John Deere XUV Gator 850D
Robot Documentation

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1 Preface

Hello Reader!

My name is Justin Poh and I am (was) a senior at Olin College who graduated in May 2016. If you're reading this document, you must be working on the John Deere Gator XUV vehicle. Well, you're joining a unique group of individuals who have been working on this vehicle starting with the 2009 - 2010 SCOPE team.

This document is meant to be a manual for how to run, use and work on the vehicle at the point that we left it. We also intended for this document to serve as something that can be continuously updated by subsequent teams of students in an easy and efficient manner. As such, in addition to the PDF and printed copies of this document, the original files are stored in a github repository at `https://github.com/olinrobotics/GatorResearch_Documentation`. Since everything was written in Latex, downloading any Latex editor should allow anyone to modify this document and update it as the state of the vehicle changes.

I hope you find this document useful as you work on the vehicle and good luck!

Cheers,

Justin Poh
Ground Vehicle Lead, Olin Intelligent Vehicles Laboratory
Class of 2016

2 The Mechanical System

2.1 Preface to the Section

Most of the mechanical components on board the vehicle were installed by the SCOPE team that first worked on the vehicle in 2009 - 2010. As such, most of this section consists of pages extracted from previous SCOPE reports. As such, you will notice that many of the figures in this section don't show up on the list of figures and the figure numbers don't line up with the figure numbers in the rest of this document. Today, this mechanical system remains largely the same except for the following changes:

1. The monitor mentioned in the original SCOPE team report is the Nortec SUN-1710-P daylight-visible monitor. The current monitor on the vehicle is a standard Acer monitor

2.2 Gas and Brake Actuation System

Both the accelerator and the brake actuation systems utilize Model 751 linear actuators available from PQ Controls (Figure 9).

Fig. 9. PQ Controls Model 751 linear actuator

These actuators have a 3 inch throw and supply up to 90 pounds of force. The accelerator pedal requires approximately 20 pounds of force and 1.5 inches of throw, while the brake pedal requires approximately 45 pounds of force and 0.5 inches of throw. This allows for comfortable margins of safety for both force and distance. The actuators run on 12VDC and draw 3.8 Amps of current at stall.

Control is accomplished through a 1-4V command line where voltage maps linearly to position. Note that the end position and linear scaling factor are based on the voltage at the time of power-up, so for simplicity's sake, the actuators should always be powered on at 1V in the fully relaxed position.

A separate 12V clutch line provides the capability for emergency override–when power is cut to the clutch, the actuator arm can slide relatively freely, requiring only 8 pounds of force to move. This is well under the force provided by pedal return springs and the force which a human operator can easily apply. For simplicity, the linear actuators' clutch and power line have been tied together, so cutting power to the clutch also removes power from the actuator as a whole.

The actuators are environmentally sealed and resistant to humidity, water, dirt, dust, and mud.

6.2 Brake Actuation System

The brake pedal actuation system consists of a PQ Controls linear actuator mounted to the vehicle frame and coupled to the brake pedal. The existing brake pedal mounting bracket–

which is located above and behind the top of the brake pedal–provides a convenient attachment point for a linear actuator mount. This bracket is show in Figure 10.

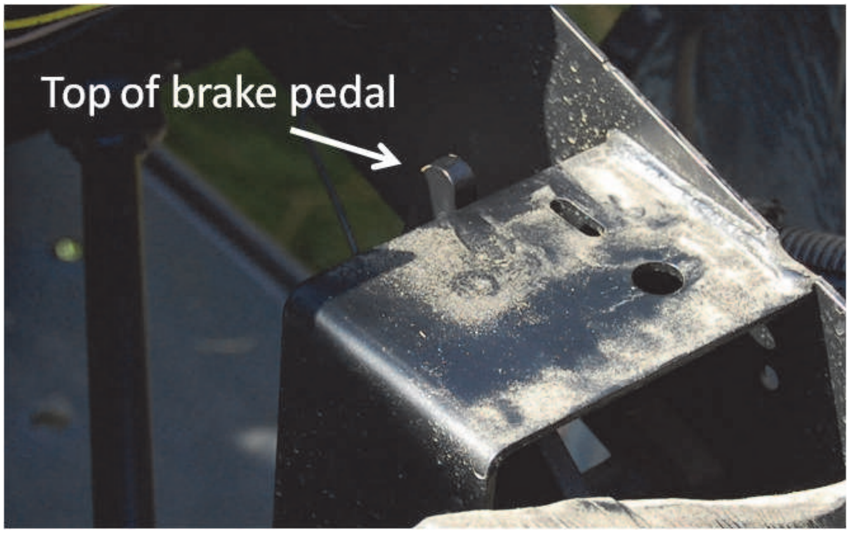


Fig. 10. The brake pedal mounting bracket.

Although this bracket provides a convenient mounting point that keeps the actuator away from the operator's feet and legs, space limitations under the Gator's hood prevent the linear actuator from being mounted in the typical fashion–that is with its mounting axis parallel to that of the axis of rotation of the brake pedal. Instead, the actuator must be turned on its side and mounted on a perpendicular axis in order to fit within the available space profile.

The actuator mounting bracket consists of a bent bar of 0.25" 6061 aluminum bar stock that holds a steel pin on which the actuator is mounted. Shaft collars prevent the pin from sliding free. In the future, the aluminum mounting bracket could be replaced with one made of black anodize steel, although this is not necessary for normal operation of the vehicle. The actuator mounting bracket bolts to the Gator brake pedal mounting bracket via two post-machined holes. Figure 11 shows the assembly before the linear actuator is added.

To allow the linear actuator to actuate the brake pedal, a brake pedal extender arm (shown in Figure 12) is manufactured from 0.25" aluminum plate and bolted onto the brake pedal. It is recommended that the brake pedal be removed from the vehicle prior to drilling the brake pedal extender arm mounting holes in order to ensure accurate hole placement and alignment.

Because the actuator is mounted on an axis which is not parallel to the axis of rotation of the brake pedal, an additional parallel axis of rotation must be introduced in the coupling linkage. This is accomplished through the use of a double clevis link–a device consisting of two parallel, pivoting pins held at a constant distance from one another. These linkages are

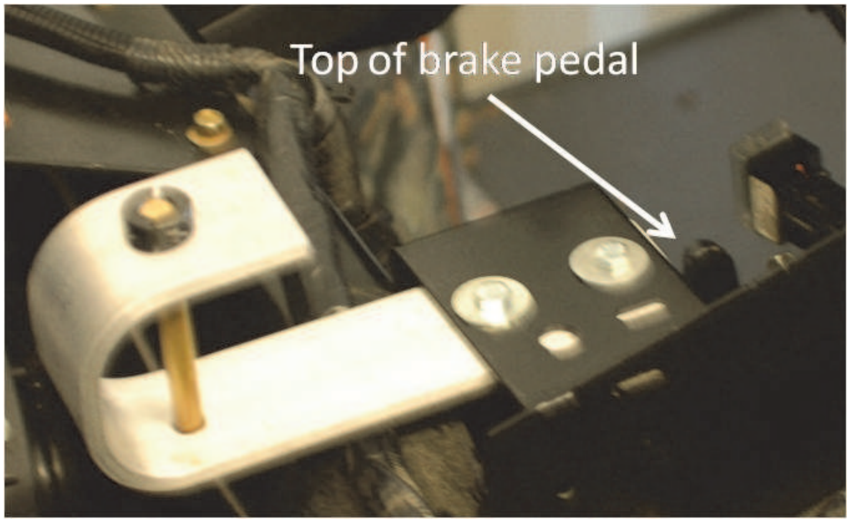


Fig. 11. The actuator mounting bracket mounted to the vehicle frame.

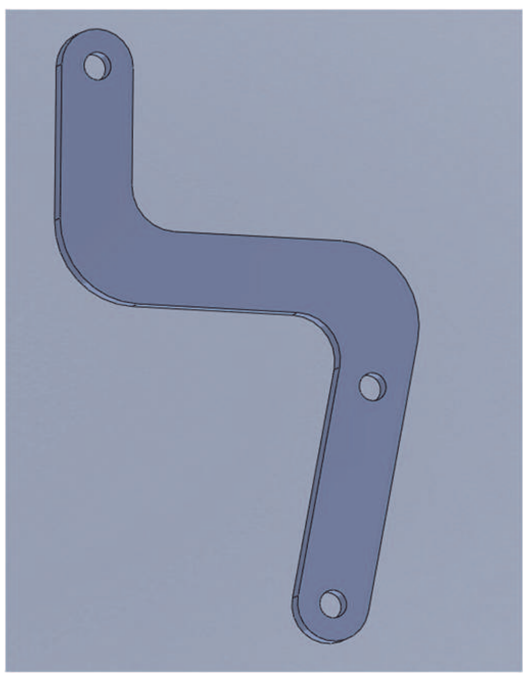


Fig. 12. The brake pedal extender arm.

available off-the-shelf from numerous hardware suppliers–the one currently used in the Gator is pictured in Figure 13. A 5/16th inch clevis link was use because it was the smallest readily available.

