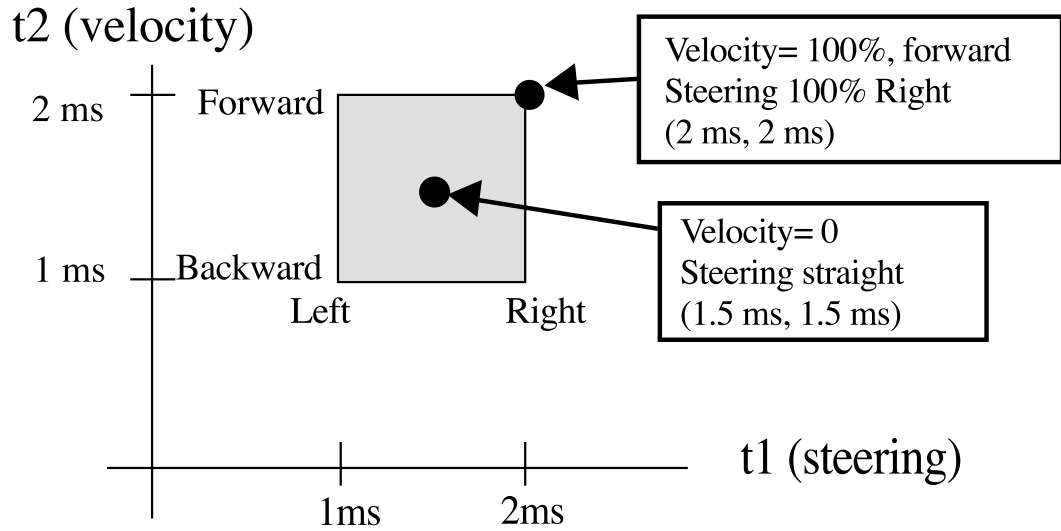
t2 (velocity)

2 ms — Forward

Velocity= 100%, forward
Steering 100% Right
(2 ms, 2 ms)

Velocity= 0
Steering straight
(1.5 ms, 1.5 ms)

1 ms — Backward

Left   Right

t1 (steering)

1ms   2ms

Figure 3. Control region in t1-t2 space. The steering joystick sets delay t1; t2 is set by the velocity joystick.

Control action is also affected by the mechanical suspension of the car. The plastic parts are rugged, but loosely fitted. Under human control, with visual feedback, this is not important. But with open-loop computer control, the biases are critical. The steering bias of the suspension tends to vary, especially if the car strikes an obstacle. Similarly, the velocity deadzone varies with the gearing backlash. These make fine steering and slow velocity control difficult.

4. Course Objectives and Structure
The learning goals, as stated to the students, are:

Knowledge Outcomes
By the end of this module, you should know:
1. How to specify signals in magnitude, time, and frequency
2. The physics and engineering of a simple communication link;
3. Common circuit elements and their schematic symbols;
4. Electronics laboratory safety and measurement procedures;
5 Fundamental Agilent VEE graphical programming elements.

Skill Outcomes:
By the end of this module, you should be able to:
1. Use a clear, organized solution procedure for analytical problems;
2. Read and make an accurate schematic of simple electronic circuits;
3. Program in Agilent VEE for signal design and instrument operation;
4. Recognize simple electronic circuit board components and traces.
5. Operate the oscilloscope, power supply and function generator.

Attitude Outcomes:
This module will attempt to foster the following attitudes:

1. A positive feeling towards the electronics instrumentation area and its challenges;
2. An increased appreciation for the way a practicing engineer approaches open-ended problems;
3. An appreciation for the importance of clarity, organization, accuracy, and neatness in engineering calculations
4. A more mature attitude toward the teacher-student relationship in a learning environment;
5. An increased sense of responsibility for one's own education and learning.

