University of Colorado at Denver

CUGAR IV

Design Competition Report
11th Intelligent Ground Vehicle Competition
Oakland University
Rochester, Michigan
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Team Members:

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Faculty Advisor: Brian Atkinson

1. Introduction

The C U–Denver Ground Autonomous Robot (CUGAR) has been an evolving award winning project that continues to be focal point of research and development for team members and Senior Design students. A three wheeled platform with Ackerman steering linkage, independent all wheel drive, and full suspension, makes the vehicle a stable foundation to develop systems for the challenges of the competition. Using a combination of proven and innovative technologies for design concept and development, a thought out design process, and refining and enhancing components of the vehicle with new systems, the team has been able to systematically design and develop upon a winning foundation.

2. Design Process

Since this is an ongoing Senior Design project that is supplemented by volunteer help from members of the CU-Denver Robotics Society, the design and implementation of projects within groups are staggered but coordinated through meetings with project and team leaders. Because of this situation, we had to adapt from the David G. Ulman's Mechanical Design Process shown in the steps shown below.

Figure 1: Design process flow chart

This process became altered to a four step process which included identifying needs, plan design process, develop specifications and concepts, and finally develop product. By identifying needs for the 2003 CUGAR IV to improve overall performance and contest demands set in the IGVC rules, the process of researching and planning for implementation of potential modifications and new system design process began. By analyzing the time, cost, and development necessary to create or improve systems for the vehicle, a solution for efficient development was decided upon by the team members, followed by development and implementation of the hardware and/or software necessary.

The design process moves through to the next phase only when project inspection and testing pass expected goals at each step of the process.

3. Design Team Organization

The CUGAR IV team consists of three Electrical Engineering students. Also assisting with the vehicle were additional Electrical Engineering Senior Design students as well as members from the CU-Denver Robotics Society, which consist of undergraduate and graduate Electrical, Mechanical, and Computer Science Engineering students. Projects and tasks were divided into groups, with team members and the faculty advisor coordinating their progress. The CUGAR IV team members are assigned to multiple responsibilities due to the small size of the team.

Table 1: Team Responsibilities

Team Member	Responsibilities	Class Level	Hours Contributed
Alex Pesidiris	Laser Rangefinder Motor Control Vision System Software	Senior	~250
Michael Duffy	Ultrasonic System GPS Navigation Vision System Software	Senior	~250
Dan Akselrod	Mechanical Systems Electrical Systems Software	Junior	~120

4. Vehicle Design

Since its inception, CUGAR has been an experimental platform for motor control, avoidance systems, and computer hardware and software necessary for autonomous navigation. While there are some core systems that have been enhanced by improvements in hardware and software design, the team strives to develop new systems to enhance vehicle performance. Here is just a general synopsis of the systems onboard the 2003 CUGAR IV.

4.1 Vehicle Design Innovations

The 2002 CUGAR IV will be incorporating a newly designed laser rangefinding system to supplement the ultrasonic array for the obstacle avoidance system, and program code for the Laser rangefinder will be integrated into the main program for obstacle avoidance. Power distribution will be enhanced and Emergency-Stop (E-stop) system circuitry will be improved. A new battery compartment under the vehicle will provide room for the required payload and camera platform on the front of the vehicle, the pothole detection camera will be moved, as will placement of the ultrasonic array control box inside the chassis for additional space needed for the laser rangefinding system. The side cameras will have filters to improve line vision for better detection. Existing algorithms for vehicle systems as well as code to handle the various contest challenge requirements will be modified to improve overall performance.

4.1.1. Laser Rangefinder – Obstacle Detection

Obstacle detection has been an ongoing improvement to CUGAR IV. Last year, the University of Colorado at Denver had acquired a laser range-finding system from EO-Devices. The equipment from EO-Devices had little documentation and proved to be a bit problematic to the integration of other hardware. Upon much experimentation with the electronics, the design team had come to the conclusion that a different Laser Rangefinder system would have to be designed or purchased to meet the requirements desired for CUGAR IV.

