

Bringing Reliability to Autonomous Vehicle Operation (B.R.A.V.O)

Mirazam Usmanov, Christopher Cox,
Henry McWhorter, Douglas Akinola

University of Central Florida Department of
Electrical Engineering and Computer Science,
Orlando, Florida,

Abstract — This document discusses the design of B.R.A.V.O. “BRING RELIABILITY TO AUTONOMOUS VEHICLE OPERATION” an autonomous vehicle that incorporates the use of a remote image processing. The B.R.A.V.O. concept focuses on traffic interaction between multiple motorized, small-scale cars. Computer vision, software engineering and electronic motor control can work together to create intelligent and efficient vehicles to deliver solutions to problems encountered on highways and in congested cities around the world.

Index Terms — Autonomous, computer vision, obstacle avoidance, pre-determined routes, sign detection.

I. INTRODUCTION

B.R.A.V.O. or “Bring Reliability to Autonomous Vehicle Operation” is a fully autonomous vehicle that incorporates the use of a remote image processing unit as well as onboard sensors to navigate a predetermined course, navigate alternate routes involving 90 degree turns and stop signs, detect potential collisions, and obey the basic “rules of the road.” In an era where technology is increasing at an exponential rate, the conveniences provided by technology have also increased. From smart phones to navigation systems, technology has provided innumerable ways of reducing stress while improving safety in many aspects of everyday life. One specific aspect of everyday life that combines both large amounts of stress and safety concerns is the seemingly simple task of driving an automobile. According to the National Highway Traffic Safety Administration, over 840,000 injuries occur each year due to traffic accidents, a number which doesn’t account for the total number of traffic accidents. This is an obvious area that technology has a potentially much larger role. If a vehicle were able to have the ability of self-navigation as well as collision detection capabilities, it would be safe to assume that the roads would become much safer. Computers do not

panic, computers do not talk on their cell phones while driving, and computers do not drive while intoxicated. Computers lack the ability to be easily distracted as humans often are, making a self-driving or autonomous vehicle, ideal for today’s roadways.

The integration of this particular project into an actual vehicle would be extremely costly as well as dangerous, so the project will focus on a smaller, less expensive platform

similar to an RC hobby car. This allows for the group to demonstrate a unique interpretation of an autonomous vehicle and provide the group with unique experience in designing, building, and testing an autonomous vehicle. The smaller scale of the vehicle also allows for the integration of B.R.A.V.O. into other technology fields that might require smaller and agile vehicles to accomplish a task such as search and rescue robots. The autonomous vehicle platform will consist of a hobby car chassis mounted with the necessary hardware that enables the vehicle to accomplish its tasks without any external human influence, highlighting the potential for this technology when integrated on a smaller scale.

The performance of this vehicle depends largely on its ability to process its surroundings through both a camera and a proximity sensor, thus this project will incorporate the use of a remote image processor. The image processor will be dedicated to extracting and calculating the data from an onboard wireless IP camera, processing that data into a relevant signal, and sending that signal to the motor controls. In order to add complexity and diversity to the project, the group will also experiment with a second vehicle that incorporates the use of off-board processing through a wireless medium where all data will be sent to a laptop for processing. Both vehicles will exhibit autonomy when completing any challenges and will conform to the requirements set forth by the group.

II. REQUIREMENTS

The main requirements for B.R.A.V.O. are to create an autonomous vehicle that is able to navigate a course with various paths and obstacles. Also demonstrate a robust A.I. that is able to determine and follow particular routes as well as make appropriate decisions regarding obstacle avoidance. Furthermore, demonstrate a smooth motor control system.