Table 1. Intended course outcomes

The module meets twice a week in the electronics laboratory for 1h 40 min, for a total of 13 sessions. The detailed schedule is shown in Table 2 below. Each class is motivated by an engineering task, e.g. "determine the controller signals associated with joystick actions" or "test the car response to your simulated signals." These tasks lead to discussions and identification of needed information or skills. New conceptual material is discussed first, e.g. reading a schematic. The second part of each class is always hands-on, concentrating on the use of the instruments, measurement of the controller signals, or Agilent VEE programming to develop control signals. Towards the end of the module, the entire period is dedicated to Agilent VEE and instrument activities. This structure attempts to demystify engineering and the controller technology, recognizing that freshmen arrive with a wide range of skills and confidence. [5]

Agilent VEE is a graphical programming language.[6] Its programs are implemented by choosing iconic elements (data inputs, functions, logical operators, instrument panels, displays, etc.) and interconnecting them with "wires" that carry data objects and control signals. Virtual sources and displays can coexist with real interfaces with the benchtop instruments. The GPIB communication and control details are often hidden behind intuitive panel drivers. Integration of Win95 tools makes the environment user-friendly and development of working programs is rapid compared to approaches using text-based languages.

Grading of the module is based on quizzes, homework, and performance of the student controller at an end-of-module rally. Each week includes a 10-minute quiz to reinforce a related skill like specifying a signal or predicting the operation of a Agilent VEE program. Weekly homework is assigned and graded. Homework is used to consolidate skills or to develop strategy for upcoming lab work. As this is an introductory course, students are given ample opportunity to build a good grade. They are encouraged to restudy the material and take a makeup quiz to show mastery if a weekly quiz goes poorly. They may also submit homework "rebids" to recoup lost homework marks. Unlike the homework, which is problem-based, the rebids involve more writing. Rebids are formulated as memos from an engineering manager to the student, asking for an analysis, design, or presentation materials related to an earlier homework. Students must submit their rebids as memos to their manager, supported by their analysis or design work. The rally, held on the last day of the module in a lobby area of the engineering building, is the final grading component. Four benchtop setups are placed on carts and moved to the lobby, allowing simultaneous runs of a car from each band. The rally course consists of driving 5m forward, turning around, and returning to the starting line.

Students are timed and their score is based on their best run-time in the 15-minute window they have for setup and driving. The performance time constraint favors students who have invested in an effective user's interface.

Class	Design	Agilent VEE	Task
1,2	Intro	Fundamentals Signals	Develop system view of Black Wolf car; Create an Agilent VEE pulse pulse generator
3,4	Specs	Scopes; Function Generators	Spec and create AM signal in PC; Use oscilloscope to measure function generator
5,6	Scholastic	Signals; Carriers	Read controller schematics and identify signals; Observe control circuit and its signals
7,8	Simulation	Generate Waveforms	Create signals to accomplish driving functions; Spec and create simulated signals on bench
9,10	Integration	Communications, Control	Describe communications channels; Control vehicle on benchtop with Agilent VEE
11,12	Testing	Choreography; Debugging	Create final signal plan for competition Test driving signals with working cars.
13	Delivery	Competition	Compete on the course (April 23)

Table 2. Schedule of module activities and classes

5. AGILENT VEE Controller Development

Student control of the cars is achieved by simulating a control signal in AGILENT VEE and injecting the signal into the transmitter amplifier to create appropriate carrier blanking intervals. Students initially discover the controller's 68 Hz blanking pulses while learning to use the scopes. They then pick a time step for simulating the pulses with adequate resolution. Initially the students specify the locations of pulses in terms of actual time increments, using built-in iteration, if-then-else, and waveform display blocks in Agilent VEE to create and display an array of -1s and 0s. This is later refined to include an intuitive interface in terms of desired control actions (e.g. right-left, 0-100%; forward-backward, 0-100%). Agilent VEE knobs and sliders can be used to make a convenient virtual controller interface on the screen.

