

Drive-by-Wire Go-Kart:
Implementing Methods of Electromechanical
Control

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Abstract. The goal of this project is to design, build, and implement a go-kart using electric circuits in lieu of conventional mechanical systems. In effect, the driver will be able to control braking and steering via electronic signals rather than physical linkages. A simple go-kart design will be used for the vehicle frame. The steering and braking input will be controlled through a joystick. The signals will be fed through integrated circuits and programmable chips. The cost of the project and its implementation is expected to approach \$1500.

Introduction. The following report is a layout of the vehicle and control design and the approach to integrating the mechanical and electrical aspects of the kart. A technical discussion will provide background and motivation for the project design, followed by a critical path method to outline the tasks and phases needed to accomplish the goal, qualifications of the engineers proposing this project, and the estimated cost of designing and constructing a drive-by-wire vehicle.

Technical Discussion. The focus of this project is on designing the vehicle apparatus, creating the control algorithms to convert electrical signals into mechanical actions, and integrating the electronics with the apparatus for performance testing.

Vehicle: The electric vehicle to be designed, prototyped, and tested is meant to serve as a low-speed transportation vehicle. It is intended for use around campus on level and gradient terrain, asphalt, grass, and packed dirt. The vehicle will operate outdoors, in an inland Eastern Pennsylvania environment, excluding snow. The vehicle will be stored indoors. Performance criteria are listed below in Table 1.1. Table 1.2 shows a detailed list of estimated vehicle loads.

Table 1.1 Vehicle Performance Criteria

Speed	5-15mph 60% at 12mph, 15% at 15mph, and 25% at 5mph
Range	1.5 – 2hrs
Rolling Resistance	Minimum = 11 lb Maximum = 40 lb
Grade Resistance	Maximum grade = 11°, Load = 134 lb
Total Vehicle Load	700lbs

Table 1.2 Estimated Vehicle Loads & Costs (Estimates are high end values.)

1. frame	square steel tubing, 1/8" wall	75lbs	\$50
2. other frame pieces	aluminum	30lbs	\$50
3. wheels/tyres	2 driving wheels (10" diameter, 3 1/2" base, pneumatic, light tread from Smitty or 18" diameter), 1 freely rotating wheel	40lbs	2 x \$40 1 x \$30
3. motor x 2	brushed dc electric, series or traction	60 – 100lbs	2 x \$400
4. battery (one or two?)	lead acid, deep cycle	100–200lbs	2 x \$90
5. single passenger	maximum allowable load of the driver	250lbs	\$0
6. sensors and controllers		15lbs	tbd
Estimated Totals	estimated maximum laden vehicle weight, to be used for motor sizing calculations	700lbs	tbd

The proposed vehicle design will take the form of a tricycle, using a triangular frame and three wheels. Though large enough for a single operator weighing up to 250lbs, the vehicle size will be kept to a minimum in order to limit weight and cost. Vehicle strength and stability for multiple loading situations will be analyzed to determine safety and ideal loading. For simplicity and ease of construction, rear-wheel direct drive will be used – connecting each of two motors to each rear wheel. Using direct drive requires that gear-heads or gear-motors be used. Gear-motors use a gearing system to increase torque and reduce angular velocity so that the necessary torque is supplied at an appropriate angular velocity to the wheels. Steering is controlled electrically, driving each motor and wheel independently, eliminating the need for a mechanical differential.

Batteries: The lead acid battery is chosen primarily because it is relatively inexpensive, as compared to nickel metal hydride (NiMH) batteries, for example. Lead acid batteries are widely used in electric vehicles for this reason. A distinguishing feature is its low internal resistance, which means that voltage does not fall off a lot when current is drawn (Larminie 2003, p30). According the *Battery Council International*, 98% of lead and plastic from lead acid batteries is recycled, and new batteries feature 60-80% recycled lead and plastic. Lead acid batteries also support the US lead industry, consuming more than 80% of lead produced in the US (*BIC*). A 24V system has been chosen to support the vehicle

propulsion system: motors and motor controllers. Because of restricted person-power, it will be best to create the system from 6V or 12V batteries (so they can be easily moved and positioned).