Fig. 13. The 5/16th inch double clevis link used in the current design.

The linear actuator rod is coupled with the double clevis link using a 5/16th inch ball-joint rod end. The other pin of the clevis runs through a bronze bushing which is press-fit into the exposed end of the brake pedal extender arm. The assembled linkage is shown in Figure 14.

A completed CAD model of the actuation system is shown in Figure 15. The CAD model is useful for understanding how the linkage converts the linear motion of the actuator to rotary motion of the brake pedal. The assembly is shown at both extremes of its actuation range–note how the double clevis linkage allows power to be transmitted without the actuator binding.

The brake pedal actuation system is fully functional and has not yet experienced a mechanical failure of any kind during testing. The completed system is shown in Figure 16.

6.3 Diesel actuation system

Our diesel actuation system is based on the same PQ Controls linear actuator as the brake actuation system. It takes advantage of the portion of the diesel pedal arm that connects to the return spring (see Figure 17). It consists of a mounting plate, a U-bracket which holds a pivot joint to mount the actuator, the actuator itself, and an arm which connects to the return spring section of the pedal arm. The return spring itself is not removed, but is simply slid to one side so both systems can mount to this section of the pedal arm.

Actuator Mounting The mounting plate for the actuator takes advantage of the center column of the vehicle being pre-drilled for a cup holder. The cup holder is held to the center column with four expanding panel clips and can be removed easily by pulling out the four retaining pins for the clips. This exposes the center column, which is made out of 0.125" steel, and four 0.28" holes drilled to mount the cup holder. An adapter plate to connect the U-bracket was machined out of 1/4" aluminum using the abrasive water jet cutter. Mounting this plate was a challenge, since the center column is welded shut from the bottom, and the

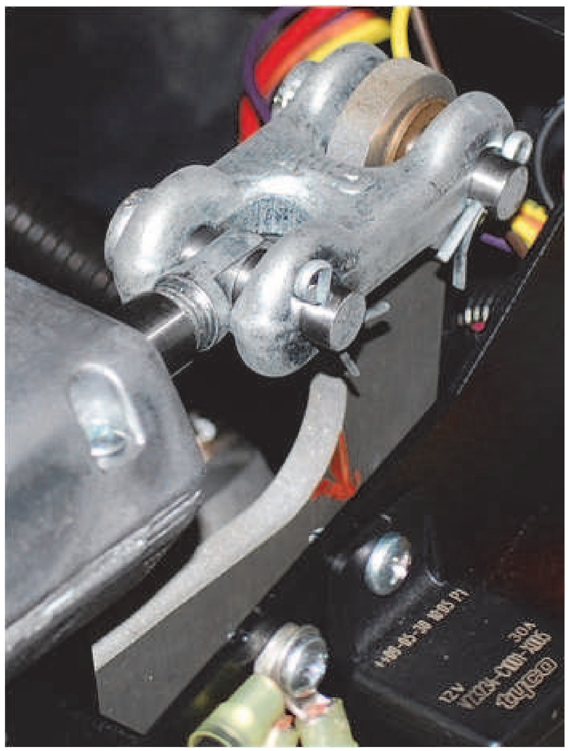


Fig. 14. The assembled brake pedal actuation linkage (top view).

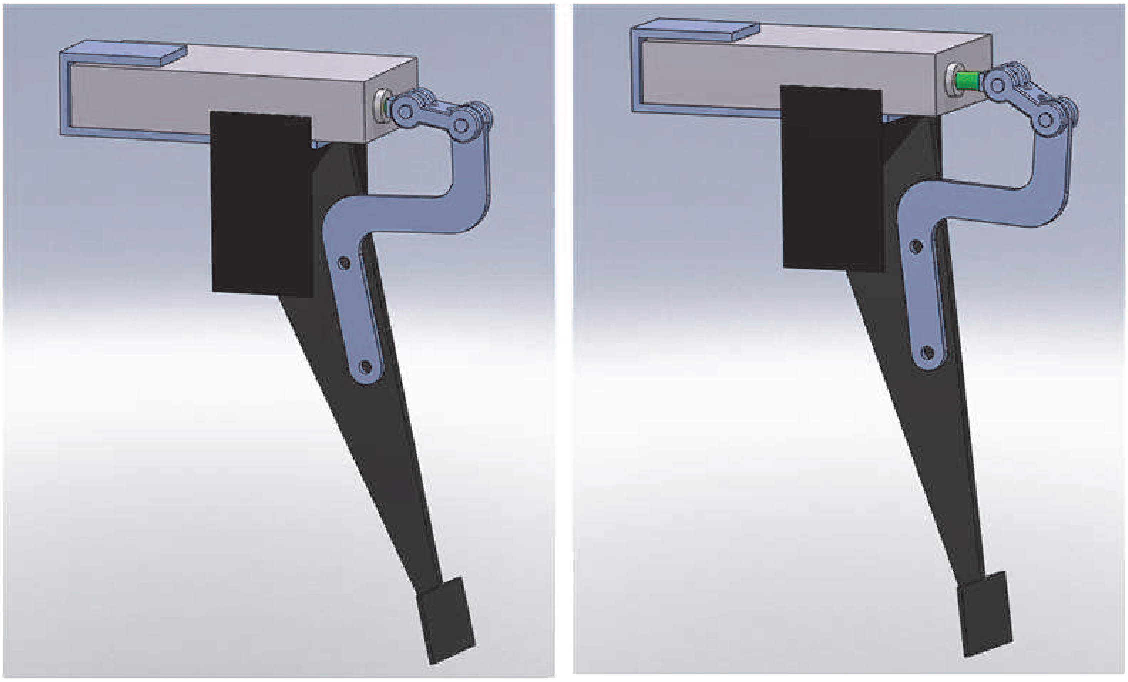


Fig. 15. The brake pedal actuation system, shown with the pedal at rest (left) and depressed (right).

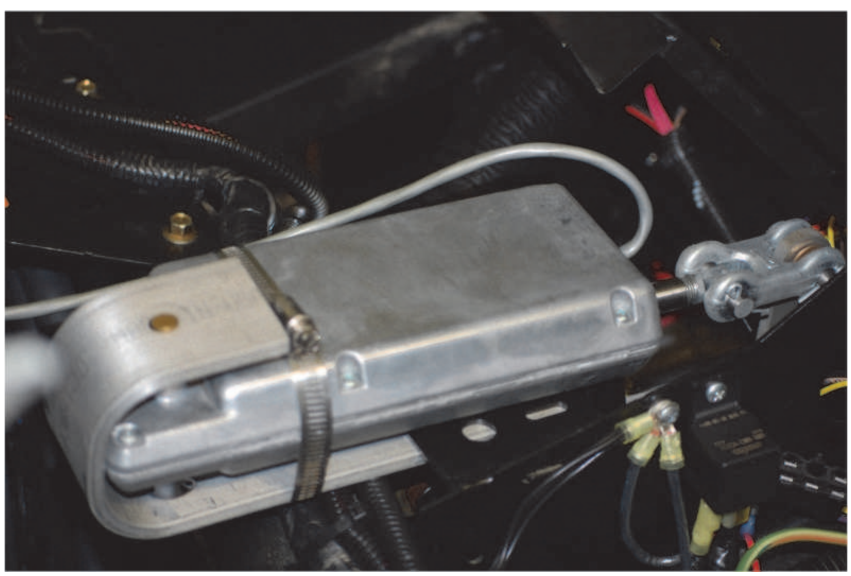


Fig. 16. The brake pedal actuation system fully installed on the Gator.