After creating an appropriate control action data array, the data are sent over the GPIB to the function generator, where they are stored as one of four possible user-generated arbitrary waveforms. The Agilent VEE function generator panel driver, which appears on screen with intuitive controls, is used to set frequency and amplitude and activate the arbitrary waveform. The function generator output is inserted at the transmitter input signal point and the appropriate blanked carrier is broadcast, making the car move.

Students quickly recognize that they need to include command <u>duration</u> in their control strategy, as well as commands for steering and velocity. They next modify their Agilent VEE program to input the seconds of command duration. This is converted to signal periods and the function generator is used in burst mode to output a precise number of control signals, giving the car a fixed time of operation. A sample of a final student Agilent VEE program is given in Figure 3.
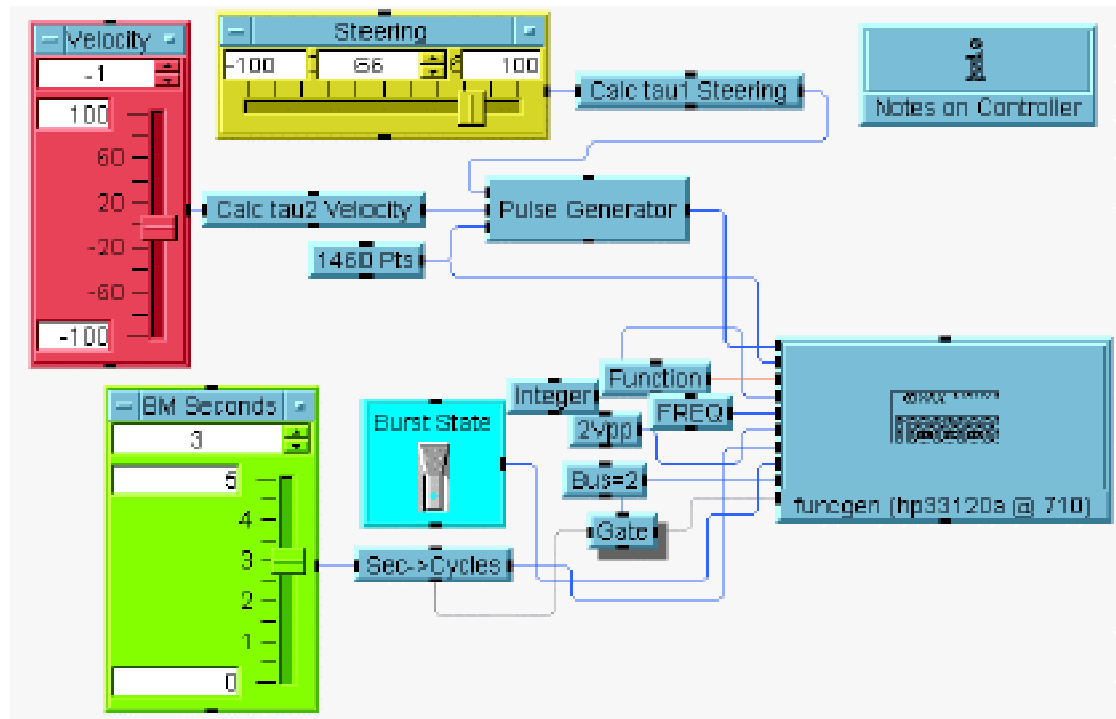
Figure 3. Iconized final controller program to simulate joystick and time control of the BlackWolf II car. 'Burst State' switch allows continuous control signals for testing. '1460 pts' input controls time resolution.