III. DESIGN METHODS

The project design consists of two vehicles BRAVO One and BRAVO Two. Each of the two vehicles will contain identical autonomous navigation units that will perform identical functions and possess same behaviors. The systems will follow a series of sequential input readings from 3 devices: a serial camera, an ultrasonic proximity sensor and a line sensor array. Data will be fetched and processed by the microcontroller and the remote PC. Processed data will be sent to the navigation AI which based on preset parameters will give an appropriate command to the motor and steering controller board. Subsequently, the motor controller will regulate power of the drive motor and the steering servo in order to perform accurate maneuvers and continuously adjust the speed accordingly. Vehicles will be preprogrammed with a certain route to follow, indicated by the amount of signs and turns encountered. For instance, the team will determine the starting and ending points of the route on the map and count the number signs that fall within that route. This data will then be stored in memory of the microcontroller unit. Once a start command is given, the vehicle will begin its journey and keep track of signs detected. Upon accounting for all anticipated signs, the vehicle will know the destination is reached and come to a stop.

IV. PROJECT MANAGEMENT

For budget and financing we aimed to be as cost efficient as possible and not put so much a financial burden on the group. We were not able find a sponsor for our project and had pay the expenses for the items out of pocket. The idea of the project being RC autonomous vehicles was decided as soon as the group was formed. The group decided to meet roughly every two weeks to talk about ideas, concepts, and progress on research of the report. Most of our meetings were productive and much was accomplished during that time. Starting the research proved not to be an easy task as initially thought. Very much thought, detail, and organization had to be put to make sure the research documentation was complete and meet the standards and necessary requirements.

V. IMPLEMENTATION

To ensure the system met all performance requirements every subsystem was tested separately by each member of the team responsible for that particular module. The team developed a systematic approach for testing. A set of criteria was composed for every hardware and software component of each vehicle. The team then prototyped all

the hardware and software designs and perform test runs on every component or a device and checked whether performance results satisfied preset criteria. Any failures was analyzed for errors and mistakes, modified accordingly and tested again. The process was continued until every system passed all of the test runs. Once the team was certain that every component is working properly, they were merged together and embedded into a single platform. The final phase of the test involved a full test run under different circumstances that will evaluate precision and overall performance of the autonomous vehicles.

V. SOFTWARE DEISGN

Once the implementation for the hardware has been completed, there still remains the arduous task of providing an optimized and reliable software interface. Simple navigation of the course requires a robust line detection algorithm that not only senses a deviation from the route, but corrects the deviation without overcompensating or undercompensating. Initially the algorithm will make use of a line following technique that records and sums the pixel values that are within a particular color threshold across an appropriately placed Y-scanline. The algorithm will then divide this number by the X-values that correspond to the numbers that were within the particular color threshold, generating a centroid of the line that the vehicle wishes to follow. The algorithm will then take this number and find the deviation from the center line or where X is equal to the middle pixel. Once this deviation is discovered, the algorithm can then compute the appropriate pulse width modulated signal to send to the motor controls for course correction. The computation of the signal must be exact, else the motors may overcompensate and display jerky movements or even undercompensate and lose the line. For more complex shapes and turns, the processor will make use of more robust algorithms such as the Hough Line Transform. With this algorithm, the vehicle will be better able to detect sharper turns and stop signs. Though beneficial, the group must also be diligent and fully optimize their code by avoiding higher math functions if possible. There is inherent latency in all function calls, especially in general functions and it might be quicker to use custom definitions instead.

To satisfy the requirements of an autonomous vehicle, the software must also implement an algorithm that allows the vehicle to decide when and what routes to follow. Colors will correspond to specific routes that will be pre-programmed into memory. Because various colors will

appear throughout the course, the vehicle must know when to follow a specific route as well as the route itself. The choice of the route will easily be determined by a random number provided by the random number generator. Certain numbers will correspond to certain routes and when a random number is generated, the robot will “choose” that route to follow. In order to avoid adding any unnecessary latency to the processing unit, the timing of when to follow a specific route will be determined by whenever the route is first encountered.