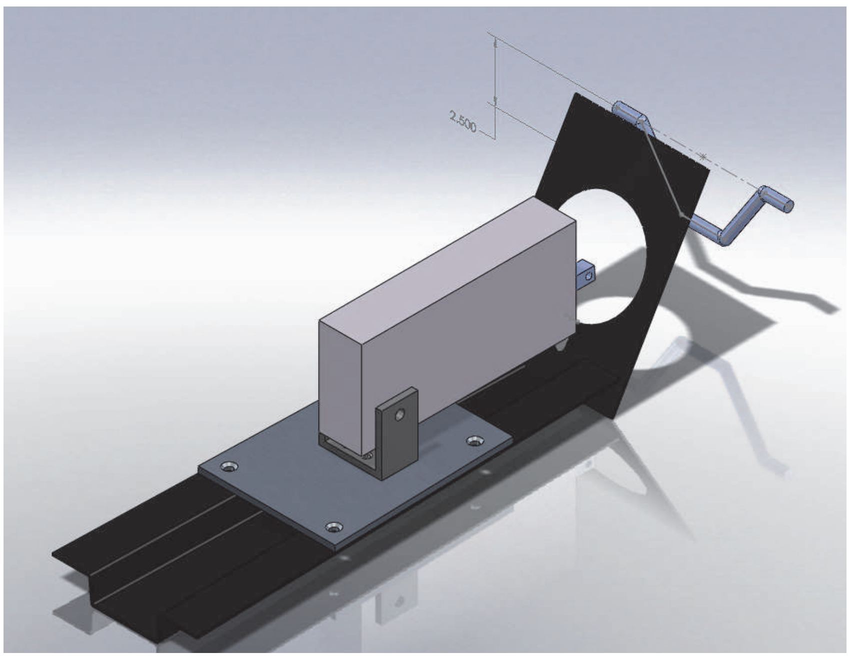


Fig. 17. A CAD rendering of the entire Diesel actuation system. The full pedal arm is not shown, but would extend from the left side of the center column of the vehicle.

power transfer shaft for the front differential is directly below two of the cupholder mounting holes. To minimize vehicle modifications, four open-end knurled rivet nuts were inserted into the four cup holder mounting holes, which must be expanded to a size of 0.4" to fit. These nuts are secured with a rivet gun, and 1/4-20 cap head screws are used to secure the mounting plate.

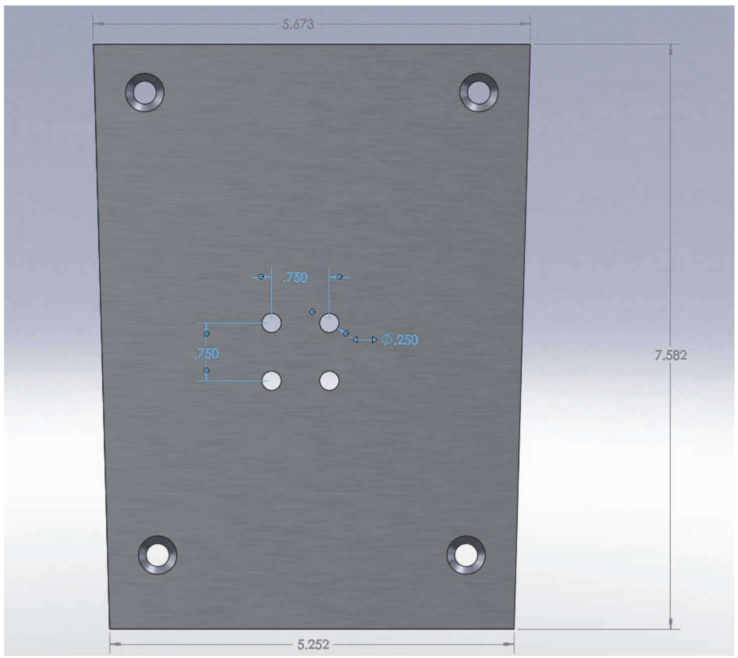


Fig. 18. A cross section of the adapter plate for the actuator mount.

The four holes in the middle of the panel are threaded for 1/4"x20 bolts. These allow for the U-bracket to be attached to the mounting plate. This bracket is cut out of a 1/4" sheet of aluminum using the abrasive water jet cutter, with 4 .255" holes for the 1/4-20 bolts which attach it to the mounting plate, and two .380" holes which will be 3.15" above the mounting plate when the bracket is bent.

A 0.375" hardened steel drill blank is fitted through the U-bracket and the mounting hole in the actuator. The drill blank is restrained using two shaft collars, and the actuator is kept from moving side-to-side (and potentially side-loading) using one additional shaft collar.

Actuating the Pedal Arm To connect to the pedal arm, the actuator uses a 3/8"x16 threaded rod, which connects to a locked-down split hanger collar (McMaster part #3023T23), held in place by a locknut. The collar uses a delrin bushing to reduce friction on the pedal arm, and to account for any misalignment between the hanger and moving shaft. Since the

PQ Actuators are built with a 7/16"x20 threaded actuator arm, a threading adapter was machined out of a section of brass rod.

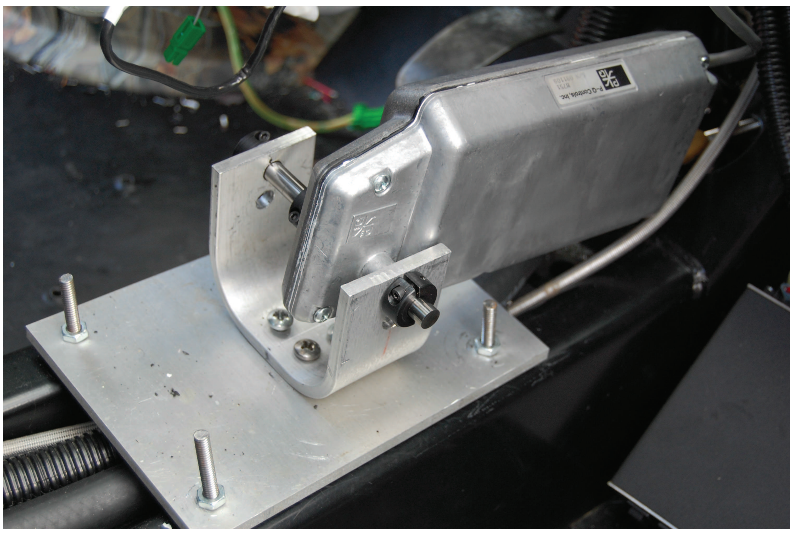


Fig. 19. A view of the entire accelerator actuator system.

Performance Because the return force of the unpowered linear actuator is greater than that of the unmodified diesel pedal return spring, an additional, stronger spring has been added in series, which means the force to fully depress the pedal is 19 now pounds, with an action arm of 6" and a throw of 6", depending on the position of the speed regulator bolt. The return spring mount is only 2.5" long, so the force required to depress the pedal by pushing on the return spring mount is approximately 45.6 pounds. Since our actuator can produce up to 90 pounds of force at a throw of 4", this performance requirement is well within its operating range.

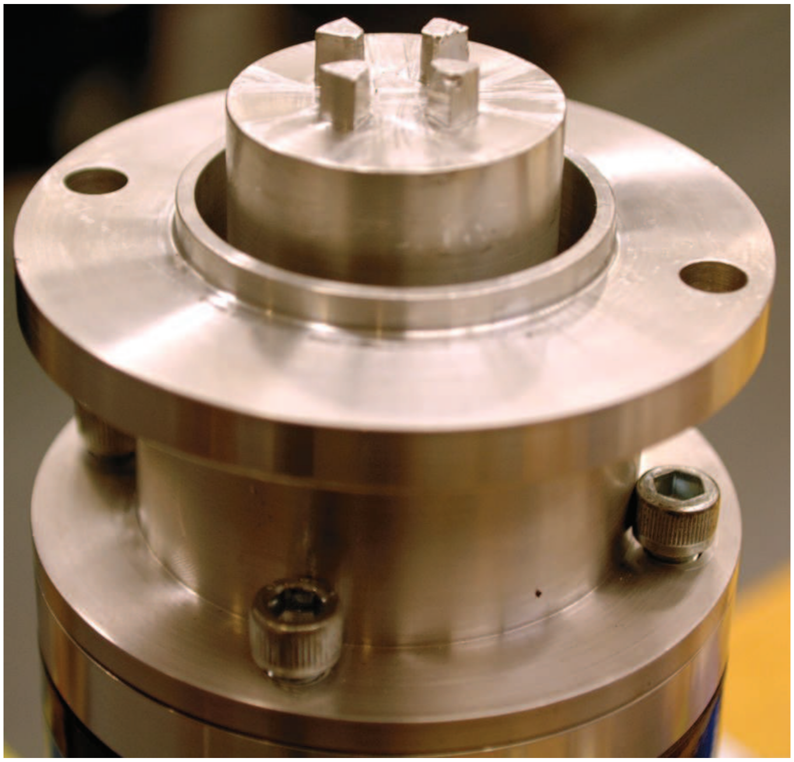


Fig. 20. Power steering motor mount.

