DARPA Grand Challenge 2004

Team CajunBot
(6 Wheeled Custom Drive-by-wire Unit)
The Center for Advanced Computer Studies (CACS)
University of Louisiana at Lafayette

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1. System Description

   a. Mobility.

      1. Describe the means of ground contact. Include a diagram showing the size and geometry of any wheels, tracks, legs, and/or other suspension components.
         Runs on 6 wheels (rubber), symmetric with 3 wheels on each side as shown in Figure 1.

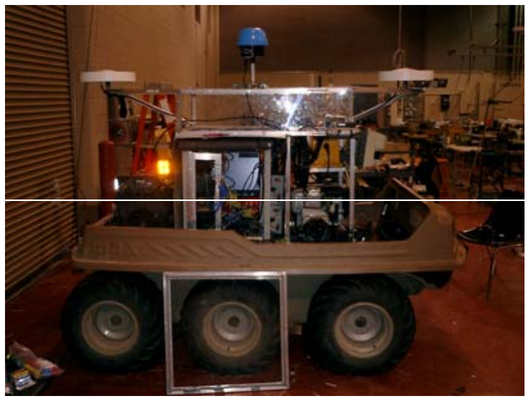

Figure 1. Vehicle dimensions.

Overall height	84" (213 cm)
Overall length	96" (244 cm)
Overall width	57" (145 cm)

Weight: Approx. 900 lb. (408 kilos)
Gross Vehicle Wt: 1270lb. (575 kilos)
Ground Pressure: 0.2-0.3 lb./sq. in. (14-21 g / cm2)
Fuel Capacity: 5. U.S. Gallons (19 liters) expandable to 27 U.S. gallons (102 liters)
Transmission: T-20 Skid Steer
Main Drive Chain: R.C. #50
Final Drive Chain: R.C. #50
Axles: 1 ¼ inch heavy-duty steel.
Towing Capacity: 1000 lbs. (454 kilos)

2. Describe the method of Challenge Vehicle locomotion, including steering and braking.

   Locomotion supplied by internal combustion engine with skid steer steering and custom designed drive-by-wire control for throttle and steering. Custom design incorporates the use of linear actuators to control the T-20 Skid Steer System. (T-20 Transmission). Braking is done with dual disc brakes and transmission braking. Transmission braking is primary means of braking and uses same levers as for steering by pulling back ½” (1.27 cm).

3. Describe the means of actuation of all applicable components.
   Drive by wire system (Steering and brakes actuated by high-torque linear actuators).

b. Power.

1. What is the source of Challenge Vehicle power (e.g., internal combustion engine, batteries, fuel cell, etc.)?

   Power provided by internal combustion engine providing 25 – 27 hp .
2. Approximately how much maximum peak power (expressed in Watts) does the Challenge Vehicle consume?

   Vehicle consumes 2.3 KW maximum peak power (not converted from engine horsepower).
3. What type and how much fuel will be carried by the Challenge Vehicle?

   27 U.S. Gallons (102 liters) of unleaded fuel.

c. Processing.

1. What kind of computing systems (hardware) does the Challenge Vehicle employ? Describe the number, type, and primary function of each.
   Two ATHLON Pc’s, shock absorbent rack, many sensors are connected to embedded PIC micro-controllers to send data to PC over Ethernet.
2. Describe the methodology for the interpretation of sensor data, route planning, and vehicle control. How does the system classify objects? How are macro route planning and reactive obstacle avoidance accomplished? How are these functions translated into vehicle control?
   Software integrates GPS/inertial/compass/pitch/yaw data for navigation. Sensor data are combined (inertial and GPS using Kalman filtering) and related to additional sensor data for accuracy. The system classifies objects acquired through sonar and radar using filtering techniques applicable to sonar and radar target identification. Radar/sonar subsystem identifies large or small objects and radar can estimate velocity for distinguishing moving vehicles from stationary objects such as rocks; which controls the logic to drive around, or stay away from the objects. Differential signals from sonar and radar help to estimate location of

object. Macro route planning is handled by factoring in known geographic locations and digital elevation models to seek or avoid plotting a best-fit route within the specified guidelines. Reactive avoidance involves driving the wheels around the obstacle and retraining on the original heading (calculated from movement sensor data or obtained via digital compass). Gate circuit is used to limit range to desired distance for near-field measurements at low speed or expand range for farther look-ahead at higher speeds. PC receives data from all sensors and adjusts motor speed via linear actuators linked to steering/drive levers.