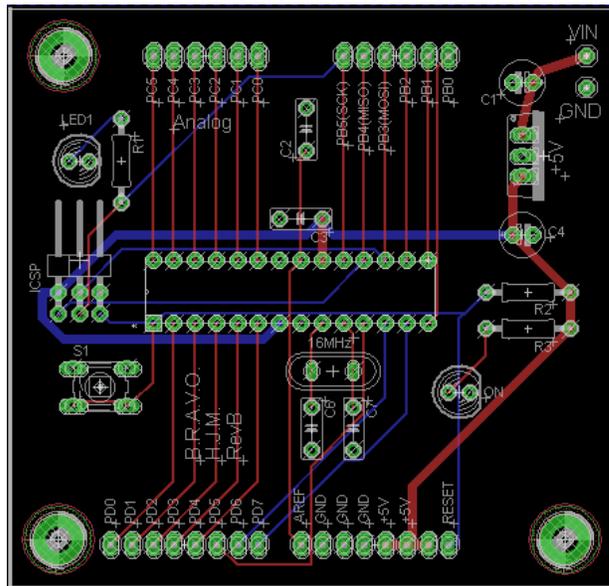
VI. MICROCONTROLLER

The PCB was designed using the Atmel Atmega328P-PU as the microcontroller. There were several requirements in the selection of this MCU: the project required six digital I/O pins as well as 6 analog I/O pins, sufficient onboard memory and speed, relatively low power consumption, and sufficient support for the programming of the MCU. The Atmega328P meets all of these requirements as it contains seven digital I/O pins and seven analog pins. The MCU has 32KB of Flash memory, 2KB of internal SRAM and operates at a maximum frequency of 20MHz. The MCU operates at roughly +5V and has a maximum current rating of 200mA with 40mA per pin. For support, when the MCU has been pre-programmed with the Optiboot bootloader the MCU is able to be programmed using Arduino scripts which is very convenient as opposed to the using ICSP.

For the design of the PCB, there was little deviation from the reference given by Arduino. The input voltage is stepped down using an LM7805 fixed 5-volt regulator where a voltage rail is provided to four output pins to be used for the sensors. A 16MHz oscillator is provided for the use of several internal timers, a green “on” LED is used to indicate power is being received by the board, and a yellow LED is used to indicate transmission through the ICSP. Default one-to-one pinouts are used for all interactions with the MCU while a tactile switch is provided for the use of a reset switch. The board contains two ground planes for both the top and bottom layers.

Figure 1 shows PCB layout for the microcontroller.

Figure 1: MCU PCB layout



VII. COMPUTER VISION

In this project, a computer vision will serve as a vital data processing unit, providing input data to navigation system, contributing to decision making and safety functions. The navigation system of the vehicle will be dependent on data provided by the computer vision. The team needs to ensure that the unit is capable of computing at relatively high rates with good precision and efficiency while possessing enough on-chip memory to reduce the latency in the transmission and calculation of any data. For testing purposes, two separate image processing units have been implemented; a primary on-board image processor and a secondary remote PC based image processor. Both prototypes have been evaluated based on overall performances to determine an optimal method. Test results have revealed that a PC based image processing is significantly more capable in terms of speed and functionality. Additionally, an on-board image processor had certain hardware and software limitations, such as processing speed and lack of available tools for real time image processing that prevented the team to successfully implement a self contained vision system. As the project relies so heavily on image processing, one of the primary goals for the hardware was to successfully mount and test a reliable camera atop the vehicle platform. The team anticipated to use a small, lightweight and affordable camera that possesses manageable processing specifications with regards to outgoing image size and communication protocols. After some additional research following the initial tests, the team had decided to use a

wireless IP camera with a built in wireless communication capability, eliminating the need for implementation of image transmission. Selected IP camera will be transmitting a continuous video feed over a WiFi channel using an RTSP protocol to the remote PC, which will read the incoming image frames and apply Canny Edge Detection and Hough Circle Transform algorithms to detect circular shapes in the image. Road signs will be represented by circular color coded shapes and will indicate specific signs based on color. Detected circles will have preset sizes such that the program will ignore any irrelevant shapes that may be present in the image. Once a circle is detected, the program will scan every color channel (RGB) to identify the color of the circle. To perform functions listed above, an OpenCV library will be employed to reduce implementation complexities and leave additional time for testing and debugging of computer vision system. A remote PC computer will run a c++ code in Visual Studio IDE. Due to the nature of the software component, there's no need to develop a graphical user interface. Figures 2 and 3 demonstrate detection of different color signs.



