RoboJackets

2004 IGVC Design Document

HARDWARE

Mechanical System

The robot uses the chassis of a former bomb disposal robot as its mechanical base. Originally a six wheeled design, the front wheels were removed to lighten the robot so that it could be more easily transported. The resulting four-wheeled robot received new batteries, 11 sonar range finders, 2 cameras, an emergency stop system, and storage capacity for a laptop, custom electronics, and the required payload. Figure 1 shows an AutoCAD drawing of the robot.

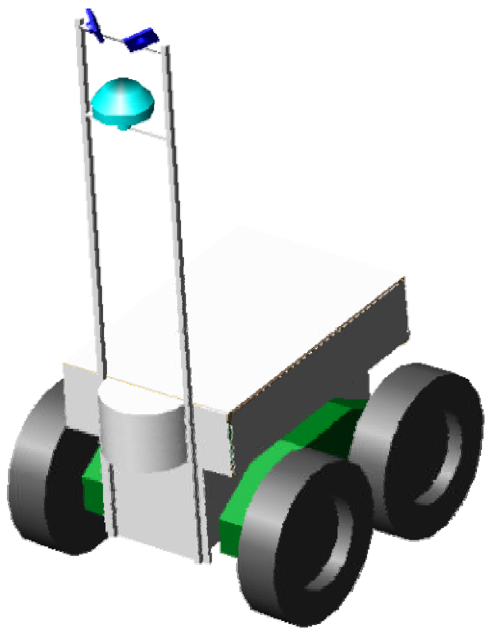

Figure 1: AutoCAD model of the robot

Electrical System

All power for the robot comes from two 12V sealed lead-acid batteries wired in series. The motor drivers and GPS receiver operate directly off 24V from these batteries. A custom power supply board provides 15V for low power electronics including the sonars, microcontroller, and motor driver interface circuitry. The power supply board also provides 20V for the laptop so that it can be powered entirely from the robot's main batteries instead of its internal battery, eliminating the need to keep the laptop battery charged along with the main batteries.

A custom microcontroller board provides the interface between the laptop and the motor drivers, sonars, and related circuitry. The microcontroller can monitor the voltage and current on the 24V and 15V busses and the emergency stop status. It communicates with the laptop via an RS-232 serial port.

The emergency stop system consists of an emergency stop button, a remote E-stop receiver, and associated circuitry. When the button is pressed or a signal from the remote transmitter is detected, an inhibit signal is sent to the motor drivers, causing them to shut down and brake the motors. The E-stop can be triggered, but not reset, on software command. The E-stop can be reset only by pushing and pulling the E-stop button.

All electrical connections are made through circular plastic connectors (CPCs) except for the main busses, which use terminal blocks. CPCs were chosen because they are polarized, locking, and low cost. The number of pins and gender of connectors were chosen to prevent cables from being connected improperly. All electronics are contained in closed metal boxes that are connected to the ground bus.

Sensors

Vision

Two cameras using fixed 4mm lenses were placed high on the robot. From that position, they can view the ground about 10 feet in front of the robot. The cameras are aligned to minimize the area of overlap between their fields of view. Images from each camera are sent to the laptop in YUV422 format at 15 frames per second.

Sonar

Eleven sonar rangefinders are arranged in a semicircle at the front of the robot. They provide a second set of sensors capable of finding barrels and other objects above the ground. They have a range of 40 feet. The rangefinders return the distance to the object detected.

The maximum time required for each sonar to make a measurement is 65ms. To operate all eleven sonars sequentially would require 715ms, which is longer than the desired main loop time of 500ms. In order to reduce the total sonar ping time, two sonars are fired at once at once. To reduce the chance of interference, only sonars that are close to 90° apart are fired simultaneously. This firing pattern results in a total time of 390ms.

GPS

The GPS unit that is being used in this robot is capable of receiving differential GPS signals. It interfaces with the onboard laptop via an RS-232 serial port. The GPS receiver is used only in the navigation challenge.

Computer

The robot is controlled by a laptop with a Pentium 4 CPU running Linux. It is connected to the two cameras via an IEEE-1394 port. The GPS receiver is connected via a USB-attached RS-232 serial port. A serial port on the laptop is used to communicate with the microcontroller. The laptop is powered by 20V from the robot's power supply so that its internal battery does not need to be kept charged.

