ELE 302 Project #2 - Mountain Rally
(Speed Control)

Overview:

Project 2 is broken into 3 sub-projects. We'll start with short summaries of the three parts and the design review. The parts are then described in more detail.

Along with car kits, you will receive a transmitter/receiver pair (for "testing" the car). We have hardware for building circuits you will need: for speed sensors, serial communications, and PWM motor control. (For Project 2, you may NOT use the electronic speed control module that comes with the car kits.)

> **2a.** Due by Monday, March 29. You must demonstrate a working RS-232 serial port.
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> **2b.** Due by Monday, March 29. You must have the car built, the board mounted on it, and you must demonstrate working speed sensors.
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> **Design review:** On March 31 there will be design review presentations (during the scheduled class hour). You must present a plan for how you will control the speed of your car. *This will include a write-up* showing how your speed sensors work, schematics of any circuits you will need to add (such as the motor drive circuitry), a description of the control algorithm you will use, and a discussion of the parameters you expect will require adjustment and your plan for finding good parameter values. You must show experimental results obtained from running step response experiments on your car (input is the motor armature current and output is the speed of the car).
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> **2c.** Due by Wednesday, April 7 at 5 pm. You must demonstrate that your car properly controls its speed on the Official 302 Mountain Rally course and on the flat course in the lab. Both team members must be present for the demonstration.

Project 2a:

In the first main part of the project you will add capability for input and output from your board. The basic idea is that you should have an easy way to input some parameters for your speed control algorithm that you can use instead of hard-coding them into the algorithm. Varying these parameters lets you fine tune your algorithm. If your hard-code them, then you need to reprogram each time you need to make a tuning change. For inputs there are several possibilities -- DIP switches, hex switches, key pads, RS232 serial port, infrared, audio (DTMF) based, ...; you must implement the RS232 serial port, working over a cable connecting your board to a computer running a terminal program. This provides two-way communication capabilities between your board and your workstation so that you can also monitor sensor data and control data and other operational data. Optionally you may add other input or output capabilities. Later on, for Project 3, everyone will add support for a wireless RS232 serial board, At that time you will have the option to build a version of a base station board on which a radio transceiver (we supply) can be mounted – so your board and your workstation can communicate without being connected by a cable. (We will supply base station support on the two workstations located on the table with the laser printers.)

Project 2b:

In this part of Project 2 you must demonstrate reliable operation of sensors to measure the speed of your car. Trying to control speed with unreliable sensors is very painful. You don't want to do it! You will build redundant speed sensor systems; one of the sensors must be based on optoelectronics. It is expected that one system will be an operational backup, allowing for "safe" speed control in the event of failure of the primary system although not necessarily adequate for meeting accuracy specifications.

First you are going to have to build the car. If you are pretty good with tools, model building, and spatial perception (a good reading knowledge of Japanese helps with some models) it should take 8 - 10 hours to build a car. It can take longer if you run into trouble (Make sure your gears and drive train rotate easily. Some people have run into problems with their gears sticking at some point as they turn, which must be fixed in order to get the speed control to work.). Next you will need to figure out a way to mount the board on the car. Remember that you will need to take the board on and off many times. We have metal angle brackets, which some groups have used. You can also use the fiber stand-offs (legs) and drill some holes in the car chassis. We also have velcro (with a sticky backing) and it has worked pretty well. You want to have the board held on securely (It is poor form and requires lots of repairs if your board falls off), but you don't want to have to take out 20 screws to get it off. It is not absolutely required that the body fit on the car with the board mounted on it as well. However, it has often been possible to make it work with the cars in the past.

When you attach the board, also think about how you will eventually run your power wires and put in a switch. For this part of project 2 you can still power your board with the bench power supplies, like you have been doing. However, it is good to think ahead a little, so you don't make a lot of unnecessary work for yourself. The switch can be mounted on the board or on the car body, but it should be easily accessible (When you have to make a diving stop, just before the car hits a wall, you don't want to miss the switch!). Eventually you will also need to put some connectors in the power line to the board, again so that you can easily take the board off for building/testing. For now, just having the power supply wires attached, as for project 2a, should be fine.