d. Internal Databases.
   1. What types of map data will be pre-stored on the vehicle for representing the terrain, the road network, and other mobility or sensing information? What is the anticipated source of this data?
      Available USGS terrain data will be used to estimate terrain surfaces for planning. Commercial road map database used for road, landmark recognition.
e. Environment Sensing.
   1. What sensors does the challenge vehicle use for sensing the environment, including the terrain, obstacles, roads, other vehicles, etc.? For each sensor, give its type, whether it is active or passive, its sensing horizon, and its primary purpose.
      Passive cameras, 2 fixed front wide-angle IR sensitive CCD cameras for visual acquisition of terrain, obstacles, other vehicles (1-90m), radar , sonar and laser range finders for distance determination between own vehicle and obstacle/other vehicles (1-100m).
   2. How are the sensors located and controlled? Include any masts, arms, or tethers that extend from the vehicle.
      Two fixed cameras positioned at front with automatic shutter control. Radar, sonar and laser range finders located in front.
f. State Sensing.
   1. What sensors does the Challenge Vehicle use for sensing vehicle state?
      Vehicle state sensed by interface with engine electronics (e.g., stalled engine).
   2. How does the vehicle monitor performance and use such data to inform decision-making?
      Data is monitored using custom software via a GPS.
g. Localization.
   1. How does the system determine its geo-location with respect to the Challenge Route?

      GPS provides initial data with available differential (wide area augmentation system) to supplement and a subscription-based GPS supplement would provide additional GPS accuracy as well as onboard differential. (Note that inertial, compass and orientation sensor will supplement GPS with additional accuracy as well as other guidance and orientation information and provide information in GPS outages.) Further, inertial (gyroscopic) navigation senses actual acceleration to combine with coordinate information. Electronic compass, inertial measurement unit provide vehicle-relative rotation information.

2. If GPS is used, how does the system handle GPS outages?

   GPS outages handled via inertial navigation (gyroscopes), and electronic compass and inertial measurement unit.

3. How does the system process and respond to Challenge Route boundaries?

   Challenge route boundaries processed as vectors that calculate to steering adjustments to change heading.

h. Communications.
   1. Will any information (or any wireless signals) be broadcast from the Challenge Vehicle? This should include information sent to any autonomous refueling/servicing equipment.
      No.
   2. What wireless signals will the Challenge Vehicle receive?

      E-stop signals.

i. Autonomous Servicing
   1. Does the system refuel during the race? If so, describe the refueling procedure and equipment.
      No.
   2. Are any additional servicing activities planned for the checkpoint? If so, describe function and equipment.
      No.

j. Non-autonomous control. How will the vehicle be controlled before the start of the challenge and after its completion? If it is to be remotely controlled by a human, describe how these controls will be disabled during the competition.
   Vehicle shifted into neutral and towed to location, where it will be switched off of manual override and a joystick is used to drive and control manually.

2. System Performance
   a. Previous Tests. What tests have already been conducted with the Challenge Vehicle or key components? What were the results?

      1. Drive by wire using linear actuators and throttle servo in conjunction with calibration software and joystick.
         The result was that the linear actuators we had used were relatively slow thus we got a new set.
      2. Calibration of inertial navigation system.
         This test was successful.
      3. Acceleration and braking tests.
      4. Turning radius and responsiveness tests.
      5. Fuel consumption tests.

6. Moisture proof tests.
7. GPS drive tests.
   We need to adjust the control parameters.
8. Top speed tests.
9. Tire pressure tests.
   We obtained the best results in this test when we used 6 psi.
10. Electronic system tests.
11. E-Stop system tests.
12. Laser rangefinder test.
    Successfully communicated with the laser range finders at high baud rate and processed data.
13. Sonar test.
    In sonar test we determined that the maximum range was 11m.

b. Planned Tests. What tests will be conducted in the process of preparing for the Challenge?

1. Improved actuator and controller tests.
   - Calibration
   - Turning radius and responsiveness.
2. Adjustment and testing of control parameters.
3. Obstacle detection and avoidance testing.
4. Radar test.
5. Sonar test.
6. Hill climbing/descending speed control test.

