TECHBOT

Autonomous Robotics Club
of
Tennessee Technological University

I, Dr. Stephen Canfield of the Mechanical Engineering Department, Tennessee Technological University certify that the engineering design of the vehicle and the systems by the current student team has been significant and equivalent to what might be awarded credit in a senior design course.

Signed,

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Dr. Stephen Canfield
Advisor, TTU Autonomous Robotics Club

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Section 1: Introduction

The Autonomous Robotics Club of Tennessee Technological University is proud to present: TECHBOT. TECHBOT is the first robot ever created by TTU ARC, and is its first entry ever into a robotics competition. TECHBOT was built from scratch based on the combined vision of ARC members and is designed to be modular and easy to transplant onto a wide variety of autonomous navigation robot chassis. The algorithms have been specifically tweaked to complete the challenges proposed by the Intelligent Ground Vehicle Competition of 2008, but were designed with broader portability options in mind.

1.1 ARC TECHBOT Inspiration

The ARC got inspiration from Explosive Ordinance Disposal (EOD) robots. These robots are invaluable to military and police operations, and provide a unique niche for automation in an already existing robotics market. TECHBOT's design makes it ideally portable to an already-existing EOD chassis with a little re-configuring to the low-level controls to match the chassis' structure.

Section 2: Team Structure

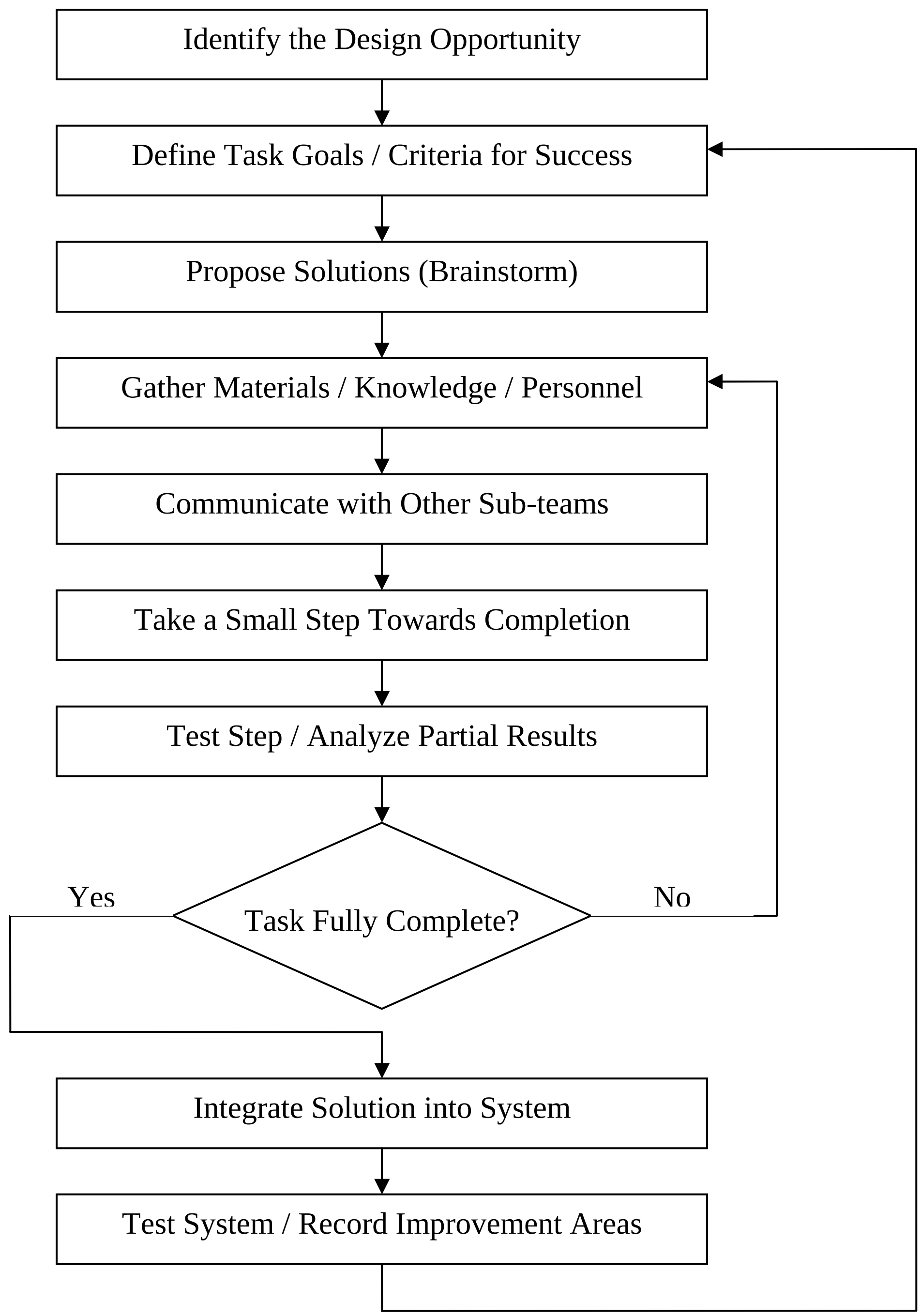
The ARC initially divided itself into four sub-teams for organization and efficiency: Mechanical, High-Level Navigation, Sensors, and Low-Level Systems. Each ARC member is listed below, along with his educational background, primary sub-team choice, and estimated hours of work.