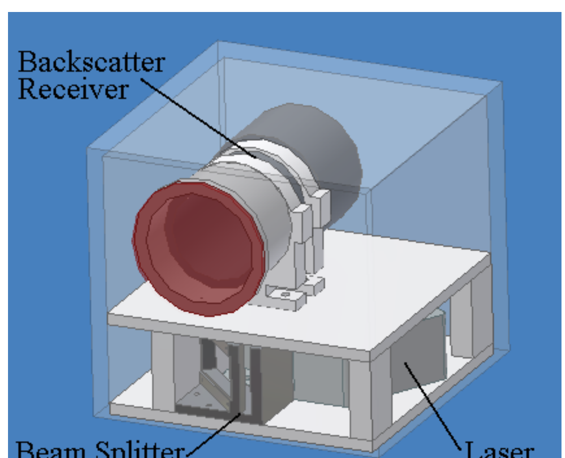

Figure 2: Laser Rangefinder

The design team was lucky enough to have members that have studied optics and low noise electronics. This allowed for newly derived theoretical techniques that would allow good accuracies and the ability to map out obstacles in an efficient manner. The design methodology for the Laser Rangefinder consisted of modulating laser pulses and receiving the backscatter from an obstacle. The backscatter received along with the transmitted infrared pulses allowed for a measurable phase difference. The phase difference is a rough distance measurement, and is augmented by a software algorithm that increases the resolution. This design methodology efficiently provides mapping data to the CUGAR IV host computer to allow for real-time maneuverability.

Starting a new design of this caliper requires careful planning and parts selection. The first main design challenge was to construct or obtain a pulsed laser diode, in the infrared range, that would allow modulation schemes of frequencies up to 1MHz and slightly above. Our final pulsed laser diode design allowed for pulsed laser operation in the desired frequencies, while incorporating a power level control and power output monitoring.

The receiver of the laser rangefinder proved to be one of the most important designs of the system. The backscattered infrared light is considerably less in power than the transmitted light. Therefore, collecting these backscattered rays and amplification of these low level signals is of great importance. After receiving low noise signals from the receiver, measuring the time difference and processing the obstacle data was of the greatest importance. The laser rangefinder is only as good as the methods used to measure the time difference. For time difference calculations, a newly derived approach was used to avoid common problems found in the time interval counting methods. Apart from the detector circuits and phase detector, all other derivations were made in software.

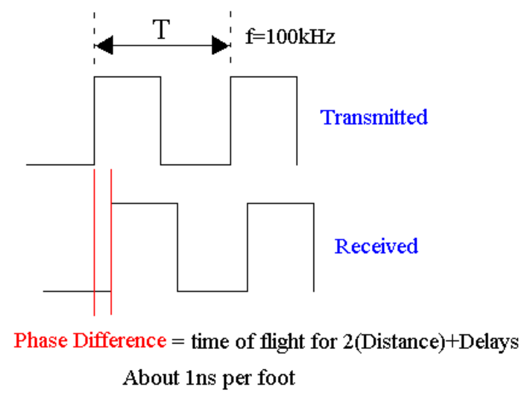

Figure 3: Time of flight characteristics

An 8-bit microcontroller was used in conjunction with a 12-bit analog to digital converter. The analog to digital converter took multiple samples at each interval angle, to allow for averaging and accuracy improvement. Once these values are averaged in software, the value of time was manipulated with other software algorithms to improve the accuracy of the range measurement. Once an accurate timing signal was achieved, the microcontroller sends time and angle data to the CUGAR IV host computer via serial communication.

The CUGAR IV host computer receives a serial communicated data stream containing time and angle information. The angle information is derived from the pan motor that the laser-rangefinder is mounted on. The pan motor has the ability to swing 180 degrees, but is often limited for different contest events. Furthermore, the pan motor has an optical encoder attached for feedback control of the motor and to derive angle measurement of the laser rangefinder.