SOFTWARE

The autonomous challenge requires using the sonar and camera inputs to select one of several paths based on relative safety of each. The image and sonar data is used to generate a danger map which indicates the perceived safety of each point in the world near the robot. The main control loop performs the following steps:

1. Acquire an image from each camera.
2. Apply color segmentation to the images.
3. Read distance values from sonars.
4. Generate danger map based on image data and sonar distance values.
5. Evaluate the safety of each path by integrating the danger map values over the path and determine which path is the safest.
6. Command the motor drivers to follow the safest path.

These operations will be performed as quickly as possible, but no slower than twice per second.

Image Acquisition

The most recent image from each camera is acquired at the beginning of each main loop iteration. These images are combined into a single image for further processing. Figure 2 shows an example raw image from one camera.

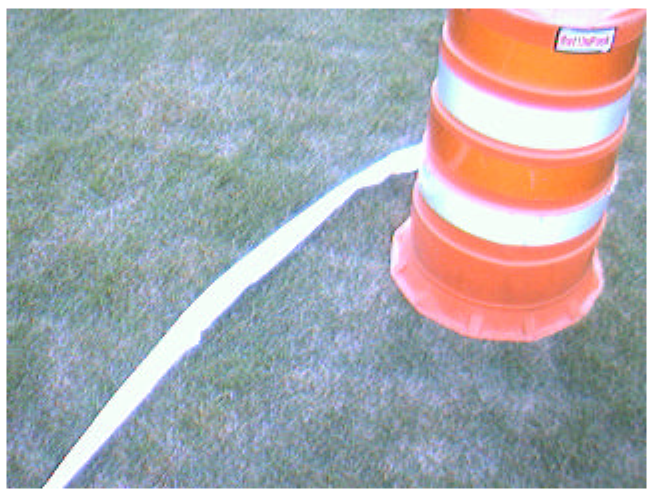

Figure 2. Raw image from camera.

Color Segmentation

The CMVision library is used to classify the color of each pixel into one of a small number of categories. Based on its color, each pixel is identified as being hazardous (barrel, pothole, or line) or non-hazardous. Color segmentation also attempts to combine similar pixels in order to reduce noise. Figure 3 shows the results of color segmentation on the image in Figure 2.

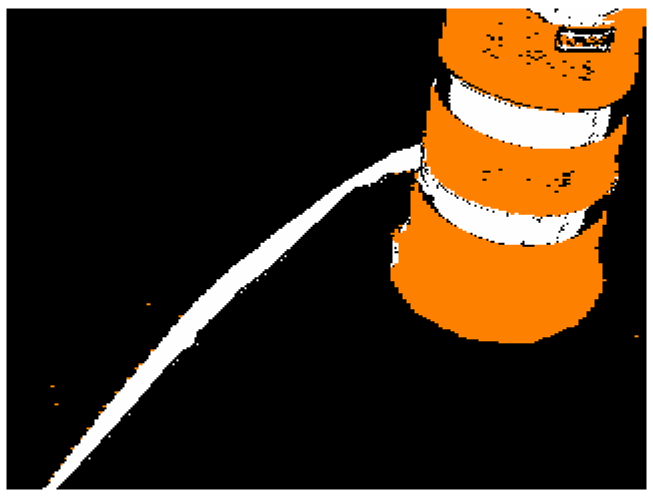

Figure 3. Image after color segmentation.

Sonar Range Acquisition

The sonars are polled in the manner described in the sensor section to get a range for each of the eleven sonars. The sonar inputs are used to estimate obstacle locations in order to detect obstacles that may be outside the cameras' field of view or which are not detected due to unusual lighting conditions. For each sonar which detects an object, a cylindrical obstacle is assumed to exist at a point determined by the distance returned by the sonar and the sonar's angle relative to the robot. The safety of each path, calculated later during path selection, is modified based on how close each path comes to a possible obstacle.

Generating the Danger Map

The danger map is a two-dimensional array of the same size as the combined camera image. Each value in the danger map represents the perceived danger of the corresponding pixel in the image.

A danger value is assigned to each pixel in the combined camera image after color segmentation. Pixels that are determined to be hazardous during color segmentation are assigned a higher danger value than non-hazardous pixels. A high danger value is also assigned to any point within a danger radius defined as

$$\text{danger radius} = \text{robot radius} + \text{barrel radius}$$

The danger values are assigned such that the danger pixels always have a higher value than non-dangerous pixels that fall within the danger radius. An example picture of a resulting danger map is shown in Figure 4.