NAME	EDUCATION	LEVEL	SUB-TEAM	HOURS
Hunter McClelland	Mechanical Engr.	Undergraduate	Sensors	450
Nick Patton	Mechanical Engr.	Undergraduate	High-Level	200
Marbin Pazos-Revilla	Electrical Engr.	Graduate	Low-Level	180
Jeremy Langston	Electrical Engr.	Graduate	Low-Level	80
John Adcox	Mechanical Engr.	Undergraduate	Mechanical	120
Jason Taylor	Electrical Engr.	Undergraduate	Low-Level	100

Ben Eckart	Computer Sci.	Undergraduate	High-Level	220
Timmy Smith	Mechanical Engr.	Undergraduate	Mechanical	120
Gerrit Coetzee	Mechanical Engr.	Undergraduate	High-Level	50
Matt Parrish	Mechanical Engr.	Undergraduate	Mechanical	40
Brett Steigerwaldt	Mechanical Engr.	Undergraduate	Mechanical	28
Jimmy Warren	Electrical Engr.	Undergraduate	Sensors	30
Tristan Hill	Mechanical Engr.	Undergraduate	Sensors	48

Section 3: Design Process

The division of ARC into sub-teams facilitated a interrelated multi-branched design process for TECHBOT. The sub-teams functioned as independent but coordinated entities, so problems were generally worked on by an individual team. The design process followed by each team for each task is as follows:



It is important to note that the design process never actually finishes. ARC recognizes that no solution is flawless and therefore decided to implement a "perpetual-improvement" design paradigm. Not only is completing each task an iterative process, but integrating each solution into the total system is also iterative, in the sense that every individual, interdependent solution opens new opportunities for improvement to the entire system.

Section 4: TECHBOT Mechanical

Many of EOD robots have a skid-steering system. However, due to the challenges of autonomizing a skid-steer robot, thus forcing unknown wheel slippage, a differential steer chassis was chosen and fabricated from scratch as a base system.

4.1 Chassis

As explained above, the chassis that is being used has a 2-wheel differential steering system with a single caster wheel for support. The advantages of the system are that there is almost no wheel slippage, the drivetrain is relatively simple, the maneuverability is very good, and the turning radius can be theoretically zero.

4.2 Drivetrain

The vehicle drivetrain that was chosen uses a Servo Systems DC Maxon servomotor for each wheel. Each servomotor has a small spur gear attached to its output shaft and has a chain running across it to a gear that is directly attached to the wheel shaft. This system allows for a large variety of gear ratios to maximize the performance of the motors, and a gear ratio of 4:1 was selected. Another key advantage of a choosing a chain drive is that it allows the fore-to-aft position of the motors to be different on each side. Offsetting the motors reduces the necessary track width of the chassis.