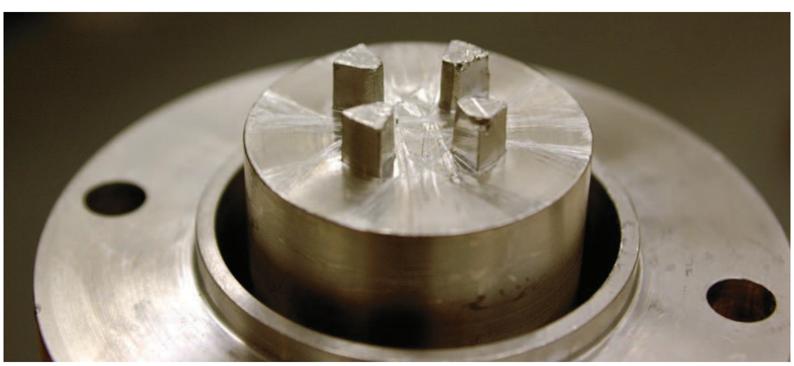


Fig. 21. Our manufactured spider coupling adapter mounted on the motor.

Fig. 22. Rear of the steering motor with additional support shown

2.3 Steering System

The steering actuation uses a pre-existing power steering assist kit that is modified to meet project requirements. This steering plan is similar to a system prototyped on the summer 2009 research vehicle, the Yamaha Rhino, and is designed by the same manufacturer. The kit required two main modifications: the addition of a more robust controllable motor and the creation of some sort of feedback method from the device. The stock motor from the power steering kit does not provide feedback and lacks sufficient power to control the vehicle in worst case conditions. Both of these issues are addressed by installing a larger motor with a built-in encoder. This solution requires several additional changes to the pre-existing kit:

1. Its position in the gator
2. The motor attachment to the rest of the power steering unit
3. The motor interface with the power steering unit to deliver power.

The motor has to deliver 150 in-lbs at the steering wheel (twice that for a sizable safety margin). The motor is limited also to 5A at 12V to remain compliant with the cRIO 9505 motor controller. The 150 in-lbs requirement was determined through experimental measurement, by turning the steering wheel from left lock to right lock and back while resting on the grass at a standstill. The motor chosen to meet these specifications is provided by Potomac Electric, and has a 4? diameter and a length of 8? with a 5/8? diameter shaft. In order to rotate the power steering kit into a more favorable position, an adapter plate was designed to fit between the power steering assembly and the brace that attaches it to the chassis. Keeping the motor in the original orientation would have required major modifications to the chassis and dashboard in order to fit the motor. Inclusion of the larger motor required development of a method for attaching it to the rest of the unit. The original motor attached to the power steering housing through an aluminum heat shrunk collar with through holes for two bolts. The diameter of the new motor made a direct analog unfeasible, requiring design a larger collar which offset the motor enough to allow use of the two existing bolt holes from the previous motor mount. Figure 20 shows this adapter.

The original motor delivered power to the steering kit through a non standard spider coupling, requiring design of a corresponding piece that fits on the new motor. The motor shaft is attached to the new spider coupling with a keyless bushing (Figure 21 shows the new coupling). When power is cut to the motor the operator has full control of the vehicle and is able to back-drive the motor. In addition to the various adaptor pieces the motor is secured by a harness on the back of the motor. The harness is shown in Figure 22 and consists of a 4? rubber-coated u-bolt, two machined plates, a threaded rod, and a split clamp hangar which attaches to pole running through the dashboard.

2.4 Steering Limit Switches

Since the steering motor encoder provides only relative position feedback, it is important to have an absolute measurement of steering position so that the vehicle can automatically calibrate regardless of the positions of the steering at startup. In the Gator AGV, this is accomplished through the use of a pair of magnetoresistive proximity sensors mounted such that the steering rack-and-pinion will trigger one at each mechanical steering endpoint.

The sensors used are Cherry MP100502 Hall Effect sensors, which output 5 volts normally and drop to 0 volts in the presence of a magnetic field of sufficient strength aligned with the sensor. One such sensor is pictured in Figure 26.

Fig. 26. A Cherry sensor.

The sensors are mounted through two pass holes drilled through the cab behind the pedals in such a way that the sensing ends are aligned with the steering rack shaft. A cab view of the back ends of the two mounted sensors is shown in Figure 27. The mechanical design of these sensors allows their effective length to be easily adjusted using the built-in clamp nuts, which is important since the effective range of the sensors is quite short and therefore precise axial positioning is required.

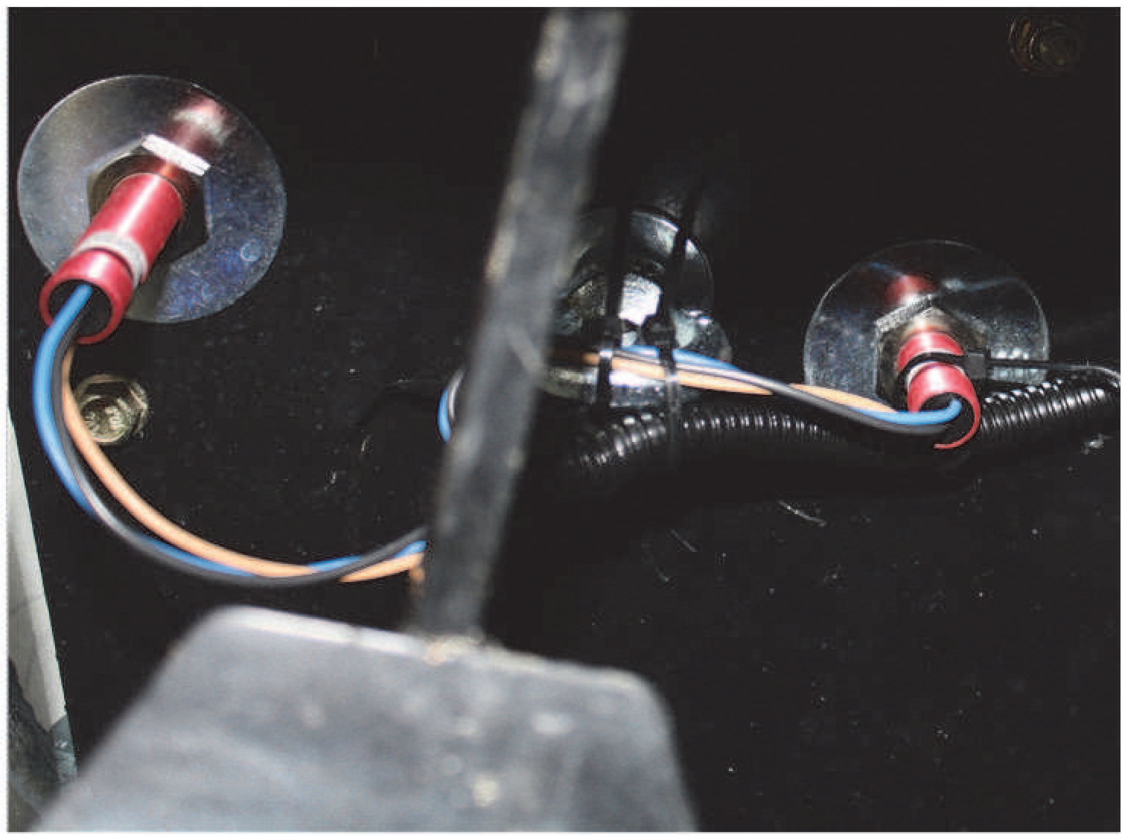


Fig. 27. Cab view of the back ends of the installed limit sensors.

To provide magnetic pickup points along the steering rack, two 3/8th inch ring clamps are attached to the rack itself, and a small circular magnet is affixed to the end of each clamp. This allows the magnetic pickup points to be easily adjusted, which in turn sets the effective position of each limit sensor as well as the steering range that they encompass. Also note that the Hall Effect sensors are only sensitive to one magnetic pole, so proper orientation of the magnets is important.

Ideally, the magnetic pickup points are adjusted so that they will trigger the limit sensors precisely inside the mechanical limit of the steering. This allows the automatic steering calibration routine to run regardless of the initial position of the steering column, as a turn in a certain direction will always hit the same sensor. Additionally, this allows the limit sensors to double as a shutoff triggers if a problem develops with the steering control software during a run, while at the same time preserving the maximum useable range of steering.