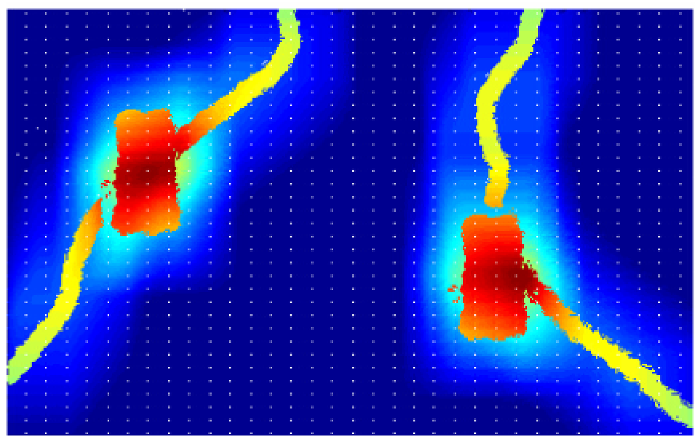

Figure 4: Example of a resulting danger map where red is dangerous and blue is safe.

Selecting a Path

During calibration, several paths were measured and points along each path were recorded in image space and in sonar world space. The values in the danger map are integrated along each path. The total danger for each path is also increased if it passes close to or through an obstacle detected by the sonars. The path with the lowest total danger is selected and the motor drivers are set to follow this path until the next main loop iteration completes. Figure 5 shows example trajectories overlaid onto a contour map of the danger map. In this example, the straight-ahead trajectory was selected as the least dangerous path.

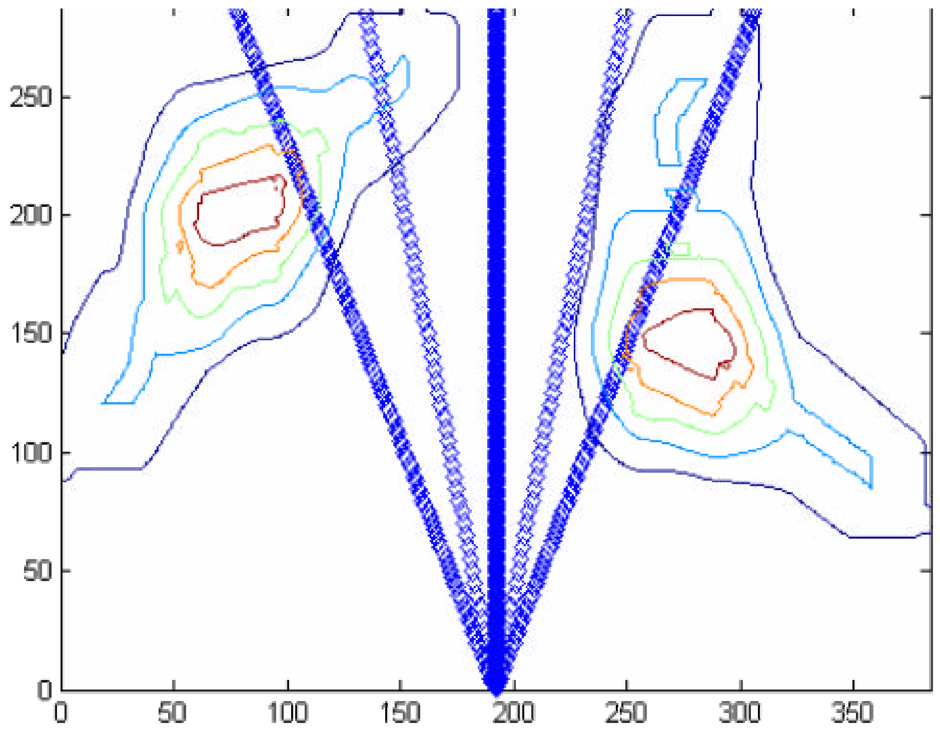

Figure 5: Example of the trajectory selection algorithm.

<u>Navigation Challenge</u>

The robot performs the same operations as for the autonomous challenge, except that the location of the next GPS waypoint is considered during path selection. The heading of the robot as reported by the GPS receiver is compared to the heading from the robot's current position to the waypoint. If more than one of the safest paths as determined above have similar total danger values, the path that takes the robot closest to next waypoint is chosen.