Three complications made computer control more erratic than hand driving with joysticks. First, all control was open loop. With hand controls, visual feedback allows rapid correction of errors. With Agilent VEE and the BlackWolf II cars, no feedback could be implemented. Second, Agilent VEE and GPIB can have substantial time delays when considering driving time scales. Time delays arise while calculating the control array, moving it over the bus to the function generator, and while setting up and initiating burst mode operation. The time delays are strongly dependent on array sizes and hence, on the signal resolution when using a fixed time step. Time delays of several seconds were common, making it impossible to execute dynamic changes while driving. Rather the cars had to be commanded to drive in a certain steering/velocity configuration for a set time, after which a new signal would have to be reloaded. Finally, most control actions would be followed by a period of coasting. During these uncontrolled periods, steering was unpredictable due to suspension looseness and obstacles/collisions.

6. Evaluation

Informal student feedback was elicited after each class with an anonymous "minute paper" asking two questions: "What was the most important idea in today's class?" And "What issue is still unclear after today's class?" Minute papers helped ensure that common questions were addressed and that ineffective exercises could be deleted or modified in the next offering. Students reacted more positively to the hands-on work, than to the cognitive information given in the early part of the meetings.

The module was formally evaluated at the last meeting with a standard student questionnaire that sought feedback about the instructor and the course. Generally student response was positive towards the applied problem of controlling the cars, and towards the strongly hands-on experimental nature of the course. Students liked being in the electronics lab as freshmen and learning to use equipment that will later be part of their curriculum.

Frustration was high among some students, especially those who felt their computer control of the cars was unsuccessful. Some attributed this to the course design, saying that it was an ambitious module that tried to cover too many aspects of measurement and AGILENT VEE. Others complained that the cars were inadequate because of their loose suspension and coasting behavior. Finally some complained that the course was not well organized, citing the need to go back and redesign components several times to account for non-linearity, car dynamics and GPIB data delays.

In our most recent offering of the module, the time allocated to developing the controller and testing the cars has been increased. We have also tightened the mechanical suspensions of the cars to make the steering stiffer. Other problems, particularly the time delays, continue to be left to the students to discover and resolve. It seems appropriate, in an Introduction to Engineering module, to incorporate non-linearity and other "real-world" complications that require art, iteration, and engineering trade-offs to resolve. Moving this module to another college of engineering would require a commitment for adequate instrumentation, computers, and software support. Any standard electronics hardware compatible with GPIB (or RS232) control could be used, as long it supports signal storage and burst mode operation. LabVIEW could be used to develop the instrument control system and simulated controller signals. Many radio-controlled car models are available, and most from Radio Shack use a similar controller. Materials from the course are available from the author.

7. Conclusions

A seven-week module using computer-based instrumentation to study and ultimately control a small radio-controlled car has been described. The module used existing electronics lab resources and a small investment in cars and controllers to provide an appealing and rich context for freshmen to explore basic electrical and computer engineering concepts. Students leave the module with an introductory proficiency in electronics instrumentation, familiarity with schematics, and experience in graphical programming in AGILENT VEE. Initial student reaction to the module has been positive and we expect to continue offering it as one of the options in our Introduction to Engineering course.

8. Bibliography

1. Hatton, D.M., Wanka, P.C., LeBold, W.K., "The Effect of an Orientation Course on the Attitudes of Freshmen Engineering Students*", Journal of Engineering Education*, v.87 (1), January 1998, p. 23.

2. Richards, L.G., and Carlson-Skalak, S., "Faculty Reactions to Teaching Engineering Design to First Year Students", *Journal of Engineering Education*, v. 86 (3), July 1997, p 233.

3. Peterson, G.D., "Engineering Criteria 2000: A Bold New Change Agent", *ASEE Prism*, v.7 (1), September 1997, p 31.

4. Carlson, B., Schoch, P., Kalsher, M., Racicot, B., "A Motivational First-year Electronics Lab", *Journal of Engineering Education*, v.86 (4), January 1998.

5. Krupczak, J., "Demystifying Technology", *ASEE Prism*, v.7 (2), October 1997, p 30.

6. Helsel, Robert. *Visual Programming with AGILENT VEE, 2 nd Ed.*, Prentice Hall PTR, NJ, 1997.