2.5 Wheel Encoder Mount System

To provide velocity feedback for vehicle control, the Gator utilizes an optical wheel encoder. The wheel encoder mounting consists of an ANSI 35 sprocket and chain system pictured in Figure 23. One sprocket is attached to the optical encoder shaft, and the other is driven by the driveshaft located under the utility bed on the right side of the Gator. The driveshaft sprocket was manually split and fitted with socket head cap-screws in order to mount it around the shaft without requiring major disassembly of the Gator platform. The encoder itself is bolted to a length of steel L-channel, which is in turn bolted to the frame of the gator using a pair of tap rivets. Using a sprocket chain allows the system to accommodate the slight yet inevitable misalignment that results from this assembly. Because of the tendency of sprocket chain to stretch over time, all sprocket chain systems require some way to dynamically tension the chain. In this system, tensioning is accomplished through the use of a flexible polymer sprocket ring designed to provide tension to roller chain systems without extra mounting hardware. Because of its natural elasticity, the polymer sprocket ring exerts a radial force on the sprocket chain loop, keeping the chain in tension as it spins. Since velocity feedback will be derived from the rotary motion of the encoder, it is important to understand the ratio between encoder ticks and vehicle speed. Since the chosen encoder has 500 ticks per revolution and the sprocket system results in 16:9 gear ratio between the vehicle drive shaft and the encoder shaft, the encoder will register approximately 890 ticks per revolution of the drive shaft. There is a one-to-one correspondence between rotations of this shaft and rotations of the tires, which are approximately 23 inches in diameter. Using this a baseline and calibrating further using field testing, it was possible to establish a ratio of 3000 encoder ticks per foot of forward vehicle movement.

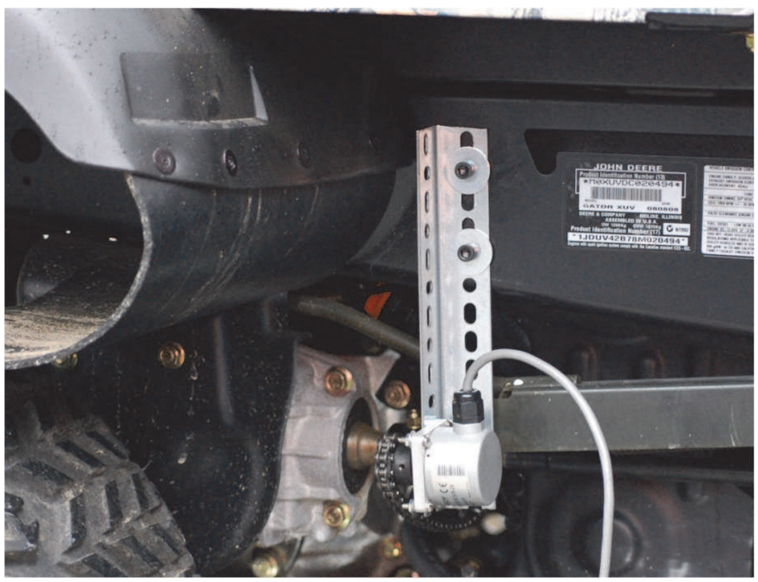


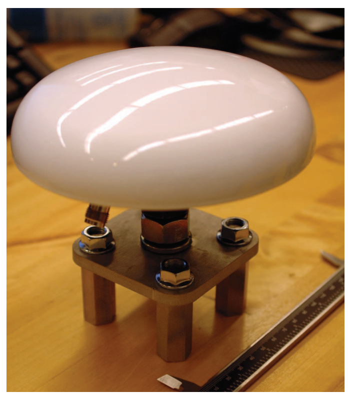
Fig. 23. Wheel encoder sprockets and mounts.

2.6 Generator Mount

The system's gasoline generator is mounted to the rear of the Gator's utility bed by two standard ratcheting tie-down straps. The straps attach to four 800-pound working load tie- down rings which have been installed in the base of the utility bed.

2.7 GPS Mount

To fulfill our goal of GPS-guided navigation within a parking lot, we needed to mount a GPS antenna. The mount had to be less than 6? in height, as it would have to clear the top of the parking container with 10? of entryway clearance while mounted on top of a roof-mounted pegboard approximately 2? in height. The GPS mount consists of a 2?W x 2?L x 1/4?T sheet of aluminum drilled to accommodate 4 3/8? holes spaced to correspond with 4 3/8? holes in the pegboard, and one 5/8? hole in the center. Four 3/8?x16 standoffs are used to elevate the plate, to accommodate for the head of a 5/8?x11 bolt which is attached threads-up to the plate using a nut with locking washer. The antenna is designed to screw onto the large bolt and is then held on using a locknut with built-in serrated washer. Altogether, the unit measures approximately 5.5 inches in height.



2.8 The Electronics Box

The electronics box mounted to the back of the vehicle is, of course, where most of the electronics including the computers, FPGA chassis, the power supplies, and most of the power distribution elements on the vehicle are housed. In order to make the box suitable for use on the vehicle, three modifications were required: cooling vents, power and signal wire ports, and a system for mounting the electronics inside the box.

The electronics box is essentially a heavily modified Nothern Tools Co. metal tool box that is mounted on two vibration isolating rails in the bed of the vehicle. The mounting system consists of two pieces of square channel high tensile strength steel with corrosion resistant coating that is bolted to the bed of the vehicle. The box is then attached to the steel with four vibration-damping sandwich mounts allowing for a relatively smooth ride. This simple system is robust and requires relatively little assembly.

The cooling system for the electronic boxes uses two 120mm computer case fans and two weatherproof vent covers (such as those used for hot air exhaust in houses) mounted on two 5? vent holes. These exhaust vents will be weather-sealed during installation using outdoor caulk. Signal wires are routed out of a third 5? weatherproofed vent on the bottom of the box, as are all power wires. The electronics plate is designed to be mounted on a supporting frame using several bolts, to reduce plate flexure and potential damage from shocks from rough terrain. The supporting frame is fastened to the sides of the electronics box using screws that have been weatherproofed with silicone sealant.

The vehicle also includes a roof-mounted optics-quality pegboard for sensor mounting.

3 The Electrical System

The electrical system consists of two parts: the power distribution system and signals. Each will be discussed in the following sections. Wiring diagrams are provided in Appendix.

3.1 The Power Distribution System

3.1.1 Power Supplies

Power to the entire system comes from the 3-prong plug running through the PVC pipe fixtures on the driver's left side of the electronics box.

Figure 1: The power strip on the side of the electronics box

The 3-prong plug attached to the power strip plugs into building power when the vehicle is in the Large Project Building and supplies power to the power strip mounted on the wall of the electronics box on the driver's left side. Alternatively, during operation, the 3-prong plug is plugged into a Honda EU2000i generator that should be mounted in the back of the vehicle:

Power to the rest of the system is then drawn from that power strip. The devices plugged into that power strip are shown in the diagram below:

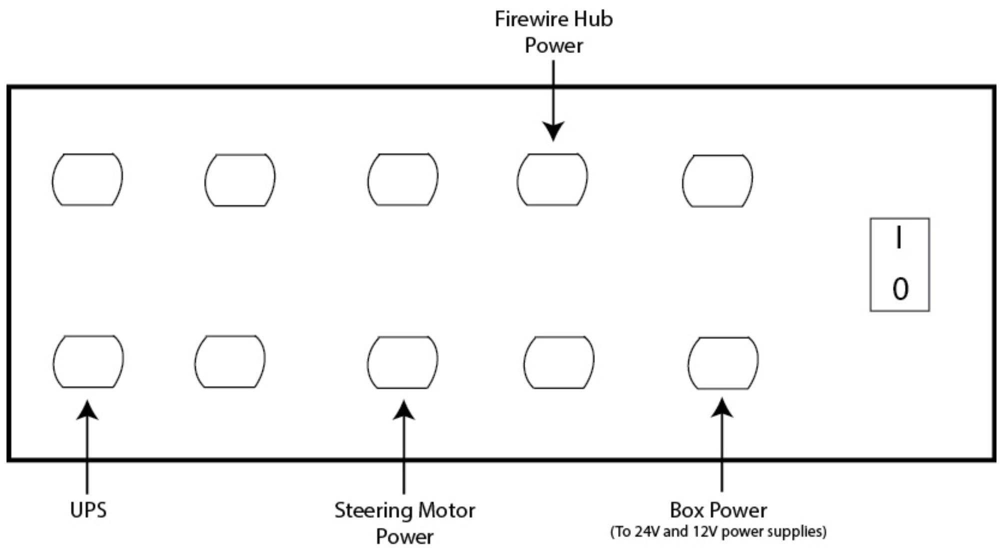


Figure 2: Drawing of devices plugged into the power strip

The entire system has 3 voltages that powers everything: 5 volts, 12 volts and 24 volts:

1. A Meanwell HRP-600-24 converts 120V AC power from the power strip to 24V DC power

2. A Meanwell HRP-300-12 converts 120V AC power from the power strip to 12V DC power

3. A Meanwell SB-15B-05 converts 24V DC power from the 24V DC power supply to 5V DC power

The 24V and 12V power supplies are located on the lower deck of the electronics enclosure and the 5V power supply is located on the upper deck.