We have parts for a variety of speed sensors, all with the idea that they would be mounted on a wheel. You don't have to mount them on a wheel, but they need to work reliably. Some groups mounted sensors on a exposed part of a drive shaft, and one or two groups were able to mount sensors on their gear boxes. There was also a group that measured the voltage generated by the motor during the ‘off-period’ of their PWM signal, although this poses several challenges. We don't have any devices that measure speed directly, so you may end up having to measure "ticks" of some kind as the wheel rotates, and then convert the "tick-rate" or "tick-period" to a speed. For example, an optical sensor and reflective tape can be used generate "ticks" whose rate (or perhaps pulses whose pulsewidths) vary inversely with the speed. Several things are important to keep in mind while you are deciding how to make your sensors:

> *i*. They must be reliable. If some sensor doesn't ever work you get the wrong speed, but at least it is consistent. If the sensor works some of the time, then your speed measurement is very "noisy", and it will be impossible to control.
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> *ii*. You want as many "ticks" per revolution as is reasonably possible. You can't measure your speed to 10% accuracy if the measurement is based on only 2 "ticks" (except in the unrealistic case of exactly constant speed). If it takes your scheme many wheel revolutions to get a decent measurement of the speed (like 10%), then the time delay will make it very difficult to keep your feedback loop stable. However, you can go overboard with trying to get too may "ticks" per revolution. If you use interrupts to process the sensor signals, you must consider the time required for your routines to service them. If you put a sensor directly on the motor shaft, the interrupts might occur quite rapidly.
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> *iii*. You want your "ticks" to be accurate. If your sensors fire several times per revolution, you need to have them evenly spaced. It does no good to have lots of samples if they vary by 20%, even at constant speed. Often the wheels (rims) are made with ribs inside which accurately divide them into as many as 8 - 10 parts. They can be used to make sure your sensor "ticks" specify accurately some fraction of a revolution.
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> *iv*. Mount your sensors on some part that is directly driven by the motor. They are very difficult to test if the motor doesn't drive them.

There are 2 main schemes for sensing rotation that have been used, optical and magnetic. One or two groups have tried using metal tape and a wire to make a commutator, but they haven't been too successful (losing contact, and contact bounce). The magnetic schemes have 2 advantages: (1) they are insensitive to light, and (2) the Hall effect sensors put out a digital signal (with an open-collector output). The headache with the magnetic sensors is attaching the magnets reliably so that they can pass rather close to the sensor (probably 1/8 inch, or less). You can use superglue or epoxy for sticking things onto parts of the cars.

There are a variety of possible optical schemes. We have individual LED's (infrared ones that you can't see but the phototransistors see very well) and individual phototransistors. Most groups use packages containing an LED and phototransistor and designed for the either reflection (again fairly sensitive to the distance to the reflective surface - typically best at about 1/4 inch), or to have the light path broken (but with a pretty narrow space between the LED and phototransistor).

Note: The current through the LED's should be limited to about 20mA for most of them (the spec sheets may or may not tell). The pull-up resistor on an open collector should probably be 1 - 10K (check the spec sheets - you don't need high speed). The collector resistor you will need for a phototransistor will depend on the way you build your sensors and how much light is hitting it. If you have trouble getting enough gain, use a comparator or an op-amp to act as a comparator.