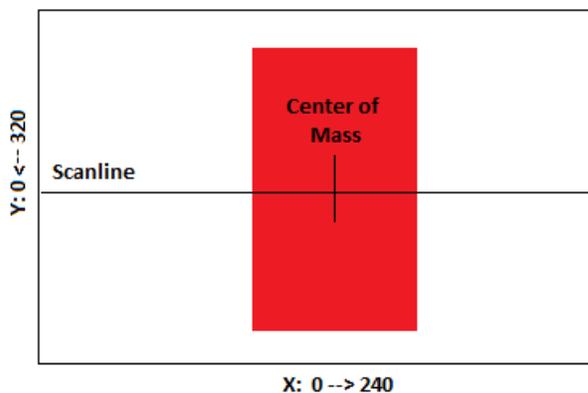
Figures 2-3: Sign Detection – Magenta and Green

VIII. WIRELESS COMMUNICATION

Wireless communication takes place between the main navigation AI (microcontroller) and a remote PC which will perform all computer vision functions. There will be 2 wireless devices transmitting and receiving data. One is the IP camera that has an embedded transmitter and communication schemes which will communicate with the PC over a WiFi link. The second is a serial communication over a Bluetooth link. Once a sign have been detected and identified by the image processor, remote PC will send a corresponding signal over a Bluetooth link to the microcontroller describing what sign have been detected. Considering the scale of the project, total area for communications will be limited to 20 meters which is consistent with Bluetooth hardware capabilities.

IX. LINE SENSOR ARRAY

The team had initially anticipated to use computer vision and image processing for line tracking. Multiple tests had raised a concern about performance issues due to change in light intensity. As a fail-safe backup system, an alternate method had been designed to compare to image processing unit. An alternate line tracking method was to use a custom Line Sensor Array. The module will can be made up of a series of photoresistors that will return reflected light from surface beneath the vehicle. Operating scheme will be as follows: If the line beneath a photocell is white, a value higher a certain threshold will be returned. Likewise, if the color beneath is of low intensity, a value smaller than the specified threshold will be returned. Using a series of such photocells would permit detecting in which direction the vehicle is drifting away from the centerline. After performing multiple test runs, it had come to the team's attention that a line sensor array performs more accurately compared to an image processor and was less prone to changes in lightning. It was decided to utilize a line sensor array as primary means for line tracking. Image below shows centerline detection.



X. OBSTACLE AVOIDANCE

Obstacle avoidance is achieved through the use of two proximity sensors: the Sharp IR sensor, and the URM ultrasonic sensor. The Sharp IR sensor has a straight-line detection range from 10cm to 80cm with a max current consumption of 40mA. The Sharp IR sensor returns an analog value which will be used to trigger an external interrupt on one of the analog pins of the MCU. The URM ultrasonic sensor has a straight-line detection range from 4cm to 500cm with a maximum current consumption of 20mA. This particular sensor has the ability to return array of values from PWM signals to analog signals. This sensor also has the ability to be pre-programmed with a set threshold and return a value only when this threshold has been triggered.

XI. VEHICLE PLATFORM

There are many factors that go into the process of selecting a technically competent and affordable vehicle



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Figure 5

XII. MOTOR CONTROL

For the velocity and directional control of the brushed DC motor, the circuit design primarily needs to be able to reverse polarity and limit the winding current. There are several different ways to achieve these requirements but the most common solution is the use of an H-bridge. The H-bridge consists of N-channel power MOSFET's at the outputs to drive the motor windings.