3.1.2 Overview of Fuses

There are 4 main fuse blocks used on the vehicle to distribute power via fuses to all electronic devices on board:

1. 1 Blue Sea Systems fuse block (C24) handles all 24V power distribution
2. 2 Blue Sea Systems fuse blocks (C12 and M12) handle all 12V power distribution
3. 1 linear fuse block handles all 5V power distribution

From the lower deck, three main power busses run to the upper deck: two 24V busses and one 12V bus. One 24V bus runs to the C24 fuse block and the other 24V bus runs to the 5V power supply that converts 24V DC power to 5V DC power. The 12V bus runs to the M12 fuse block. The C12 fuse block is powered from one of the outputs on the M12 fuse block.

3.1.3 24V Power Distribution (C24 Fuse Block)

Five outputs on the C24 fuse block are used:

1. Signal to a 24V sensing probe
2. LIDAR power
3. LIDAR power
4. Navcomm GPS power
5. Safety light power

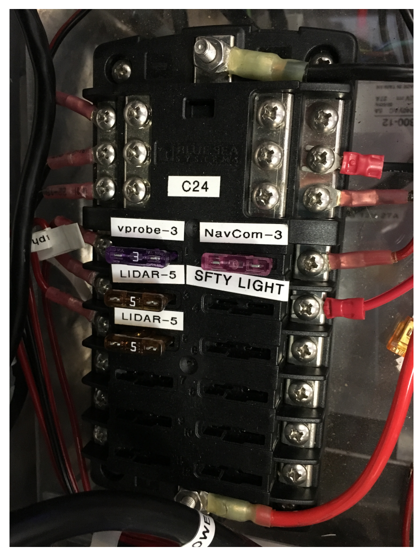


Figure 3: C24 Fuse Block

Except for the signal to the 24V sensing probe, all of the other 4 lines run to the appropriate equipment outside the electronics box. The signal to the 24V sensing probe runs to the voltage sense project box (discussed in a later subsection).

3.1.4 12V Power Distribution (C12 Fuse Block)

Five outputs on the C12 fuse block are used:

1. Power for the cab fans
2. Signal to a 12V sensing probe
3. INS power
4. Power for ethernet switch
5. E-Stop 12V power

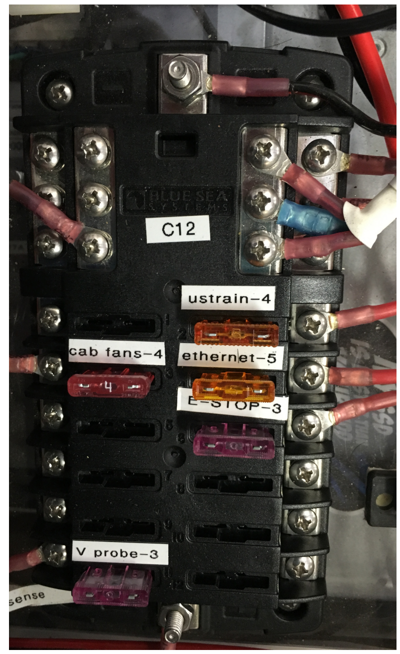


Figure 4: C12 Fuse Block

Power for the cab fans and INS power run to the appropriate equipment outside the electronics box. The signal to the 12V sensing probe runs to the voltage sense project box (discussed in a later subsection) and power to the ethernet switch runs to the netgear ethernet switch on the back corner of the electronics box on the driver's right side of the vehicle. The E-Stop 12V power is utilized by the E-Stop system, which will be discussed in a later section.

3.1.5 12V Power Distribution (M12 Fuse Block)

All six outputs on the M12 fuse block are used:

1. Right tilt unit motor power
2. Power to the C12 fuse block
3. Power to the linear actuators
4. Left tilt unit motor power
5. Box fan power
6. Box fan power

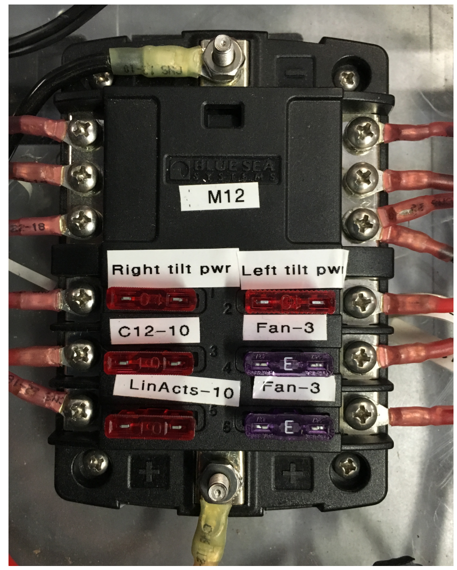


Figure 5: M12 Fuse Block

The power to the C12 fuse block is obtained from the appropriate port on the M12 fuse block. The power to each of the fans mounted to the front of the electronics box that cools the electronics box is also obtained from 2 of the outputs. Power to the right and left tilt units is also drawn from the M12 fuse block outputs and power then runs to the appropriate equipment outside the electronics box. Finally, the power for the linear actuators runs to an E-Stop relay first, then connected to two fuse terminals on the linear fuse block (discussed on the next page)

3.1.6 Linear Fuse Block (Various Power Distribution)

The four lines on the linear fuse block are:

1. Fuse for motor power coming from the steering motor amplifier headed to the steering motor

2. Fuse for the 5V DC power output from the 5V DC power supply headed to the 5V DC power terminal strip

3. Two fuses to distribute 12V power from the E-Stop relay to the gas and brake linear actuators

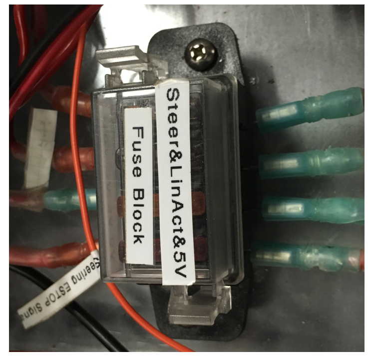


Figure 6: Linear Fuse Block

3.1.7 Terminal Strips (5V DC Power and Ground)

There are two terminal strips that serve as busses for 5V DC power and ground. The 5V DC power is used for:

1. Both commfronts that process serial signals from the LiDARs

2. To steering encoder

3. To cabin 5 volts

4. Signal to a 5V sensing probe

The ground terminal strip is used for:

1. Ground connection for the E-Stop magnet coil

2. Ground to the 5V sensing probe

3. Ground to the E-Stop relay

3.1.8 Emergency Stop System

The emergency stop system is designed to mechanically cut power to the actuators in the event of an emergency. The last part of the power distribution system is the Emergency stop system. The system is relatively simple and consists of the following components:

1. 2 red mushroom-head emergency stop switches with black plastic mounting box, 1 located in the cab and one located on the outside wall of the electronics box

2. A magnecraft 788XBXM4L magnet coil relay with 70-463-1 relay socket located on the upper deck of the electronics box

3. The E-Stop sensing probe at the voltage sensing project box (discussed in the next section)

The power source for the E-Stop system is a fused 12V terminal from the C12 fuse block. One branch of thsi line is then run through all the E-Stop switches. There is a second branch of this line that then runs to a relay on the upper deck of the electronics box. This relay controls power to the linear actuators and steering motor amplifier. When the E-Stops are not pressed, the line reads zero volts. When the E-Stops are pressed, the line is pulled up to 12V and that triggers the relay to open the normally-closed circuits and close the normally-open circuits, shutting down power to the linear actuators and disabling the steering motor amplifier.

3.2 Subsystems and Signal Connections: Steering System

The steering system is comprised of the following components:

1. Potomac Electric DC motor and steering encoder, which is an after-market power steering assist motor purchased by the 2009-2010 SCOPE team

2. Advanced Motor Controls 30A20AC analog servo drive with filter card

3. National Instruments NI9263 module that sends +/- 10V control signals to the analog servo drive

4. National Instruments NI9411 module that reads the steering encoder signals

The 30A20AC analog servo driver and filter card are powered directly from the power strip on the side of the electronics box. The 30A20AC analog servo driver and filter card then used to drive the Potomac Electric DC motor. The steering encoder is powered via a 5 volt power line to the encoder.

The 30A20AC analog servo driver takes PWM inputs and puts out motor voltage to the steering motor. In the LabVIEW FPGA code, the steering controller code communicates with the NI9263 module and uses the NI9263 module to output PWM control signals to the 30A20AC analog servo drive. Based on those PWM signals, the 30A20AC analog servo drive will then pass the appropriate motor voltage through the filter card before passing those signals to the Potomac Electric DC Motor mounted below the steering wheel. The steering encoder signals are read by the NI9411 module.