Motors: Brushed DC electric motors are selected for their low-cost appeal. Series, traction, or permanent magnet motors will supply an appropriate torque-current proportionality for the purposes of this vehicle. As discussed above, the use of a gear-motor has been selected to supply high values of torque at lower angular velocities. The motors are selected to meet performance criteria: to operate on level ground and asphalt at 12mph, to accelerate from 0 to 4mph in six seconds, and to climb a hill with a maximum 11% grade. Motors with appropriate stall-torque, continuous torque, and no-load speed features have been selected to maximize efficient use. Relevant calculations are appended at the end of the document.

Electrical Control: The control aspect of this project requires an electronic control unit (ECU) which will consist of an integrated circuit board with programmable chips. The overall schematic of the control system is shown in figure 1 below. We will use potentiometers as sensors because of their relatively low cost and ease of implementation. For the steer-by-wire and break-by-wire aspects of the project, the potentiometers will be used to measure the position of the joystick (i.e. how much it moves along the x and y axes) which is the input into the system. A combination of A/D converters, integrated circuits, and programmable chips will then process the analog signal and output it in the form of the dc motors' response and consequently the movement of the rear tires of the vehicle. The programming will most likely be executed with Matlab or in simple C code, because of our familiarity with its use; however, we are also going to explore alternative programming for communicating with the circuit board. We are also considering placing sensors on the wheels in order to measure wheel speed and angle, which will then be used as feedback into the circuit to adjust the wheel speed and direction. Optical sensors seem to be the most common means of achieving this. We will experiment with the concept of PID control to process the feedback and smooth the vehicle movement. The cost for the electrical control portion of the project is detailed in Table 1.3.

Bill of Materials (Control)

Material	Supplier	Quantity	Cost	
Joystick	CH products	1	\$20	
circuit board	Engin Dept	4	tbd	
brake pads		2	\$20	
potentiometers	Engin Dept	tbd	tbd	
current meters	Engin Dept	tbd	tbd	
digital encoders	Engin Dept	tbd	tbd	
A/D converters	Engin Dept	tbd	tbd	
D/A converters	Engin Dept	tbd	tbd	
microcontroller	Engin Dept	tbd	tbd	

Table 1.3 We are estimating at least 6 hours of technical help a week from Grant Smith. It is expected that most of the materials required for the circuitry be available in the Engineering department labs.