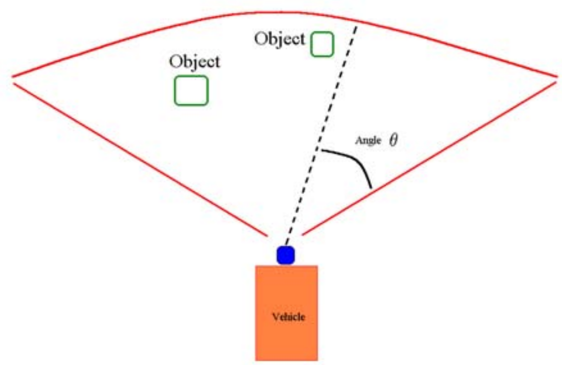

Figure 4: Panning of laser rangefinder

With these new advances made in obstacle detection process, the CUGAR IV will have a fine tuned ability to acquire obstacle detection data with little difficulty and process this data in real-time.

4.1.2. Power Box Enhancements

A major problem encountered in the 2002 competition was with our power control system - in particular, the MOSFET switching circuit board used as part of our E-stop system. We observed a catastrophic failure of the circuit due to back EMF generated by the motors when the E-stop was activated during the competition exceeding the regulator threshold voltage, forcing us to forgo the last two runs in the third heat of the autonomous challenge. To correct this, a filtering capacitor and resistor were added to the circuit, and a frequency analysis to disconnect power to the motors in the event of hazardous operating conditions such as the vehicle veering off course or spectators inadvertently crossing the path of the vehicle. The tests showed that threshold voltages were within 75 percent of the maximum 40 volt limit, providing enough headroom for proper system operation. A new circuit board has been designed, and will be incorporated into the current power control box.

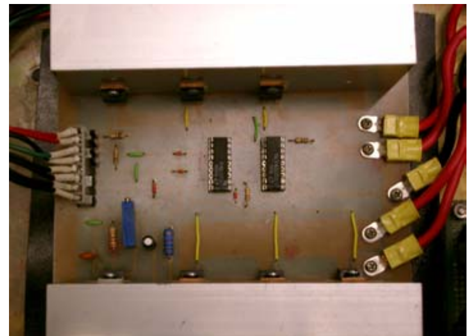

Figure 5: Original Mosfet switching circuit

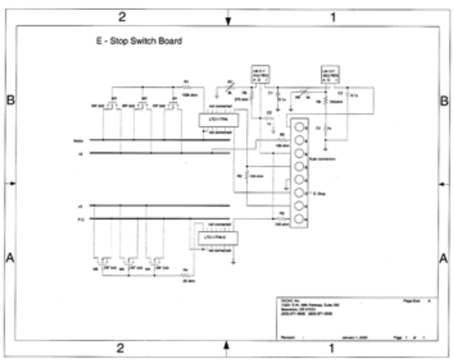

Figure 6: Modified E-stop circuit schematic

4.1.3. Battery Containment, camera mount, and Ultrasonic Control Box Placement

With the incorporation of the laser rangefinder and new requirements for the 20 pound payload placement for wireless camera mounting for observation, the battery compartment, front pothole detection camera mount, and ultrasonic control box needed to be moved to make the required space available. The battery compartment was originally designed to slide onto a set of rails on the underside of the vehicle; however, the rollers on the tray were unreliable, leading to the batteries falling to the ground, leading to the battery placement on top of the vehicle. The compartment has been redesigned with a stronger plastic box and metal rod replacing the rollers will provide the structural integrity necessary to safely stow the batteries to run CUGAR IV and also provide a means to quickly change batteries when needed.

The pothole detection camera that was mounted on the original swivel tray used for the first generation line detection camera needed to be moved for the payload and for placement of the rangefinder on the front center of CUGAR IV. The solution will be to simply use another tripod unit and place the camera directly above the laser rangefinder unit that will be placed on the swivel base frame. This complete assembly will be below the top shelf surface of the vehicle to make way for the payload and wireless camera which will be securely strapped into pace to ensure safe operation for the vehicle.