3.3 Subsystems and Signal Connections: Gas and Brake Actuators

The gas and brake pedal system consists of the following components:

1. 2 PQ Controls linear actuators, one for the brake ane and one for the gas pedal

2. National Instruments NI9263 chassis that sends analog control signals to the appropriate linear actuators

The linear actuators share a common 12V power line that originates from the M12 fuse block. That power line is then split into two at the linear fuse block so that each linear actuator receives 12V power.

The linear actuators accept anywhere between 1 - 4 volts and voltage corresponds linearly to position. Given that the linear actuators both have 3 inch strokes, the conversion should be 1 volt per inch of stroke. The voltage that controls the linear actuators is provided by the NI9263 chassis that is controlled by the FPGA code.

3.4 Subsystems and Signal Connections: LIDAR Serial Communication

Serial communication with the left and right LIDARs on the front of the vehicle involves the following components:

1. 2 Sick LMLS291 LIDARs
2. 2 CommFront serial converters, one for each LIDAR
3. National Instruments NI9401 chassis that reads the serial lines

Each LIDAR receives power from a terminal on the C24 fuse block. The CommFront serial converters are needed in order to convert the RS485 serial signal from the LIDARs to an RS232 signal that the NI chassis can interprete. After the CommFront serial converters, the signals are both fed into the NI9401 chassis to be read by the FPGA code.

3.5 Subsystems and Signal Connections LIDAR Tilt Units

The tilt unit system that nods the LIDARs consists of the following components:

1. 2 National Instruments NI9505 motor controller modules
2. 2 Bodine Electric DC Motors rated for HERP

Unlike the steering system, the tilt unit system is driven entirely from the NI9505 motor controller modules. The modules themselves receive power from two sources: motor power for each module originates from a terminal on the C12 fuse block and connected to the input V+ and V- terminals on each module. The power for the controller electronics is received from the chassis itself. Each NI9505 motor controller module then drives its associated Bodine Electric motor by putting out power on the M+ and M- terminals. Each NI9505 motor controller module also handles the encoders for its associated tilt unit. The NI9505 motor controller module uses 5 pins on the serial connector on the module. 2 of the pins provide power and ground for each encoder and the other three pins handle the A, B and index outputs of the encoder. NEEDS SIGNAL DESCRIPTION?

3.6 Cabin Wire Routing

There are four areas where cables are routed into the cabin of the Gator. The first two pass-throughs are previously existing holes, located behind the driver-side seat and designed for 3/8? conduit. Conduits for communications with the cabin e-stop button and linear actuator are routed through these holes, and follow pre-existing conduits running along the left roll bar of the Curtis cab, with their last zip-tie fastening in the center of the hood, under the dashboard. The power cables for actuators and steering motor are passed through another pre-existing hole, this one located behind the battery compartment, behind the driver?s side seat and directly above the FWD crankshaft located on the passenger side of the vehicle. The final pass-though is located between the two seats, a half inch above the seat belt mounting brackets. It is not pre-existing, and is drilled to be 1.45? wide, to allow for a VGA cable for the monitor to be passed through. Conduits for monitor power and signal, as well as USB and IEEE 1394 connectivity and signal from the Cherry magnetic sensors (used as end-stops for steering and located in the driver side firewall) in the cabin are passed through this hole.

3.7 Encoder Signal Connections

The encoder signal line, including the pull-up resistor breakout boards, all obey the following pin diagrams. On the connectors closer to the encoder, circular connectors are used. When looking at the connector from the inside of the tilt unit housing, the following pin arrangement is observed:

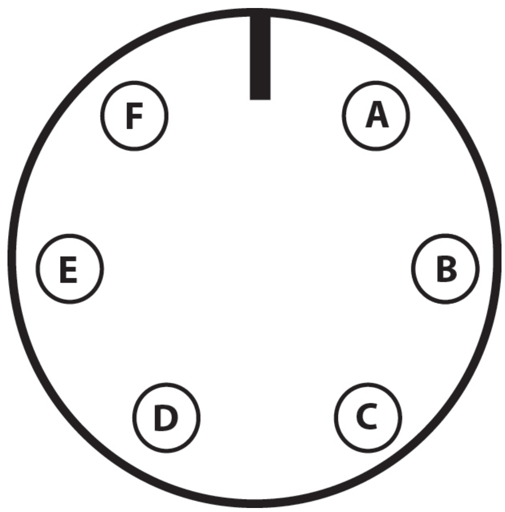


Figure 7: Pin Diagram for 6 Pin Circular Connector for Tilt Unit Encoders

The pins correspond to the following on the encoder:

Table 1: Pin Designations for Circular Encoder Signal Connector

A	A+
B	-
C	GND
D	+5V
E	Z+
F	B+

On the other end of the encoder signal cable is a 9-pin serial connector with the following pin arrangement and designation:

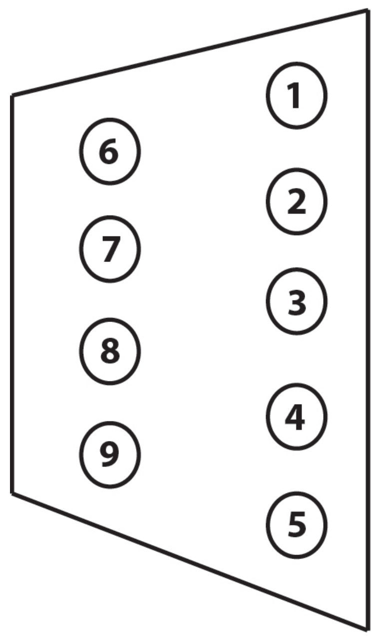


Figure 8: Pin Diagram for 6 Pin Serial Connector for Tilt Unit Encoders

The pins correspond to the following on the encoder:

Table 2: Pin Designations for Serial Encoder Signal Connector

1	A+
2	B+
3	Z+
4	-
5	+5V
6	-
7	-
8	-
9	GND

Table 3: Pin Designations for Serial Encoder Signal Connector

1	A
2	F
3	E
5	D
6	B
9	C

4 Overview of the Software Architecture

The software that runs the Gator includes a stack running on Robot Operating System (ROS) on the Intel Nuc computer in Linux and a second stack running in LabVIEW on the windows 7 rack computer. The LabVIEW code is designed to be minimally intrusive to any intelligent operation. It's sole purpose is to keep the vehicle safe and prevent the vehicle from sustaining damage. The ROS code, on the otherhand, is designed to have most of the intelligence required for performing missions. This segregation of responsibility therefore facilitates different teams with different mission requirements, allowing any team to run their code on the vehicle with minimal additional set up time. As long as the ROS-LabVIEW interface is obeyed, the software architecture will support swapping out the ROS-based code at any time and the vehicle should still run.

The software on the vehicle is broken up into three main parts: Forebrain, Midbrain and Hindbrain. Each part has a different function and operating speed. The hindbrain has the fastest operating speed and is used for low-level control of the control surfaces on the vehicle such as the gas and brake pedals. As such, the hindbrain is implemented on a National Instruments NI FPGA. The midbrain has two parts: one handling LabVIEW internal processing and another handling passing of sensor and vehicle information from LabVIEW to ROS. Finally, the forebrain is entirely ROS-based and handles all the high-level processing tasks such as path planning and intelligent obstacle avoidance.

In the upcoming sections, the various components of the software stack will be discussed in full detail.

5 Software System Definitions

As in any large-scale system with multiple subsystems, the must be common system-level definitions that are obeyed by all subsystems. In the robot's software, too, there are common definitions obeyed by all layers of code in LabVIEW and in ROS. As such, this section will detail the common software system definitions.

5.1 The Vehicle Co-Ordinate System

The vehicle co-ordinate system is defined using the standard used on most ground vehicles: with the positive x direction straight ahead. In order to maintain a right-handed co-ordinate system, the three axes of the vehicle co-ordinate system are therefore defined as:

1. The positive X axis is pointed to the front of the vehicle
2. The positive Y axis is pointed to the left of the vehicle
3. The positive Z axis is pointed upward

Figure 9: Vehicle Co-ordinate System Definition

The respective rotations in the vehicle co-ordinate system are therefore defined as:

1. Positive rotation about the X axis (Positive Roll) is roll toward the driver's right side of the vehicle
2. Positive rotation about the Y axis (Positive Pitch) is pitch downward toward the ground
3. Positive rotation about the Z axis (Positive Yaw) is yaw toward the driver's left side (counter clockwise yaw) of the vehicle

5.2 LIDAR Co-Ordinate Definition

By default, the Sick LMS290 LIDARs are programmed to transmit distance measurements in millimeters (mm) and angles in degrees with 0 degrees on the right and 180 degrees on the left as shown in the image below:

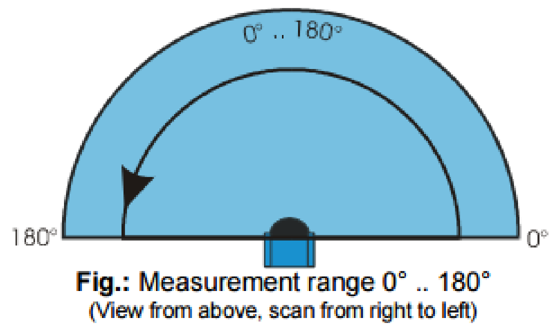


Figure 10: Sick LMS290 Angle Definition [1]

[1] Information obtained from Quick Manual for LMS Communication Setup

6 The Robot Software System (LabVIEW)

6.1 The FPGA Hindbrain

As discussed in the software overview section, the Hindbrain of the vehicle is implemented on a LabVIEW FPGA in order to ensure that control loops and essential data processing is done at the fastest possible speeds to reduce system latency even when the vehicle travels at higher speeds.