Section 5: TECHBOT Sensors

The sensor suite consists of a laser rangefinder, a camera, wheel encoders, GPS, and a compass. All of these sensors, except the wheel encoders, are connected to a laptop computer, which does the “high-level thinking” (See Section 7). The wheel encoders are connected to an embedded microcontroller which does the “low-level” transforms (See Section 6). Each of the sensors’ drivers has been custom modified or re-designed for TECHBOT’s particular needs.

5.1 SICK Ranger

The first major sensor is the SICK LMS-291 Laser Ranger Finder (Fig 5.1). The main function of this sensor is physical obstacle detection. TECHBOT’s SICK Ranger has a maximum

Figure 5.1

distance of 32 meters with a resolution of 10 millimeters. The rangefinder takes 181 length measurements at 1° increments per sweep. The high-level navigation software converts these measurements and plots them on the map as obstacles.

5.2 Camera

The next sensor is the Unibrain Fire wire Digital Camera (Fig 5.2). This is the only sensor in the suite capable of line detection for TECHBOT. It has a resolution of 640x480, a field of view of 42.5°, and an update rate of 15 frames per second. It captures images and sends them to the high-level program for image processing and data extraction.

Figure 5.2

5.3 GPS

TECHBOT's GPS sensor is a Geoexplorer Series Trimble Unit (Fig 5.3). This unit assists in verifying dead reckoning and helps with map building. It is also used in competition to locate and communicate way points to the high-level processes. Its specifications are as follows: accuracy 1 to 3 meters, on board memory of 512 MB, and battery life of 24 hrs.

Figure 5.3

5.4 Wheel Encoders

Each Maxon DC motor has a separate encoder mounted to the driveshaft. The specifications of the encoders are unknown, but ARC experimentally determined that one wheel revolution is 5100 encoder ticks. TECHBOT's encoders are the primary sensors used to reposition the map between decisions. The encoders also provide the primary input to the velocity PID control. All encoder calculations assume no wheel slip, so TECHBOT has several algorithms to detect wheel slippage and correct the encoder data (See Section 7).

5.5 Digital Compass

Global orientation is sensed by a Devantech Magnetic Compass, model CMPS03 (Fig 5.4). This sensor is redundant to

Figure 5.4

the calculations from the wheel encoders, and therefore provides a check on their accuracy. Its resolution is 0.1°, but its accuracy is affected significantly by tilting away from the horizontal.

Section 6: TECHBOT Low-Level Systems

During the initial design phase, ARC made the choice to build its own motor and low-level controllers from an HCS12 microcontroller along with IC's (integrated circuits) for driving the motors and capturing encoder counts. Through the use of real-time interrupts on the HCS12, effective real-time control is possible. The Mini-Dragon HCS12 board has two serial lines and many I/O pins through which interfacing with sensors and other hardware is conducted. ARC built the entire system from the ground up, including making custom printed circuit boards and developing code. This do-it-yourself approach gives a much more versatile product than an off-the-shelf solution, it drastically reduces cost for the components, and it builds a knowledge foundation that ARC, being a rookie team, has not yet acquired.

6.1 Electronics Development

The goal of the electronics system is to supply appropriate power to all necessary components and to provide servo loops on the DC motors. This system involves numerous subcomponents in order to compartmentalize the design for increased modularity and subsequent benefits from layer abstraction. Once a subsystem is complete and thoroughly tested, it can be effectively ignored. Modularity allows for parallelism in design, therefore multiple team members may work on different subsystems individually without fear of conflict. Subsystems, such as the servo loop, began with a simple engineering design. Due to the iterative nature of design processes, the design underwent changes – some more significant than others. Development included SPICE simulations, logical layout, breadboarding, prototyping, PCB (printed circuit board) layout, PCB etching, and, ultimately, PCB milling and assembly.