3. Safety and Environmental Impact

a. What is the top speed of the vehicle?
   30 mph.

b. What is the maximum range of the vehicle?
   200 mi.

c. List all safety equipment on-board the Challenge Vehicle, including:

1. Fuel containment
   Twin heavy-duty waterproof off-road racing grade fuel tanks.

2. Fire suppression
   Fire extinguisher located behind electronics containment area.

3. Audio and visual warning devices
   Vehicle's siren triggered by fault in system as well as short bursts to indicate avoidance measures. Visual warnings supplied by two amber strobes atop vehicle. When we have an emergency or any kind of warning from the control part based on the sensing elements, there are two kinds of stopping to be taken: stop as soon as possible and stop when available. These should be ready functions in the software stored on the onboard

computer. (First of all, we have to signal our intent to stop as early as possible via lamping similar to traditional automobiles.).

d. E-Stops.

1. How does the Challenge Vehicle execute emergency stop commands? Describe in detail the entire process from the time the on-board E-Stop receiver outputs a stop signal to the time the signal is cleared and the vehicle may proceed. Include descriptions of both the software controlled stop and the hard stop.

   Upon receipt of a normal E-Stop signal, vehicle releases throttle, applies brakes to decelerate at a non-locking rate, and idles; actuators remain energized (i.e., steering actuators maintain position). Upon receipt of a clear signal, vehicle reverses procedure and resumes goal-seeking behavior. We should have a map stored in order to know the best stopping area closest to where the vehicle is now and how to reach it and to come from there back to our route, and based on that we have to know when to signal so that the others notice to slow down and then start slowing down and take the best route for the stopping area.

   Regarding negative obstacles holes and hills on the road, we use sonar with a certain inclination that allows the vehicle to stop in a safe distance from the object. The radars and the laser range finders use beams that will be reflected back from the road. When we have a hole or a hill the time will be larger or less respectively than the reflected wave from flat road.

   Upon receipt of a hard E-Stop signal, vehicle releases throttle, applies brakes to decelerate at a non-locking rate, and cuts power to electronic ignition system stopping the engine finally to restrict rolling and de-energizing steering for free manual movement if necessary.

2. Describe the manual E-Stop switch (es). Provide details demonstrating that this device will prevent unexpected movement of the vehicle once engaged.

   Manual E-Stop switches will be located on front side of vehicle and will consist of buttons controlled by humans but not easily accidentally engaged by rocks being kicked up.

3. Describe in detail the procedure for placing the vehicle in "neutral", how the "neutral" function operates, and any additional requirements for safely manually moving the vehicle. Is the vehicle tow-able by a conventional automobile tow truck?

   Neutral disengages the engine drive output from the drivetrain in a conventional manner and is normally controlled by a lever. The vehicle is tow-able by a conventional automobile or tow truck.

e. Radiators.

1. Itemize all devices on the Challenge Vehicle that actively radiate EM energy, and state their operating frequencies and power output. (E.g., laser, radar apertures, etc.)

Radar devices operate at 24.725 GHz with a maximum power output of less than 5mW. Laser range finders are class one eye safe infrared.

2. Itemize all devices on the Challenge Vehicle that may be considered a hazard to eye or ear safety, and their OSHA classification level.
   None. Laser range finders are class one eye safe.
3. Describe any safety measures and/or procedures related to all radiators.
   Radar low-powered so as not to cause harm at close range.

f. Environmental Impact.

1. Describe any Challenge Vehicle properties that may conceivably cause environmental damage, including damage to roadways and off-road surfaces.
   None.
2. What are the maximum physical dimensions (length, width, and height) and weight of the vehicle?
   Max Length x Width x Height: 96” x 57” x 84” (244 cm x 145 cm x 213 cm). Max Gross Weight: 1270 lbs (575 kilos).
3. What is the area of the vehicle footprint? What is the maximum ground pressure?
   5472 sq. in. (35830 cm^2); 0.23 lb / sq. in. (16 g / cm^2).