The front panel and block diagram of the top-level hindbrain VI is shown below:

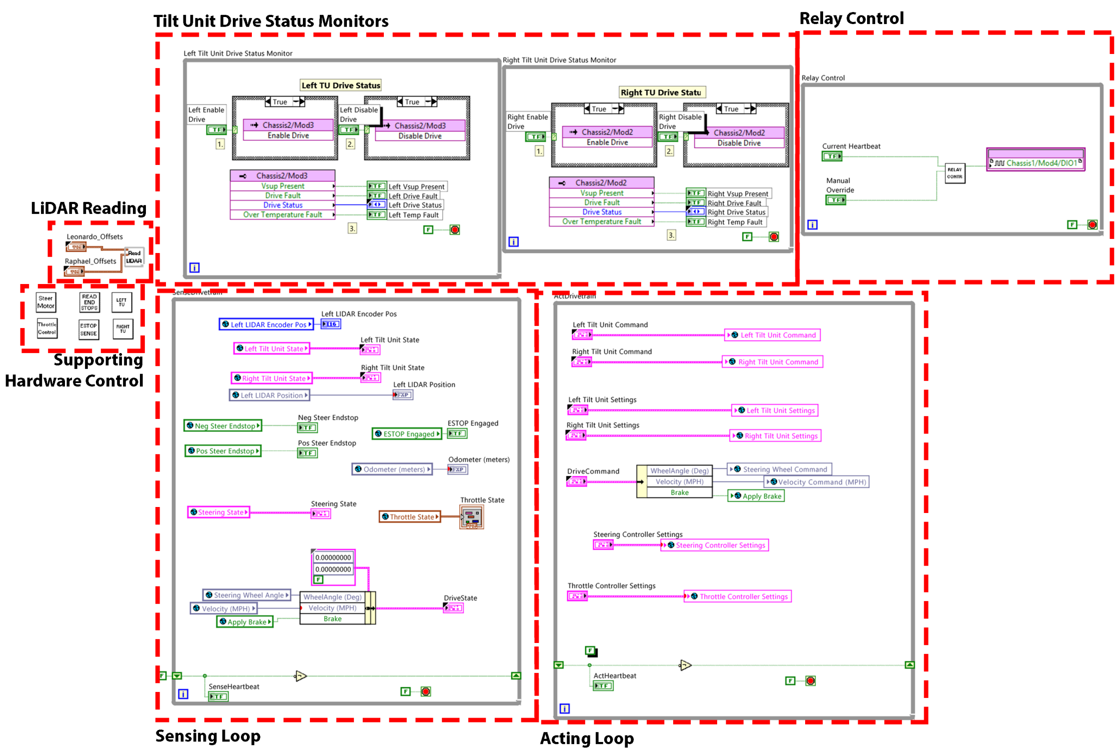


Figure 11: Hindbrain top-level VI block diagram with subsections annotated

As can be seen in Figure 11, the main subsections of the FPGA hindbrain are:

1. Sensing Loop
2. Acting Loop
3. Tilt Unit Drive Status Monitors
4. LiDAR Reading
5. Supporting Hardware Control
6. Relay Control

6.1.1 Sensing Loop

The sensing loop of the FPGA hindbrain essentially passes status information and data from other parts of the FPGA hindbrain code up to the front panel so that the real-time code can access these variables. The block diagram for the sensing loop shown in Figure 11 is shown zoomed in below:

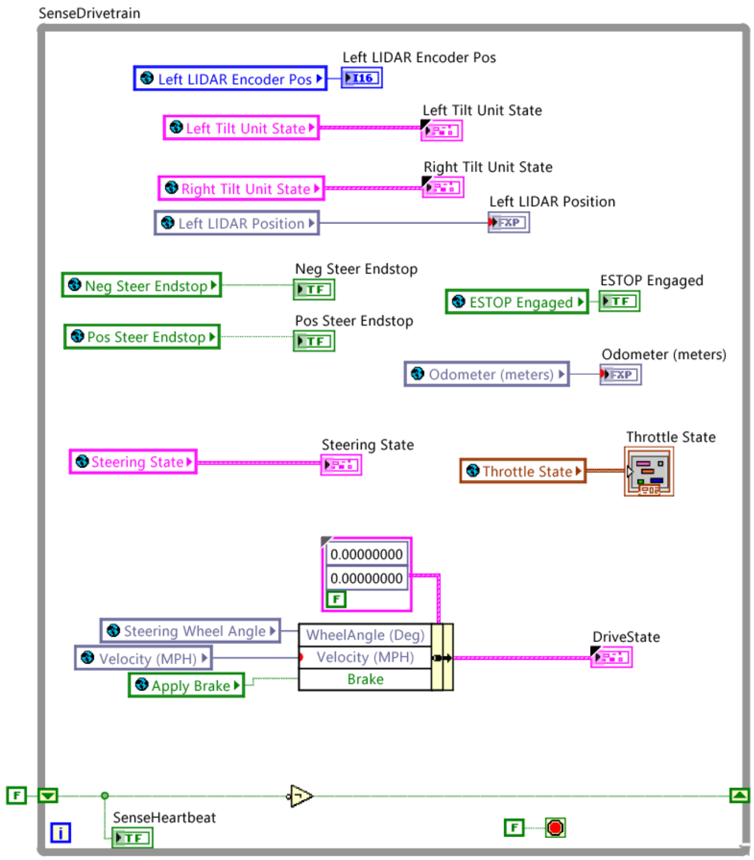


Figure 12: Sensing loop in the hindbrain VI

As shown in Figure 12, the sensing loop is responsible for exposing front panel elements for the following pieces of data to the real-time code:

1. Left LiDAR Encoder Position: A debugging indicator that shows the encoder position of the left LiDAR in units of encoder ticks
2. Left Tilt Unit State: A cluster containing an indicator for whether the index had been found, whether the tilt unit has been told to be in initialize mode, whether there is a position error in the tilt unit and the encoder position.
3. Right Tilt Unit State: The same cluster as the left tilt unit state cluster used for the right tilt unit

4. Left LiDAR Position: Another debug indicator that shows the position of the left tilt unit in degrees after the encoder ticks have been converted to degrees

5. Negative Steer Endstop: A boolean that represents whether the negative steer angle endstop has been triggered

6. Positive Steer Endstop: A boolean that represents whether the positive steer angle endstop has been triggered

7. Estop Engaged: A boolean that represents whether either of the physical estop buttons have been triggered

8. Odometer (meters): The distance travelled by the vehicle since the code started running

9. Throttle state: A cluster containing indicators for the gas and brake pedal voltage being sent to the linear actuators for the gas and brake respectively

10. DriveState: A cluster indicating the driving state of the vehicle including the steering wheel angle in degrees, the velocity in miles per hour and the boolean that represents whether the vehicle should apply the brakes

11. SenseHeartBeat: An indicator that simply provides a blinking light that confirms the while loop is running

6.2 LIDAR Point Transform

6.2.1 Overview of the Transform Process

The data returned by the Sick LMS290 LIDARs is in the co-ordinate frame of the LIDARs by virtue of the way in which the LIDARs take readings. In order to do useful work with the LIDAR data, the LIDAR data has to be transformed to make it iwth reference to the vehicle co-ordinate system.

The transform process has two parts:

1. Convert each scan from polar co-ordinates to cartesian co-ordinates

2. Rotate the coordinate frames such that the frame local to the LIDAR is in the same orientation as the vehicle co-ordinates

3. Translate the coordinate frames such that the frame local to the LIDAR is translated to line up with the vehicle co-ordinate system

6.2.2 Constant LIDAR Transform Properties

Based on the design and placement of the LIDAR mounts, the following properties of the LIDAR transform to t

7 The Robot Software System (ROS)

8 The OCU Software System