6.2 Low-Level Logic PCB (Servo Loop)

To provide for a higher degree of position reckoning, the robot drive system uses a closed loop servo circuit. Each DC motor is equipped with a 1,000 count encoder, which is increased to 5,100 due to the shaft's gearbox. This information is fed back into the microcontroller using a special logic PCB. In this PCB is an Agilent 2032 Quadrature Decoder. This IC takes two encoder inputs and counts up and down the number of ticks the encoder sees. This information is stored internally in a 32 bit register which is accessible by the use of several command signals and 8 data lines. To decrease the complexity of the microcontroller software, a simple gather-reset routine is implemented which retrieves the bits 15 to 8 of the 2032 IC and then resets the count back to zero. The relatively high speed of the microcontroller allows for minimal error due to lost counts. The information gathered on encoder counts is then used in the microcontroller's PID control algorithm. PID control, which is explained in the following section, attempts to supply drive signals such that the robot's accelerations and speeds are maintained stably and controllably. These drive signals are sent as pulse-width modulated signals to the motor drivers. To allow for maximum resiliency, industrial drivers were used in lieu of simple H-Bridges such as the L293's and 33886's. The drivers are fed 24V DC from the power distribution circuitry to induce the field inside the DC motors.

6.3 Velocity Control

For the low-level motor controller, a proportional–integral–derivative (PID) closed-loop control system was coded on the Mini-Dragon HCS12 microcontroller. A representative diagram of the loop is shown in Figure 6.1. Velocity is controlled by creating “setpoints” in terms of encoder ticks per interrupt, dictated via serial connection by the high-level control on the laptop. The PID system turns the setpoints into PWM outputs which are sent directly to the motors. The entire system is simple yet robust, with the control loop running at 1024 Hertz. The serial communication between the laptop and the microcontroller is bidirectional; the laptop sends motor speeds and receives encoder data for dead reckoning during map building.

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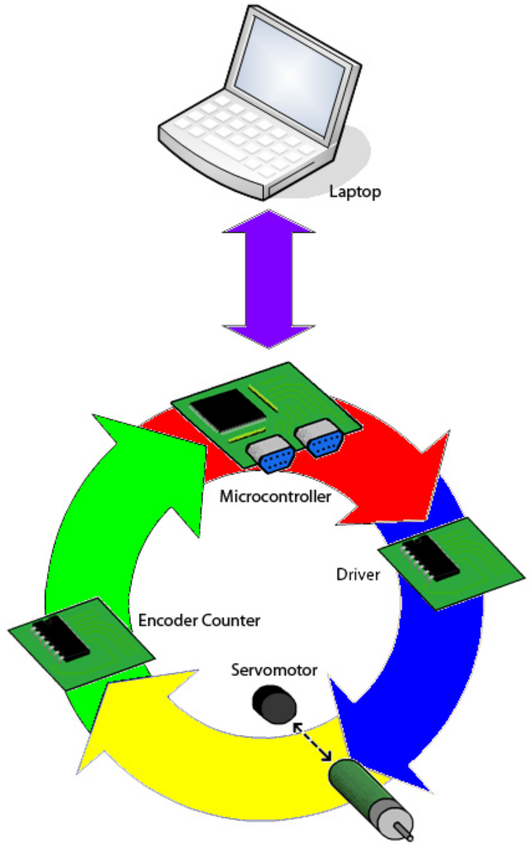

Figure 6.1

6.4 Power Distribution

TECHBOT is powered via two 12V 55A/h lead-acid batteries connected in series; providing a first stage 24V power source from which all the remaining power stages are derived. A 20V DC relay and switch provide the electrical interface between the first and second power stage.

The second power stage consists of two high current linear voltage regulators; each encapsulated in TO-3 package and bolted to a 12W heat sink. These regulators have negligible voltage drop and can withstand peak and steady currents of 12 and 8 amps respectively. In addition, their built-in current and thermal sensing capabilities provide a layer of protection to the remaining underlying circuitry and electrical devices. The regulated output from this stage provides power to the motor drivers and to a third power stage.

The third power stage consists of two linear voltage regulators providing 5V to the logic circuitry and 9V to the microcontroller, both encapsulated in a TO-220 package and bolted to their respective 5W heat sink. Both regulators have internal thermal shutdown and current limiting capabilities, in addition; a small network of external discrete components was added for short-circuit protection.