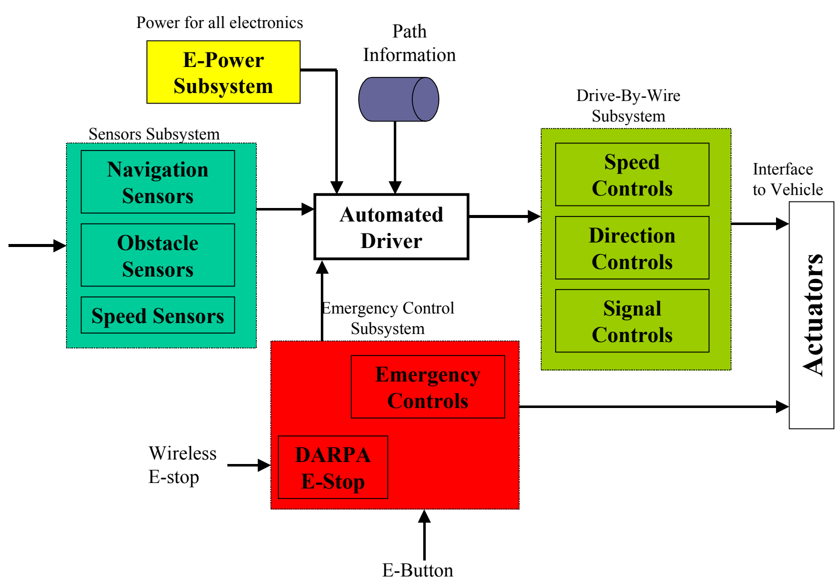

Figure 2. CajunBot Autonomous Guidance System

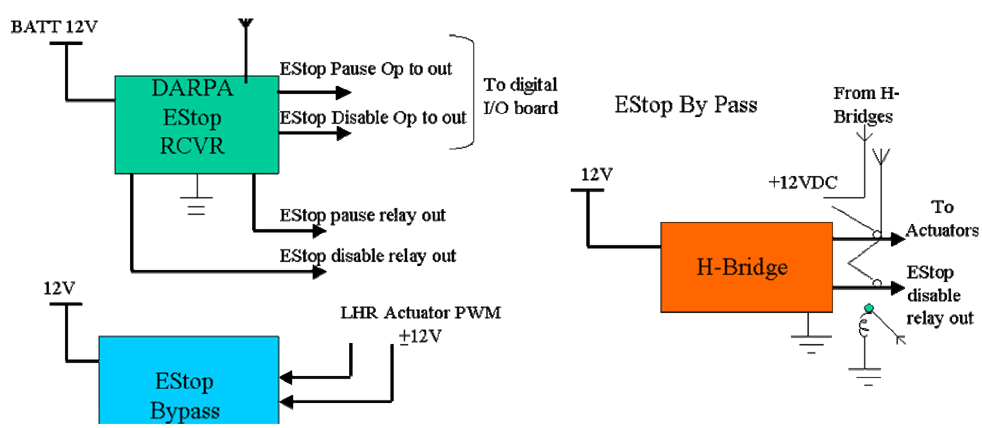

Figure 3. Emergency Control Subsystem

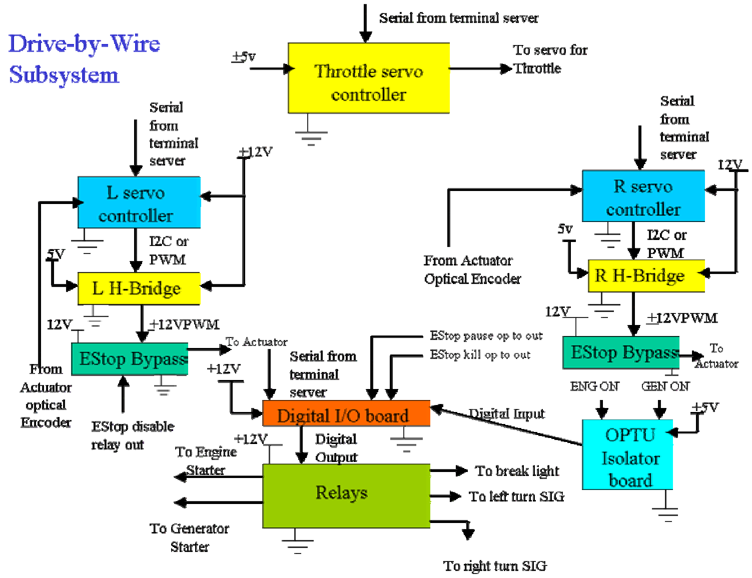

Figure 4. Drive by Wire Subsystem

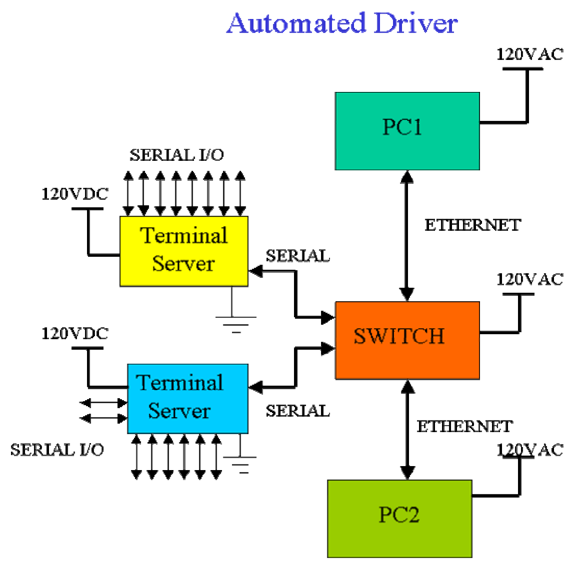

Figure 5. Automated Driver

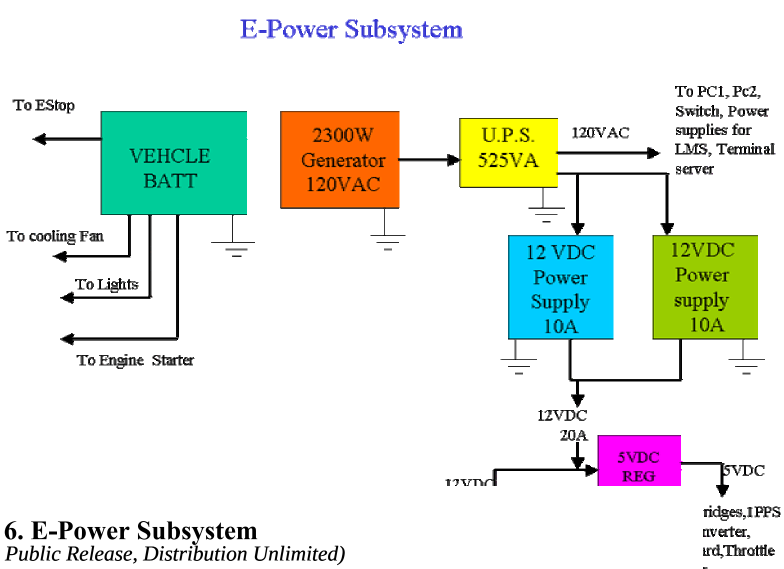

Figure 6. E-Power Subsystem

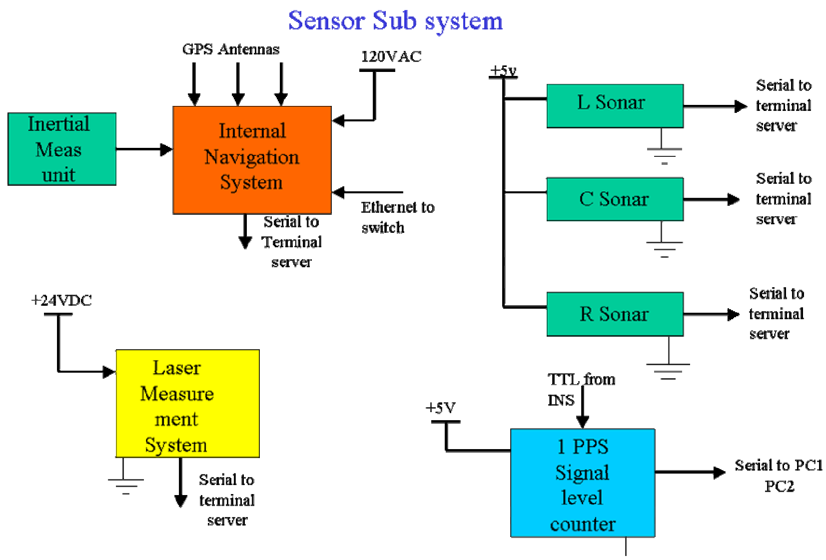

Figure 7. Sensor Subsystem

The CajunBot Autonomous Guidance System (figure 2 - 7) encompasses all electronic and electromechanical subsystems of the CajunBot Autonomous Ground Vehicle, including sensors, electrical power supply, computer, controllers, and actuators. First of all, the central component is the Automated Driver, which consists of the computer and the software running on the computer and is driven by the Navigation and Obstacle/Boundary Avoidance Algorithm and the path information provided by DARPA as a waypoint data file. The Drive-By-Wire Subsystem interfaces the Automated Driver with the Actuators and consists of relays, power transistors, and H-bridges to take the low voltage, low current input from the Automated Driver and convert them into high voltage, high current output to the Actuators. The Actuators consist of solenoids, high-torque servos, and high-power linear actuators, which take the electrical pulses and drive the transmission, steering, and braking. Finally, the Electrical Power (E-Power) Subsystem powers all of the electronics and actuators. The E-Power Subsystem includes a high-capacity battery and may include a solar charger to extend the usable battery life. Monitoring of the battery voltage would be done via a comparator linked to an input line on the Automated Driver. The Sensors Subsystem is what gives CajunBot awareness of relevant surroundings and its location and is made up of the navigation sensors, obstacle sensors, and speed sensors. Navigation sensors