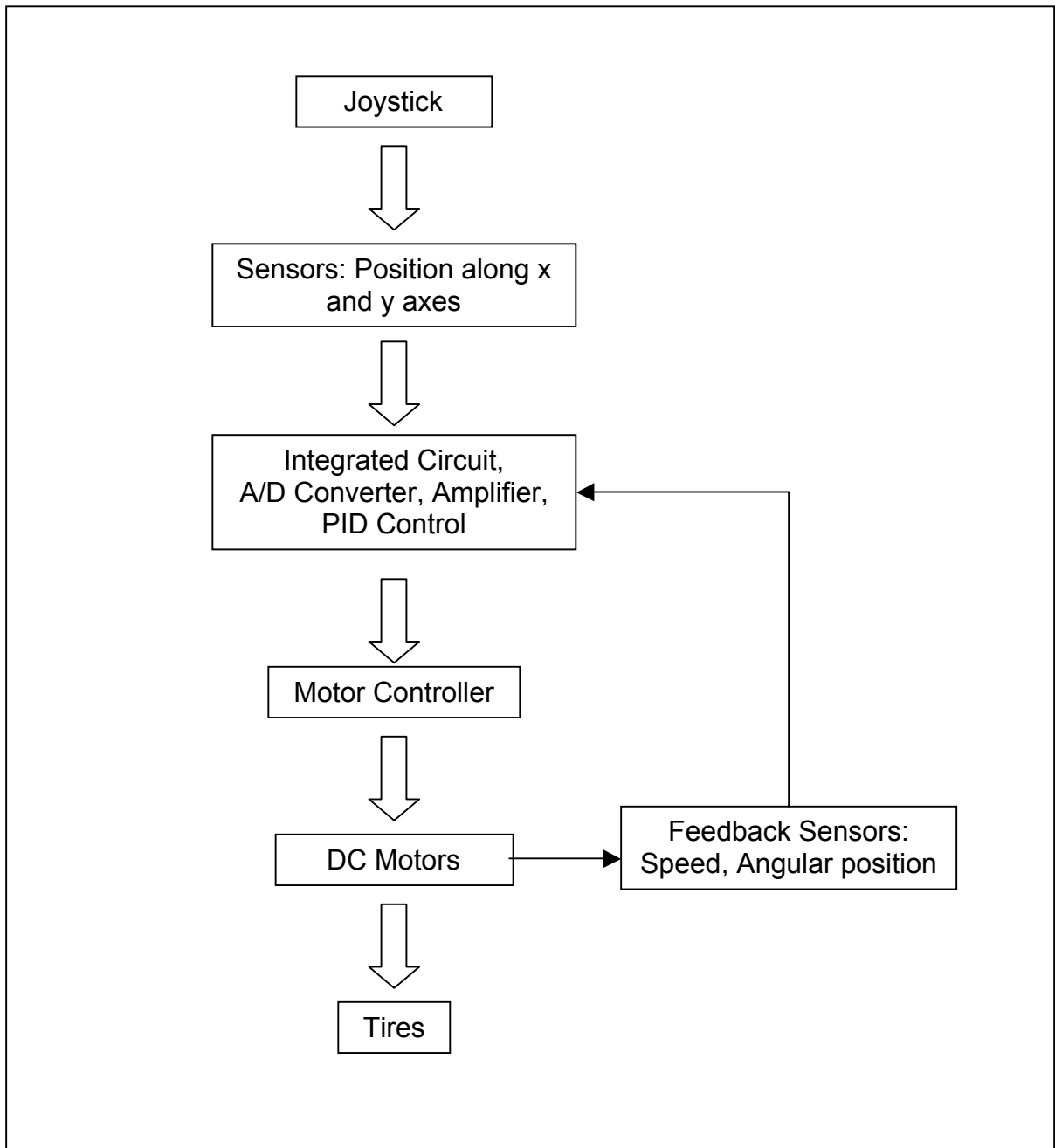


Figure 1. Diagram of control system of drive-by-wire vehicle.

For the analysis portion of the project, we plan to create a program for data acquisition, which we can use during the integration and testing phase in the lab (this will be considered the theoretical performance of the vehicle). While running control algorithms on the vehicle apparatus, we can simultaneously output the maximum wheel rotation speed, the unloaded lifecycle of the battery, and efficiency of the vehicle (work of motor versus work output of vehicle) to a computer. During the performance testing of the go-kart on

an actual road (the experimental performance of the vehicle), we would like to have some way of measuring and displaying the speed of the vehicle and the distance it has traveled. We could then record the maximum and minimum values of each parameter during testing, or store these in memory and analyze it at a later time. Afterwards we can compare the theoretical to experimental values to analyze the overall performance of the vehicle design.

Safety.

As with any engineering project, there are safety concerns which must be addressed. The first and foremost concern is that of the driver. To protect the driver from injury while operating the drive-by-wire vehicle, we will include a seatbelt to minimize the chances of the driver being ejected from the vehicle if he or she should drive onto rough terrain or experience any abrupt motion changes in the vehicle. We will also include a roll-bar similar to the type of stop bar found on motorcycles to prevent the vehicle from rolling or tipping over. Another serious safety issue is a fail-safe braking mechanism, should there be a glitch in our control code or in our circuit. Our solution to this problem is to implement a two-stage braking system. The first stage would be triggered by a button on the joystick control which would cause the dc motors to disconnect from the power source. The second stage would then be a brake pedal, mechanically linked to brake pads, which, when pressed, would apply friction to the surface of the tires and cause the tires to stop rotating.

Project Plan.

The Critical Path Method outline and diagram are displayed below.