A plastic enclosure was used to house TECHBOT’s power circuitry, which includes among other components banana plugs and panel mount connectors providing input and output interfaces; all labeled according to their respective functionality.

6.5 Emergency Stop

Two emergency stops have been installed as safety measures. The wired E-Stop is simply a push-button which disconnects the batteries from the rest of the system. TECHBOT's wireless E-Stop is carried out by use of RF transmitter/receiver pair. The transmitter modulates an 8 bit coded pattern using a binary form of amplitude modulation using a carrier signal of 433 Mhz. Once a button is pressed the transmitter feeds this signal to a ¼ wavelength omni-directional antenna, transforming the electric signal into an RF electromagnetic wave. The receiver end demodulates the signal and checks for the 8 bit pattern; upon a match, a relay is used to interrupt power.

Section 7: TECHBOT High-Level Navigation

At the onset of the project, ARC decided to attempt a more traditional robot AI in lieu of the increasingly popular reactive paradigm. Reactive paradigms work well in heavily constrained environments, like the IGVC competition, but it seems that the most widely applicable solution is a robot that plans and makes intelligent decisions based on its past sensory information. Though IGVC is foremost a competition, the spirit and reason for the event is innovation and discovery. Therefore, ARC decided to integrate sensory information into a topographical map, from which the navigation algorithm makes decisions. The paths are generated in the form of continuous differentiable curves, and are transformed all the way to motor voltage commands. All of this is done in original Python or C code. Ultimately, although a deliberative-hybrid robot is more difficult than a reactive one, TECHBOT truly aspires to the “I” in IGVC.

7.1 Mapping

TECHBOT visualizes the world through its primary unit of sensory information, the “blip.” Blips asynchronously accrue from the detection sensors by the use of multithreading in the Python high-level controller. The navigation algorithm, however, does not need to be evaluated for every blip, because a multi-tiered control scheme with different asynchronous sensor and computational rates runs as outlined below:

System	**Data Rate (Hertz)**
Navigation / Path Planning / Map Building	2
GPS	2
Camera	15
Sick LMS291	75
PID Control Loop	1024

Table 7.1

The blips accumulate as a list of discrete coordinates coupled with metadata, including a timestamp and various types information. Through the use of Python's object-oriented language features, the blip object is generic enough that it can be used to represent lines, obstacles, or any other desired object on the map. Thus, all sensory information can be overlaid on the same map in a unified fashion.

The tiered control scheme assembles a map only when necessary in order to conserve computation; thus, a map is created only when the navigation algorithm asks for it. The system is made extremely efficient by keeping transform matrices for groups of blips based on the robot's absolute location. The absolute location of the robot is deduced by dead reckoning based on the encoder count data from the microcontroller. To prevent error propagation due to wheel slippage, the encoder data is often checked against compass and GPS data. When the map is needed by the navigation algorithm, a windowing matrix transform is applied to the data, putting the blips onto a discrete grid. During this process, confidence values are made based on the blip's metadata. The end result is a generic confidence map to which any navigation algorithm can be applied.

7.2 Vision

TECHBOT utilizes a camera to identify course lines for the purposes of navigation. The lines are identified on images, transformed to topographical data, and then placed as objects on the confidence map. The first step in analyzing the images is a gray-scale threshold: the image is set to a grey-scale and then all shades that are darker than a certain preset value are discarded. This leaves only light colored objects in the picture. Ideally, the remaining pixels only belong to bright lines, however, there will always be noise in the picture due to reflection or random data. To eliminate the noise, the image is passed through a blob filter. This filter eliminates pixels that do not belong to a group or body of pixels. The remaining pixels are ported directly to the confidence map as line objects allowing TECHBOT’s navigation algorithm to use the data. Breaks in the lines are handled by identifying, mapping (as described above) and following the other line until the missing line reappears.