include GPS, inertial, and solar sensors to get the most accurate location information with continuous availability. Sonar and radar as well as IR/visual cameras provide input to the obstacle detection software that assesses and detects obstacles and uses the navigation/obstacle avoidance algorithm to avoid the obstacle. Boundary checking is done through a combination of visual, radar, and coordinate information based on the waypoint data file, including the width of the path. If there are barriers, then those are used for reference; if not, then coordinates provide information as to the boundaries of the current segment of the path. The emergency control subsystem consists of the DARPA-provided E-stop equipment and emergency controls that directly interface with the actuators, bypassing the Automated Driver in the event of a hard E-stop. In the event of a normal E-stop, the computer will initiate a recoverable stop, that is, one in which the vehicle may restart and continue in the race.

CajunBot uses obstacle (radar/sonar) sensors and coordinate sensors (GPS/inertial) information to determine its distance from boundaries and obstacles. In the example shown in figure 8, the distance d_{left} from the vehicle to the left boundary is less than the distance D from the centerline to the boundary. Therefore, the vehicle turns right until it reaches the centerline and the distances are again equal. Similarly for d_{right}. The navigation/obstacle avoidance algorithm, shown in figure 9, first checks if the obstacle sensors detect an obstacle. If so, then the algorithm calculates distances from the vehicle to the obstacle/boundary and from the centerline to the obstacle/boundary. Otherwise, the algorithm will use the coordinates to determine distances. In either case, if the left hand distance d_{left} is less than D, then the vehicle will turn right and the opposite for d_{right}. Otherwise, the vehicle will move forward ("MFW").