DESIGN METHODOLOGY

Overview

After competing in the previous year’s competition, the first step of the design process for this year’s robot was to evaluate what improvements needed to be made. Table 1 lists the proposed improvements in three areas: equipment and budget, programming, and mechanical and electrical systems.

Table 1: Proposed improvements for 2004

Equipment / Budget	Programming	Mechanical / Electrical
New laptop	Automatically adjust cameras to lighting conditions	Use keyed, locking connectors
New obstacle detection sensors	Improved path following	Tethered remote control
Better cameras	Improved obstacle detection	Power from large 12 V batteries only
Budget for travel and lodging ~$1000	Additional testing	Boxes for laptop and electronics
		Insulated tools

It was decided that a new top was needed to house the electronics and the laptop. Each group member made a scale model out of poster board. This allowed the group to form a consensus about which features were considered important. The top was then drawn in detail in AutoCAD. After several changes to reduce the amount of materials required, the design was finalized.

Many of the design decisions were made to increase safety. The battery terminals were coated in liquid electrical tape and terminated with shielded, polarized connectors to prevent incorrect connection. All connections between electronics were made using circular plastic connectors. The remote control was tethered to eliminate the possibility of sharing the same frequency with another team and to eliminate the need to keep another set of batteries charged.

The barrel detection sensors were selected to be reliable, have a range of about 10 feet, and to be robust enough to work indoors and outdoors. Sonar and infrared sensors were tested on barrels similar to those used in competition. The infrared sensors failed to provide the needed distance reliably in daylight conditions. The sonars used previously detected an object within 10 feet, but would continue to output the last range value if no objects were detected within their field of view. New sonars were purchased that did not suffer from this problem.

Team Organization

The project team was composed of undergraduates and graduates from various backgrounds, as shown in Table 2. The estimated total number of person-hours expended on this project is 800 hours. The cost estimate is listed in Table 3. The total estimated cost to replicate the robot is $8,850.

Table 2: Team organization

Team Leader: Ian Campbell – ME (gr)		
Mechanical: Daniel Bauen – ME (sr)	Electrical: Ben Johnson – CmpE (sn)	Software: Brian Byrne – CS (sn)

CS = Computer Science
CmpE = Computer Engineering
ME = Mechanical Engineering
gr = graduate student
sn = senior

Table 3: Cost estimation

Part	Cost
Chassis*	$4,000.00
GPS Receiver*	$1,500.00
Batteries	$600.00
Motor Drivers	$200.00
Microcontroller Unit	$100.00
2 Cameras	$900.00
11 Sonars	$550.00
Laptop	$1000.00
Total	**$8,850.00**

*Denotes a donated or lent product

Software Design

The design for the control algorithm, particularly the use of a danger map, was inspired by that used by the Mars Exploration Rovers. Stereo vision was considered but eventually discarded to simplify development. The algorithms were first prototyped in Matlab and later converted to C for use in the actual control software.

The way that sonar and camera input was used underwent several revisions. The initial plan called for the danger map to be processed in world space and to be modified to include "virtual obstacles" that were detected by the sonars. This required a translation from world space to image space to be performed while generating the danger map. The design was changed to process the danger map in image space, which reduces the amount of processing required to generate the danger map.

ANALYSIS AND EVALUATION

The electrical and mechanical systems were rigorously tested. The robot was driven under manual control through a variety of environments with a large payload. The robot's maximum speed is approximately 3mph. The robot is capable of climbing ramps of at least 15°. Due to the robust base, it is expected that the robot will be capable of handling any environment present in the autonomous and navigation challenges. The electrical system performed as expected during these tests. A single set of fully charged batteries will easily power the robot for multiple runs in the competition. During this testing, the temperature of all high-power electrical components was measured with an infrared thermometer and found to be within acceptable limits.

Software components are still being evaluated. The laptop can acquire images from the cameras and perform initial image processing at 15 frames per second with acceptable CPU usage. The color segmentation code was tested in bright daylight and overcast conditions. Camera settings may require adjustment in some lighting conditions to prevent saturation of pixels, which results in saturated (white) pixels being incorrectly identified as part of a line.

COURSE EQUIVALENCY

I, ____________________________, certify that the engineering design in the vehicle (original or changes) by the current student team has been significant and equivalent to what might be awarded credit in a senior design course.

Professor:___________________________ Date:______________________