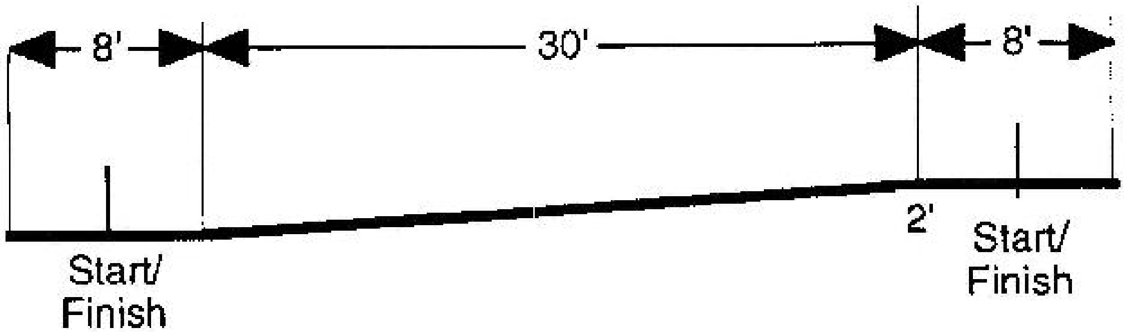
Requirements for 2b:

You must demonstrate redundant working sensors. If you used "ticks", generate a 1 millisecond pulse every time a sensor "fires". The pulse length should be accurate to within 1 microsecond. Other sensors approaches should be demonstrated appropriately. We will test the cars by attaching power to the motor and driving the wheels at various speeds. For "ticks", the pulse lengths should remain constant, independent of speed up to reasonable speeds (maybe 10 mph, not 40 mph), and pulses should be evenly spaced (to within 10%) at constant speed. There must be no "missing pulses" due to a sensor not firing reliably.

You can put out your pulses on whatever pin you want - we'll just need to look at it on a scope for the demo. You should be able to run the motor slowly from the power supplies in the lab (you should be able to run your board off one supply, and the motor off the other.) However, the maximum current limit is 2A, which is not enough to run the motors fast.

Project 2c:

You must design and build the circuitry to drive the motor on your car with your processor. (Pulse-width modulation using a power MOSFET is strongly recommended; although not required, you may later want the capability of driving in reverse). Then you need to design and implement algorithms to control the speed of your car. The speed control will be tested on the ramp leading to the lower level of the Energy Wing (G-wing) of the EQuad -- near the loading dock. The ramp rises about 2 feet. The course looks approximately like:



The actual timed section starts and ends a few feet before and a few feet after the sloping part of the ramp, at the Start and Finish lines shown in the figure. There is at least 4 more feet on each end so that your car can accelerate, and there's room to catch it before it hits a wall. In both directions it should maintain a speed of 3ft/sec, give or take 10%. The times from start to finish (both uphill and downhill) will be measured, and both average speeds must meet this specification. Do not rely on the distances shown above as being exact. You can only count on starting and finishing on a flat area, with a few feet to accelerate. Once you have satisfied the speed control requirements on the ramp, showing that your speed control is robust in dealing with variations in gravitational forces due to the slope, you must run your car on a flat 30 ft course in the lab and achieve 2% accuracy for the nominal 3 ft/sec speed (9.8 to 10.2 seconds elapsed time) to receive full credit for the demonstration.

We have several "dynamometers" (test stands) for testing the speed of your car under a vague approximation of "real world" conditions. The inertia of the rolling pins is considerably less than that of the car, but better than nothing. One useful test is to put your hand on the rolling pin to see if your control loop will compensate by raising the power to the motor, and then whether the control loop will oscillate when you take your hand off. Since the real car has more inertia than the rolling pin, the same parameters probably will not work both in the box and on the ramp. There is an optical sensor to pick up the speed of the rolling pin. It is an LED and phototransistor. The datasheet is attached to the side of the box. Remember, the maximum forward LED current is 40mA (20 mA is plenty), the maximum reverse voltage on the phototransistor is 2V (make sure you have the polarity right before turning on the power) -- do not burn out the sensors, and if you do, make sure you let the Gene in the EE shop know so that it can be replaced. The rolling pin is 9 1/4 inches in circumference and there are 10 foil strips around it, so you can measure the output of the phototransistor with your scope and determine the speed from the frequency (30 mi/hr is 44 ft/sec. and corresponds to about 572 Hz).

- Both members of a group must be present for the demo.
- A write-up which discusses the final hardware and software design, including any changes from the plan you presented at the design review (there is **no** penalty for changes), a commented program listing, etc. must be turned in at the beginning of class one week after the demo deadline.