7.3 Path Planning & Decision Making

Given a discrete confidence map of obstacles, lines, and other objects, any of a set of traditional navigational algorithms can be applied, producing many different possible paths to the goal. Sampling from these paths, control points can be picked for the robot's path trajectories. These trajectories are given in the form of parametric Bezier curves (see Figure 7.1). TECHBOT evaluates the Bezier curves based on various heuristics, including arc length and radius of curvature. To prune the search and retain optimality of the search space, the navigation employs the A* algorithm to find the best path. A sample Bezier path space is shown below in Figure 7.2.

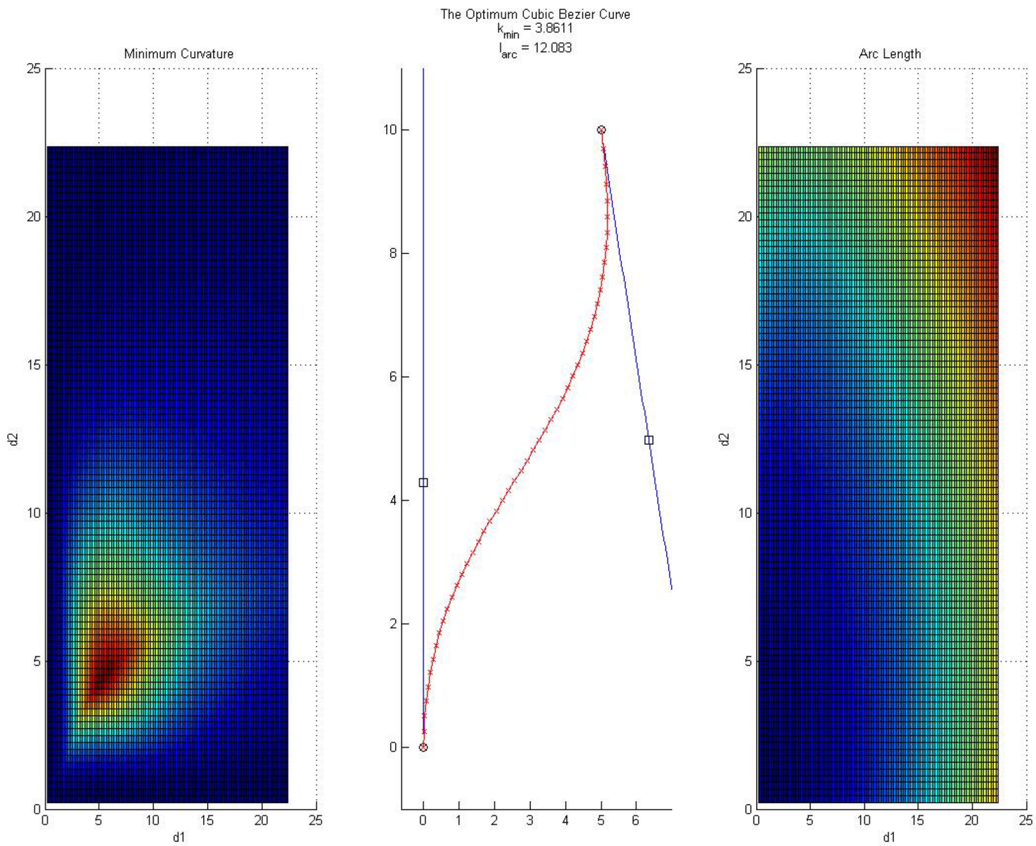

Figure 7.1

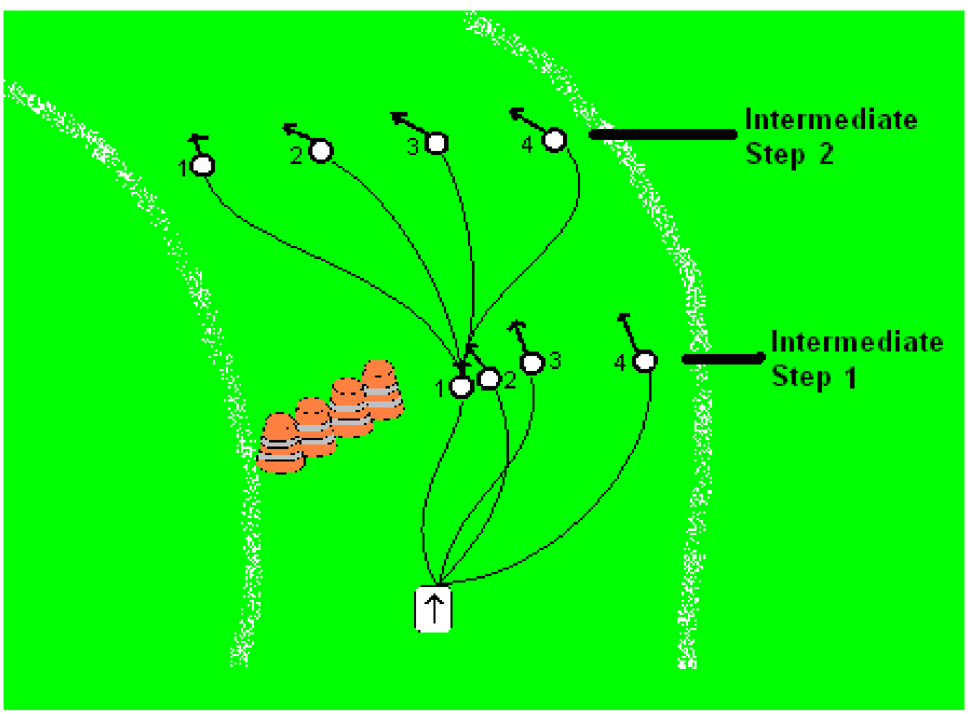

Figure 7.2

Once the path is selected, it is transformed to a velocity profile, which is then sent periodically to the microcontroller. The high-level navigation algorithm is evaluated about twice a second. Bezier curves have the property that they are continuous and differentiable. Furthermore, Bezier curves can easily be attached to other Bezier curves and retain both continuity and differentiability. This property means that when TECHBOT decides on a new "best" path, it does not stop and change its heading. Bezier curves allow it to achieve fluid motion while avoiding obstacles and staying on the path.

Section 8: Performance Characteristics

TECHBOT's top speed was designed to be 5 mph per IGVC regulations, but when it first started navigating, it peaked at just over 1 mph. It can handle inclines of up to 25°, and the PID control scheme prevents uncontrolled downhill coasting. TECHBOT's battery life is