The ultrasonic control box needed to be moved to make way for the other systems. This control box was always meant to be placed inside the vehicle, but with testing and enhancements it was put on the front of the vehicle for convenience. It will be put in its rightful place next to the power distribution box and computer, and rewired accordingly.

4.1.4. Line Detection Camera Filtering

The Sony Handicams that have been used on CUGAR the last two years have been a great asset to the vehicle's performance. With auto exposure, white balance, and anti-jitter capabilities, combined with video recording for evaluation and testing of he vehicle in the lab, these cameras have been a vital part of our strong visual navigation system.

One problem that has been observed has been the light noise experienced during the morning hours where reflected sunlight off of the contest track makes it hard for the vehicle to discern the course lines from the scattered noise, compromising our navigation on the course until the sun risen enough to cut back on reflections or clouds block the direct light altogether. This was solved using a pair of Sunpak 37 millimeter circular polarizing filters on the two side cameras. This filter is designed specifically for video cameras that

Figure 7: Sony Handicam With circular polarizing filter

incorporate CCD elements as well as for 35 mm SLR film cameras with auto exposure systems in that light that is passed through the filter travels circular in fashion instead of linear, resulting in a more even removal of scattered light noise with the object being viewed to be clear and undistorted. This will extend our competitive time on the courses, resulting in more trials and the ability to succeed at winning the Navigational Challenge.

4.1.5. Software Improvement

With integration of the Laser rangefinder into the programs used to run CUGAR IV in the three contests, it became apparent to look at the algorithms used for senor and video data acquisition, decision making, and steering / drive motor control and see if modifications could be made to improve performance. Last year saw a major improvement in obstacle avoidance, but when an obstacle was cleared the return to general navigation was delayed, causing course navigation problems. Part of this is due to sensor sensitivity parameters that were set to high and time delays set in the obstacle avoidance code to ensure that there would be sufficient time to clear objects and potholes. Most of these problems can be fixed through adjustments of parameters and values within the code; however, with the addition of the laser rangefinder, additional modifications of the main code will also be necessary to ensure proper data gathering and decision-making based on data from both the laser rangefinder and ultrasonic array.

4.2. Existing Systems

There were several major components that were already existent that were decided to be satisfactory for use in this incarnation of CUGAR that were either kept due to reliability and performance capabilities or from lack of time or budget constraints. In both instances the reused aspects of the vehichle were evaluated and maintained as necessary by the team to ensure reliability and safety, with minor adjustments as needed to improve vehicle performance. These systems include the frame, 3wheel independent drive train, Ackerman steering, power management, vision, GPS navigation, and ultrasonic array systems.

4.2.1. Vehicle Frame and suspension

The frame, composed of aluminum, is a five-sided box design that is proportioned to proved balanced weight distribution and optimal handling to the three wheels. Equipped with a mountain bike Rock Shox suspension to smooth out rough bumps that could degrade obstacle and video system performance, this rugged platform needs only minor maintenance to the suspension system.

4.2.2. Three wheel independent drive with Ackerman steering system

The vehicle has three wheels, two in front and one in the rear, coupled via cyclo-reducer with 17:1 gear reduction, are driven by three one quarter horsepower brushless DC servo motors. Feedback to the motor controller board by an encoder on the motors ensures positive traction to all wheels. The Ackerman steering mechanism ensures a smooth skid free efficient turning radius and additional stability to the vehicle

4.2.3. Power Management System

Other than the Mosfet switching circuit in the power box used for the emergency stop system for the vehicle, the power system for the vehicle has been very reliable. CUGAR IV will operate of four 7-amp hour 12-volt lead acid gel cell batteries in series, providing a 48 volt effective power supply. Power is converted down to the proper voltages for the computer, motor, and peripherals by using Lambda DC to DC power converters, and distributed from a central fused power box. Only minor modifications to accommodate the new laser rangefinder and general service to the wiring harness will be necessary.