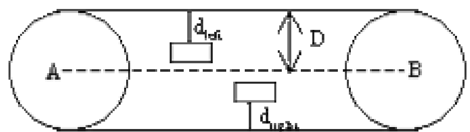

Figure 8. Lateral Boundary

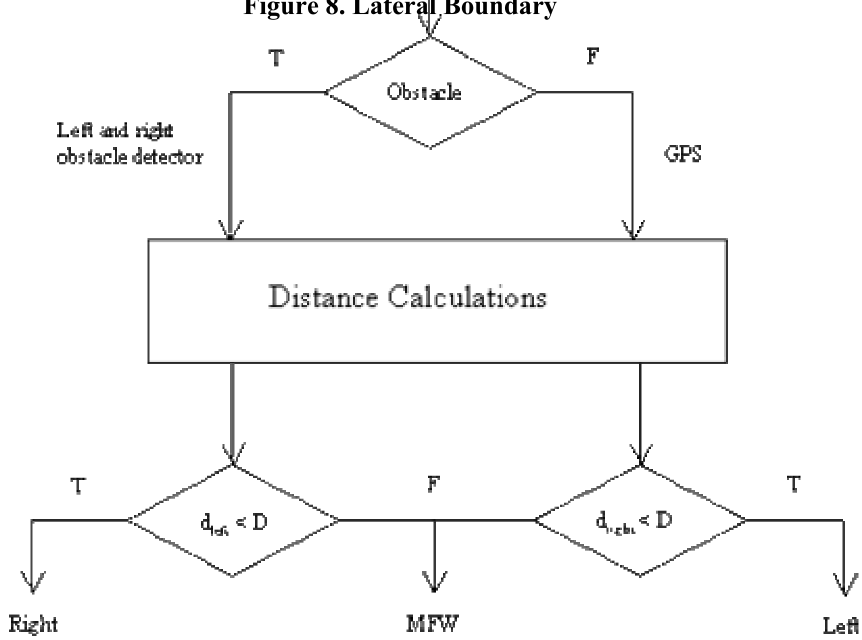

Figure 9. Navigation/obstacle avoidance algorithm

Custom Drive-by-Wire System

The T-20 Skid Steer system (Skid Steer is similar to a military tank where in order to go forward wheels / tracks on both sides are rotated forward and in order to make a turn one side can be stopped) as used in the MAX ATV has linkages on each side for both braking and direction of rotation. We allow each side to be independently braked.

The basic block level diagram of connections is shown in figure 10. The throttle interfacing is done using a High Torque servo (example Hitec HS945MG). The skid steer transmission is shown in figure 11, and the MAX ATV is shown in figure 12.