The availability of commercially manufactured H-bridges is diverse and provides consumers with many options. One of the most important aspects in the selection of a motor controller for use in an autonomous vehicle application is the ability to limit the current through the motor windings. The engineering team needs to be able to adjust the movement to desired levels and it would not be efficient to turn the motor of an on repeatedly in order to achieve a desired velocity or response. The current through the motor windings can be reduced or modulated via frequency pulse width modulation (PWM) current regulation. When used in DC motors, the current control feature is used to limit the start-up and stall current of the

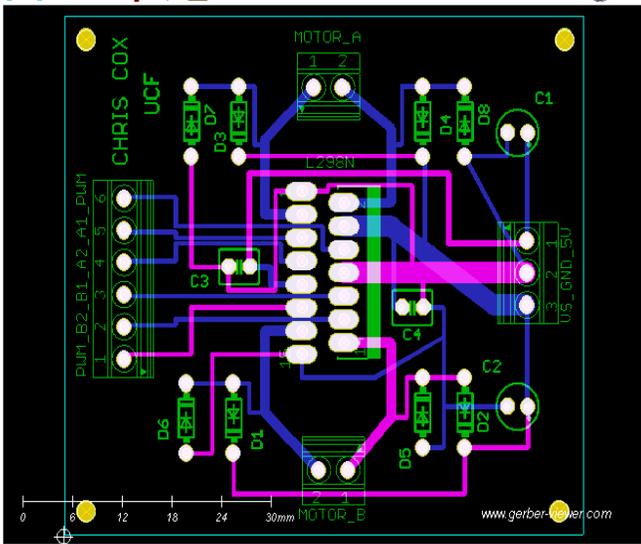


Figure 8

XIII. POWER SYSTEM

The goal of the project is to have the BRAVO vehicles are able to run for an extended period of time while navigating through its pre- determined route. For our power supply the team chose to use rechargeable batteries so that we can reuse them as many times as we needed for the vehicles. Out of all the batteries we researched, the Lithium Polymer battery technology was best suitable for our needs. The battery is light weight, has a high energy density, very efficient and safe to use. The BRAVO requires 7.4 V for the vehicle and DC motors and 5V each for the components A 7.4V 1600 mAh Lithium Polymer battery will be powering each RC vehicle along with the DC motors. The battery will also be charging the microcontroller, bluetooth radio, line scanner and IR proximity sensor. Four AA NiMH rechargeable batteries will be used to power the camera.

XIV. COURSE CONSTRUCTION

There is a large outer circle with several “off” and “on” ramps that the autonomous vehicle will be able to use to access the inner road system consisting of a four-way stop, varied and challenging routes such as those involving 90 degree turns or where the path is temporarily unknown. The vehicle should finally be able to navigate the route back to the outer circle. The goal of this test track is to not only test the design’s ability to navigate a roadway, but to interact with other cars using a combination of proximity sensors and image processing integrated with a

strong artificial intelligence framework. Below is a sample test track that the group would like to use for the prototype. The track will be drawn on a hard smooth dark colored surface using a white colored tape to represent the centerline of the roadway.

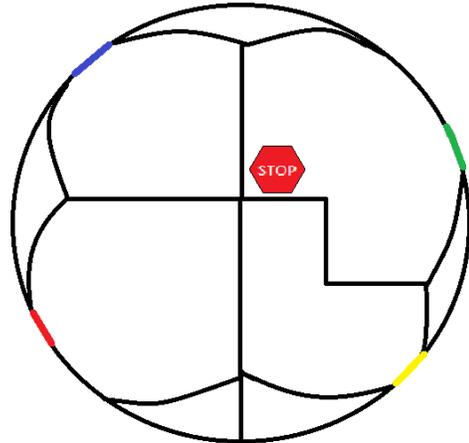


Figure 9

The goal of the pre-determined course is to provide a series of challenges that will test each component of the autonomous vehicle such as the image processing system, the proximity sensors, and the ability of the system to react. The course will consist of an outer path similar to that of an interstate bypass that might circle a large city. The outer loop will have various “off-ramps” as well as “on-ramps” that will be designated by different colors that will represent the beginning of multiple and varied paths. The various paths will consist of challenges and obstacles that will test the ability of the autonomous vehicle such as 90 degree turns, stop signs, road obstacles, another car using the roadway, and path discontinuities.