Arrow	Task	Follows Task	Task Duration (in days)	Effort (in hours)	Task Completed (by week)
A	Research drive-by-wire and go-kart design				
B	Preliminary vehicle design calculations: load, power, etc.	A			
C	Preliminary electrical design: sensors, controllers, etc.	A	3	10	
D	Finalize chassis design	A,B	3		
E	Order: steel square tubing, aluminum plating, wheels, dc motors, lead acid battery/(ies)	A,B,D	10		
F	Shop work: weld frame; install seat, batteries, motors, drive shaft, and wheels onto frame	A,B,D,E	10	30	
G	Order sensors, controllers	C	18	5	
H	Research chips and op-amps	-	2	6	
I	Design circuit board	-	7	20	
J	Order circuit board	I	10	2	
K	Assemble and test circuits: send signals from joystick to microcontrollers, from microcontrollers to motors, from sensors to microcontrollers (position and speed of wheel rotation)	J	6	20	
L	Produce forward wheel rotation and acceleration	G,K	6	20	
M	Produce Reverse rotation, acceleration, and braking	G,K	5	20	
N	Get wheels to turning left and right	G,K	5	24	
O	Combining all control codes	K,L,M,N	2	5	
P	(Integrate Adem's steer-by-wire control)	-	?	?	
Q	Limited integrated testing: Get circuit control and joystick integrated into car while keeping connection to computer alive. Test to see that appropriate outputs show on computer	F,O	6	30	
R	Complete physical integration of control and vehicle: Disconnect computer from circuit board. Electrical control and chassis should be completely integrated into car and joystick to wheel control should be operational.	Q	8	32	
S	Create data acquisition code	O	1	5	
T	Performance testing and Analysis	R,S	6	18	
U	Adjusting Control	T	3	6	
V	Write Report	U	10	30	
W	Project Presentation	V			

Project CPM

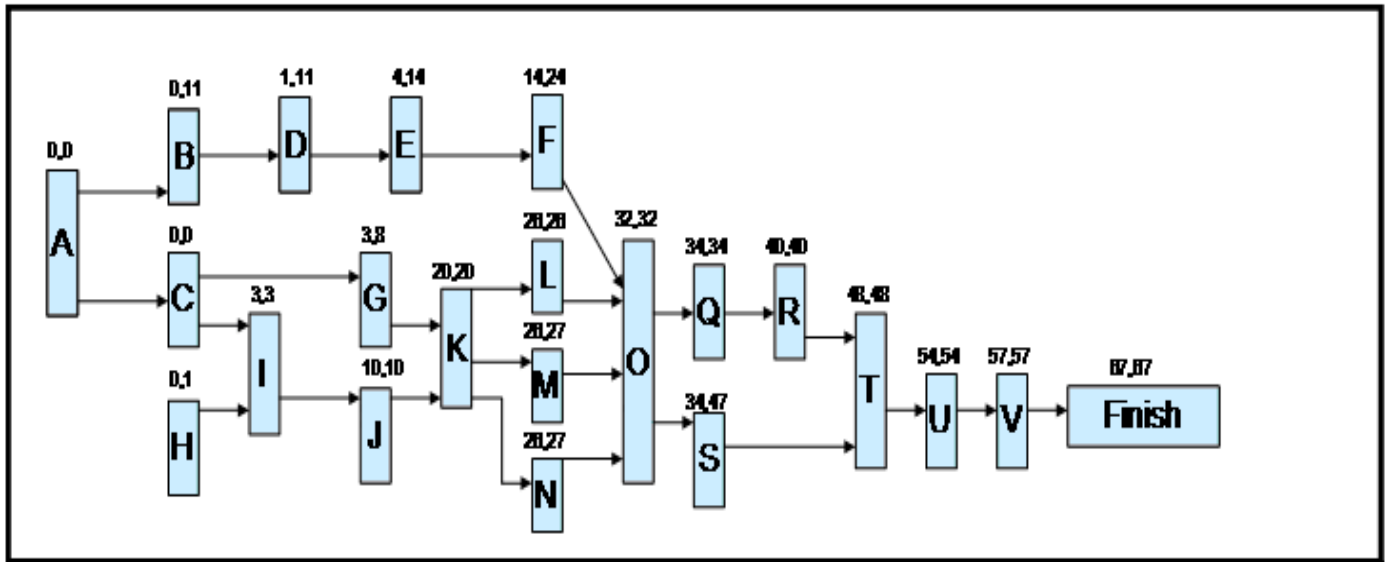


Figure 2

Project Qualifications. For the mechanical aspect of the project, we will be drawing on concepts we have learned in Statics and Dynamics and Mechanics of Solids courses. We hope to apply what we have learned in our Electric Circuit Applications, Control Theory, and Digital Systems courses to design and implement control algorithms for the electrical system.