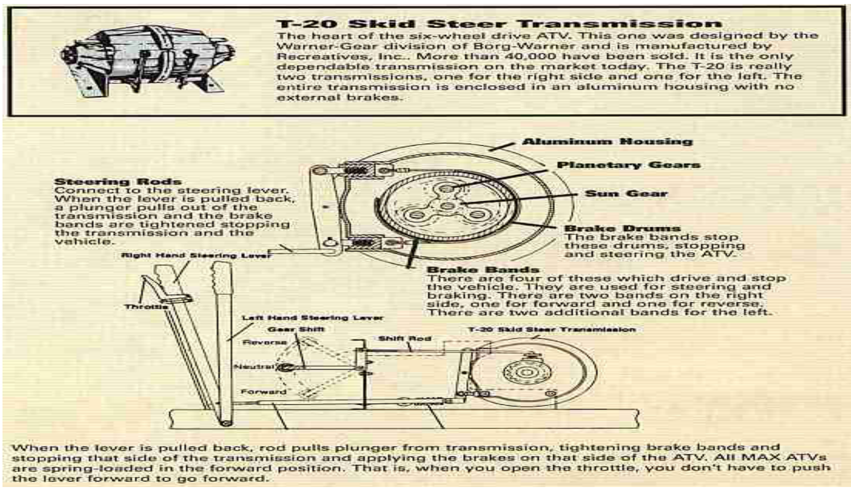

Figure 10. T-20 Skid Steer Transmission

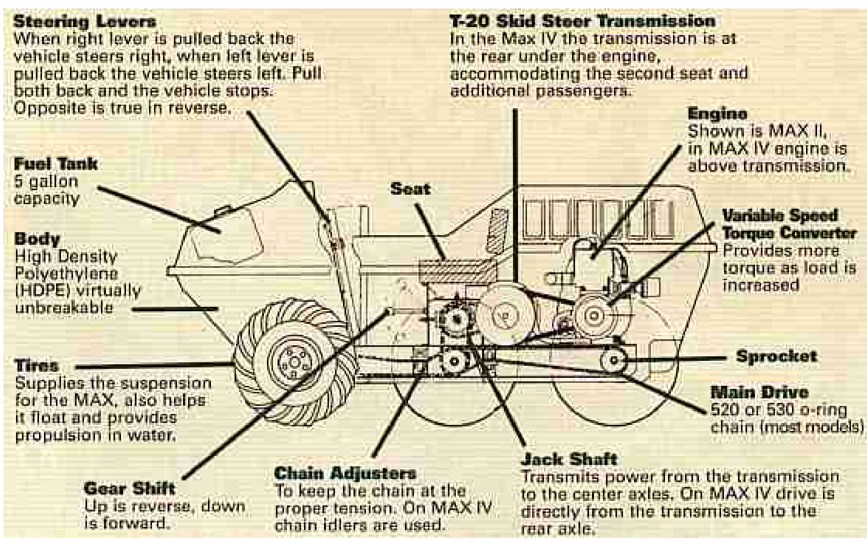

Figure 11. MAX ATV

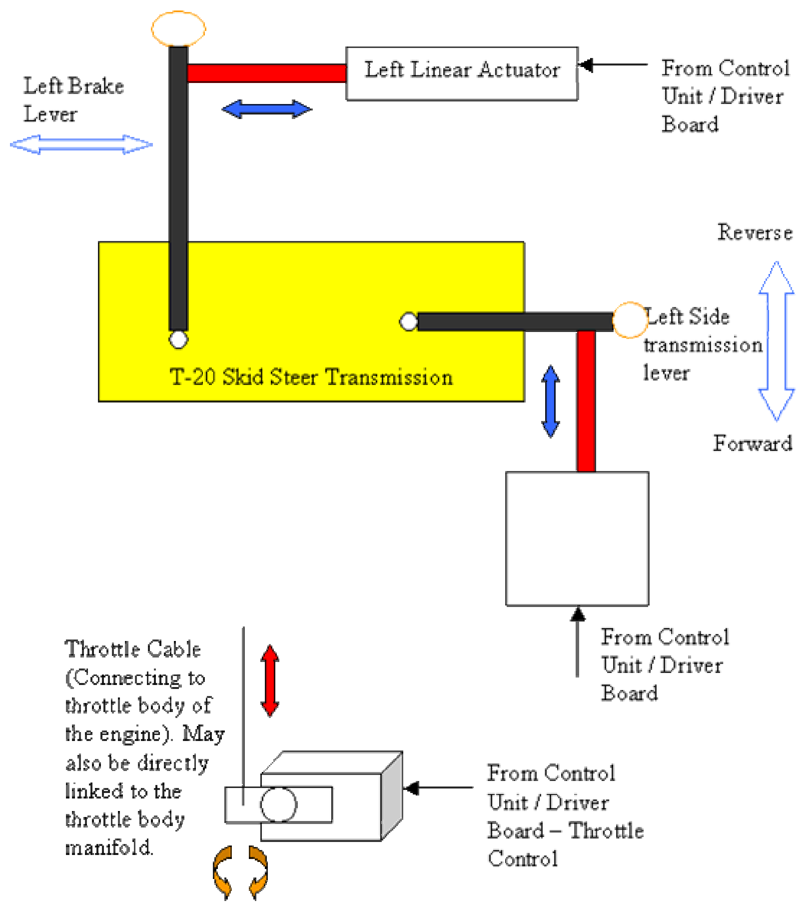

Figure 12. Vehicle-actuator interface

Modifications to the T-20 Skid Steer Transmission

Figure 12 shows the main modifications of the linkages to suit our needs. The diagram depicts the modifications done in order to connect the T-20 transmission to our computer-embedded controllers module. The linkages on the right side are the exact same design as the left side design shown below. There is a single throttle control using a High Torque servo to control the opening and closing of the throttle plate.