Each particular path should provide a unique challenge to the vehicle while each obstacle will be designed to test specific aspects of the entire system. The 90 degree turns will test the ability of the image processing system to react to a sudden change in the path while the path discontinuities will test the A.I. software implementation of the system. If the vehicle temporarily loses the path, a routine needs to be in place to handle such an event. The stop signs will also test the ability of the image processing system, as the system will have to recognize various shapes and colors. The obstacles will test system’s proximity sensors as well as the entire system’s ability to react to sudden changes and to compensate for these changes. The addition of a second car to the course will challenge the vehicle to make quick decisions which is

why the group chose to include four-way stop. Though seemingly a simple task, a four-way stop represents a programming challenge that the A.I. of the system will have to account for. The colors representing the various paths will also test the programming of the vehicle and its ability to make decisions without external influence.

Once a path is completed the vehicle will navigate back to the outer loop and make a decision on the next route to take. The final goal of this test track is to not only test the design's ability to navigate a roadway, but to interact with other cars using a combination of proximity sensors and image processing integrated with a strong artificial intelligence framework. Below is a sample test track that the group would like to use for the prototype.

XVI. CONCLUSION

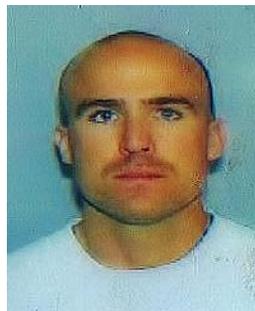
B.R.A.V.O. is a project that the group was excited to design, build, test, and showcase for the spring of 2013. It is a project that is diverse in its respective components, combining the skills and knowledge of both electrical and computer engineering. From embedded systems and servo controls to image processing and artificial intelligence design, the project allowed the group members to expand their knowledge of engineering by taking the learned concepts of the classroom and apply those concepts to the actual experience of building and testing a working project. The project allowed us to gain valuable experience of working as team to accomplish a common task.

As engineers, problems often arise that require the expertise and knowledge of more than one individual. The experience of working in a group that necessitates the input and knowledge from each individual member will be valuable as each member enters their respective line of work. The idea for the autonomous vehicle was inspired by the emergence of driverless cars over the last decade and though the task of incorporating this technology onto a larger scale was the initial goal, cost and safety concerns were the deciding factors in choosing another route. Driverless or autonomous cars have enormous potential when considering the future of individual transportation from avoiding hazardous driving situations such as a sleepy or intoxicated driver, to optimizing traffic flow in rush hour traffic, a driverless car that is able to detect potential collisions while safely navigating a pre-determined route is beneficial for the safety of all drivers.

B.R.A.V.O Group members



Douglas Akinola is graduating from the University of Central Florida with a Bachelor of Science in Electrical Engineering. Once he graduates he would like to work in the industry. He is also interested in continuing his education with a Masters degree in Electrical Engineering.



Christopher Cox is a graduating senior in electrical engineering with a decade of expertise in electrical and mechanical design and repair of various sub-disciplines. Previously a resident of Andros Island, Bahamas and a Texas native, upon graduation he will pursue a career in the electronics field for a multi-national, Fortune 500 company and spend his free time sailing the islands of the Caribbean.



Henry McWhorter is an electrical engineer student with a minor in computer science. He is currently seeking his second bachelor's degree in the hopes of obtaining a fulfilling career in advanced technologies. He enjoys the outdoors and hiking the Appalachian trail when he has the spare time. He hopes to one day become a project manager in either the space or defense industry.



Mirazam Usmanov will be graduating with a Bachelor's degree in computer engineering. He will be joining MTS as a telecom engineer intern over the summer and return to UCF in the fall to start his graduate studies in computer engineering.