

Solar Autonomous Beach Buggy Design Project

Caroline Kamm, Patrick McBryde, Olesya Nakonechnaya, William Zhang

Dept. of Electrical Engineering and Computer Science, University of Central Florida, Orlando, Florida, 32816-2450

Abstract — This project presents a solution to a design competition posed by the University of Central Florida, namely to build an autonomously navigating beach vehicle that runs completely on solar energy. This solution is expected to meet various operational and safety requirements, making it a valid solution to both safe vehicular beach transportation and minimization of environmental and wildlife impact. In doing so, this multidisciplinary design incorporates several technologies such as proximity sensing, pathfinding with computer vision, solar panels and smart power regulators, and motor controls.

Index Terms — Solar energy, autonomous vehicles, computer vision, microcontrollers, maximum power point trackers.

I. INTRODUCTION

Multidisciplinary students from the University of Central Florida will be participating in a new project called the Florida Solar Beach Buggy Challenge. This inaugural competition, sponsored by Duke Energy and the University of Central Florida, was created to stimulate interest in both autonomous vehicle design and solar-powered devices in a way that introduces both technologies to everyday life. The beach-going experience is integral to the Florida lifestyle, and by providing an additional form of transportation in the beach environment, it becomes more accessible to more people. Moreover, this project is an excellent way to promote renewable energy and environmental awareness while addressing the safety concerns associated with beach vehicles through its autonomous collision avoidance system.

Several parameters were introduced in the competition guidelines to heighten the challenge such

as payload, total distance, time limit, and budget. The resulting design includes an inventive frame design made out of wood, PVC, and aluminum, and a unique handmade solar array module on an adjustable mount. The following design description encompasses only the electrical and computer engineering-related systems, but the final product delivers an all-inclusive multidisciplinary solution to this challenge that epitomizes the forward-thinking nature of this competition.

II. POWER SYSTEM DESIGN

The power system for the vehicle includes the battery array, the solar array, the motor driver, the charge controller, the converters, and protective circuitry. The battery array was selected based upon hourly power consumption calculations. It consists of two 12V AGM batteries rated at 120Ah. The converters were added to drop the 24V battery array to 5V and 3.3V required to power the microcontroller and processors. The remaining power system components are described in the following sections.

A. Solar Array

The solar array was designed as a handmade array rather than a commercial product due to weight and cost considerations, while not sacrificing power output. The array consists of 180 solar cells. The size of the solar array was limited by the charging capacity of the batteries, which is approximately 0.2C or 30A. In the configuration shown in Fig. 1, the maximum expected current output given average weather conditions is approximately 12A at 48V, which translates to 24A charging the battery. This constraint limits the wattage of the solar array to 850W STC, or around 600W during operation. Table 1 lists the power specifications for the purchased Gintech 3BB Douro solar cells.

In addition, this solar array is equipped with three bypass schottky diodes per panel to minimize voltage drop during partial shading or breakage. Each diode is rated for 15A and has a forward voltage drop of 0.55V. For additional safety, a 20A fuse holder is installed between the charge controller and solar array, which can be used to turn the panel off when in storage.

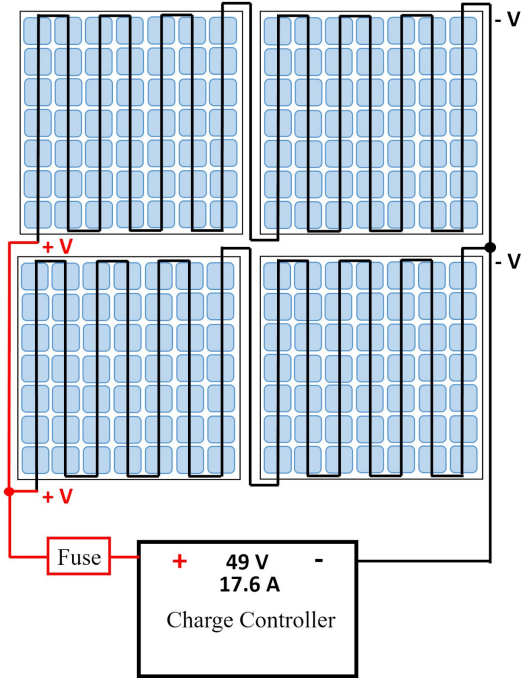


Fig. 1. Solar array configuration and connections at charge controller.