Linear Actuators used to control brakes

A pair of linear actuators similar to the one depicted in figure 13 drives the left and right transmission brakes. For example, the Ultramotion Linear Actuator (www.ultramotion.com) uses a servo motor for control and a screw drive.

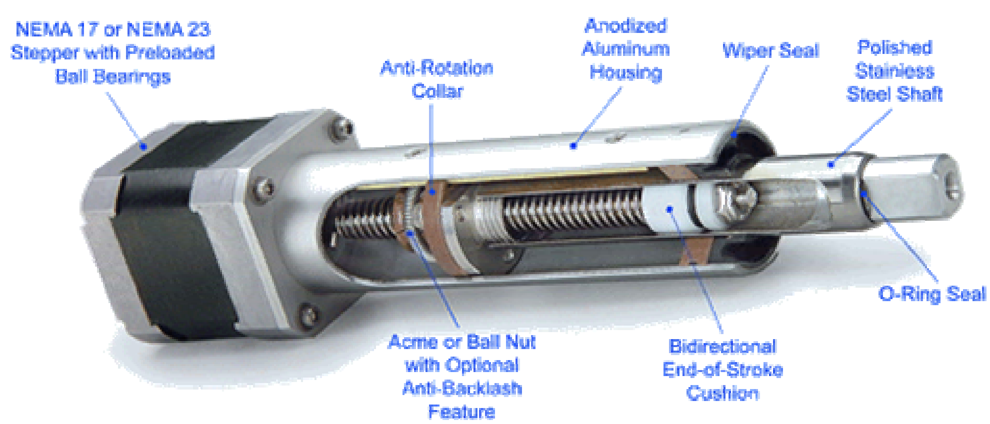

Figure 13. Linear Actuator Example

High Torque Servo used to control throttle

Typical Torque: **390 (approx) oz/in. (28.08 kg.cm)**
Example Hitec HS805BB Servo

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