greater than 6 hours, but the laptop battery runs out at around 5 hours without charging. The laser rangefinder detects obstacles at a distance of 32 meters, and the camera sees them around 10 meters. Per IGVC regulations, the waypoint accuracy is slightly below 1 meter.

Section 9: Cost

Table 9.1 is a list of the estimated value of the components on TECHBOT:

Item	**Estimated Retail Cost**	**Cost to ARC**
Aluminum Tubing	$300	$25
Electronic Boxes	$50	$50
Aluminum Plates	$75	$0
Laptop	$1300	$0
Wheels	$60	$0
Servo Motors	$600	$0
SICK LMS	$6180	$180
GPS	$4600	$0
Unibrain Fire Wire Camera	$140	$140
12 V Batteries	$280	$0

Motor Drivers	$1200	$0
HCS12 Microcontroller	$80	$0
Plexiglass	$110	$0
Gear Train	$40	$40
Miscellaneous	$50	$50
TOTAL	**$15065**	**$485**

Table 9.1

Section 10: Conclusion

TECHBOT is designed with three true, overarching goals in mind. The first is to develop and implement deliberative intelligence strategies into a robotic system, enabling it to handle a wider variety of environments and challenges. The second is to afford a grand entry for Tennessee Technological University into the field of collegiate robotics competitions. And the third is to gain knowledge and experience for the newly-formed ARC which can be passed to future members, and which will also be taken by the current members into whatever robotic fields their individual futures hold. The continual improvement design paradigm continues to afford a vast array of improvement opportunities, and is in full swing even at the time of publishing this report. In summary, TTU and the ARC are very proud of TECHBOT and believe that it has already met, and continues to meet, the most important of its true design goals.