Video System

The video system that provides the ability to perform course line tracking and pothole detection is centered around a Willow Peripherals frame grabber card and three SONY Hi 8 CCD-TR818 Handycam camcorders. This system has the flexibility to view both sides of the course by the two side cameras to acquire a constant analysis for position regardless if a border line disappears on one side or the other for optimal course steering correction, while the pothole camera looks forward to avoid obstacles. An

Additional feature is that a course can be simulated by videotaping a 'testing track', and play back the video into the vehicle while it is on jack stands to check steering and drive system performance.

4.2.4. GPS Navigation

The GPS navigation system was introduced to CUGAR last year with outstanding results for its inaugural year in the GPS navigation challenge. With a Garmin Etrex Vista GPS receiver with built in electronic compass and a B2SX PIC basic stamp for coordinate input and data output for directional control, this system was responsible for a third place win in last year's competition. Other than some minor software adjustments to improve steering accuracy, this reliable and accurate system is ready to compete in this years challenge.

4.2.5. Ultrasonic Array

The ultrasonic array has been a primary obstacle system for the CUGAR until this year, with the addition of the laser rangefinder making this a secondary source for detection. Equipped with six Polaroid emitter / detectors and a Motorola 68HC11 microcontroller, this system scans the area around the front of the vehicle with an effective distance of 17 feet. Through software control, the scanning range for avoidance of obstacles is set to 10 feet in the front of the vehicle and 2 feet around the front sides to ensure vehicle clearance while passing obstructions.

5. Expected Performance

Performance expectations for CUGAR IV are expected to be a major improvement from last year's vehicle in obstacle avoidance and course navigation. The new laser rangefinder will have an effective range of 30 feet and a 180 degree angular sweep to scan for approaching obstacles, which in conjunction with the ultrasonic array will complete a reliable system capable to sampling conditions at approximately $1/10^{th}$ of a second for obstacle avoidance. Drive train performance has been proven to provide a top speed of 5 MPH, while currently regulated to move the vehicle at a rate of 2.5 MPH. Inclines of 30 degrees are not a problem for CUGAR IV to manage. The power system provides a run time of 45 minutes. Our software strategy of setting priorities of following the course via line vision / navigation (GPS, tracking leading vehicle via laser rangefinder and ultrasonics) with decision making when obstacles are encountered has proven to be a stable algorithm for reliable autonomous operation. The E-stop system provides an almost instantaneous stopping of the vehicle, well beyond the distance for remote operation of the system, and with stopping ability within contest specifications. The GPS system is accurate within 5 feet to ensure making contact at the specified waypoints consistently.

6. Budget

Our financial outlook for this year's vehicle is optimistic due to the fact that most of the modifications were student designed and built. Additionally, donations of parts and materials helped to defray costs. Costs of supplies are rounded to the nearest dollar, and are an accurate representation as of this writing.

Table 2: Estimated Costs

Item	**Cost**	Remarks
Laser Rangefinder	$275.00	Optics donated, student built
Mosfet Switching Circuit	$140.00	Student Built
Circular Polarizing Filters (2)	$64.00	
Batteries	$275.00	12V gell cell and 7.2V Li-ion
Hardware (Mechanical)	$70.00	Supplies partially donated
Hardware (Electronic)	$85.00	Supplies partially donated
CUGAR IV Project Total	$909.00	

7. Conclusion

CUGAR IV will be ready to meet the challenges at the IGVC this summer, and he team is looking forward to another successful run. This project would not be possible without the help of Electrical and Mechanical Engineering Senior Design students, the CU-Denver Robotics Society and its volunteers, CU-Denver Electrical Engineering instructors and faculty, and the ongoing support of Engineering Department Dean Renjeng Su.