Power	4.74 W
Short Circuit Current	9.31 A
Open Circuit Voltage	641 mV
Current at 0.5V	9.12 A
Maximum Power Current	8.78 A
Maximum Power Voltage	544 mV
Fill Factor	79.95
Efficiency	19.40%
Total Power	853 W
Total Current Output	17.6 A
Total Voltage Output	49 V

Table 1. Power specifications of the installed Gintech 3BB Douro solar cells and specifications of the final system.

B. Charge Controller

A charge controller is necessary for regulating down higher voltage solar arrays to batteries, and MPPT charge controllers can offer 95% power conversion efficiency or greater. The MPPT charge controller chosen for this system was the TIDA-01200, a reference design provided by Texas Instruments. An improved design with upgraded MOSFETS and input capacitors was implemented for the 48V solar system and is capable of handling up to 40A, even

though it is not strictly necessary; these changes offer improved heat dissipation abilities at no added cost. The charge controller is also designed for real world considerations, including programmable software that can raise alarms and output system statuses. The controller was implemented on a custom PCB and was over \$100 cheaper than equivalent commercially available products, making it the best design choice for this project.

C. Motor Driver

The motor driver component was purchased commercially and includes all necessary functions to control both the steering and drive motors. The selected model is the Cytron Technologies SmartDriveDuo-30 (MDDS30), a dual channel bi-directional brushed DC motor driver with a continuous 30A capacity. The motor driver is also capable of handling 80A of peak current for a few seconds upon start-up [85]. It retails for about \$65.00, which is considered acceptable for the budget and is the cheapest known option for these specifications. Although the MDDS30 is compatible with RC, Serial, and PWM communication, analog PWM is implemented to communicate between the microcontroller and the motor driver. The MDDS30 is also equipped with additional features such as thermal protection, multiple input modes, battery over- and under-voltage indicators, and current limit protection. Manual push-buttons are included for quick manual testing to check functionality and for resetting the system.

C. DC/ DC Converter, Fuse Box, and Smaller Electronics

The smaller electronics include the two printed circuit boards, the msp430 5529, the two raspberry pi's, the three servos, the five sensors, the stereo camera, and the gps module. The printed circuit boards require a 3.3 volt input and the rest of the smaller electronics require a 5 volt input. The batteries output 24 volts that is then stepped down to 5 volts by the DC/DC Converter Regulator Reducer 24V Step Down to 12V 10A 120W Waterproof Voltage Convert Power Supply Transformer Volt Module. The main concern for the buck converter was meet the current requirement of an output of 10 amps. As shown in the table below this was to

guarantee that there would be enough amperage to power all the smaller electronics at once for 20 miles.

Part	Current Draw
Raspberry Pi (2)	2.000 A
Printed Circuit Board (2)	0.200 A
Msp430 5529 (1)	0.02 A
Ultrasonic (4)	0.015 A
Infrared (1)	0.050 A
Servo (3)	1.000 A
GPS (1)	0.020 A
Stereo Camera (1)	1.000 A
Total	8.55 A

Table 2. Power specifications of main control unit and peripherals in the final system design

The battery is connected to the charge controller that is then connected to the batteries. As shown below, the power layout of the system shows the main purpose of the buck converter and the fuse box. The buck converter is connected to the fuse box which has an input of 24 volts coming straight from the batteries. The fuse box creates a protection layer for the smaller electronics. The fuse box has two 30 amp fuse blades and two 40 amp fuse blades of which the buck converted is connected to the 40 amp rated fuse blade.

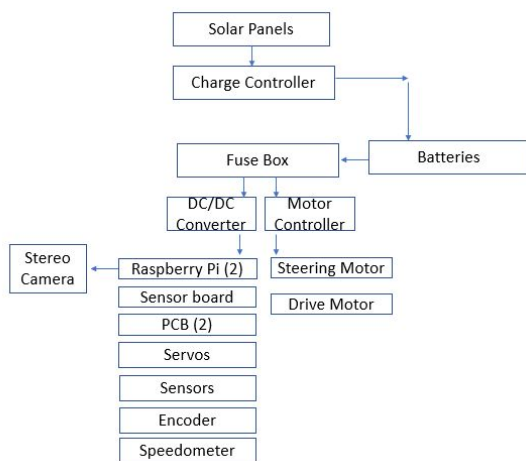


Figure 2: Project Power Distribution

Along with the buck converter, the motor controller was connected to another 40 amp fuse blade that then

receives the PWM signal from the main control unit (printed circuit board). Another main focus was to create a power distribution circuit to provide all the electronics with the correct voltage in parallel. The power distribution circuit also has a 3.3 voltage regulator for the two PCBs. Connecting the Raspberry Pi to the 5 volt rail, the stereo camera gets its power directly from the pi.

III. Sensor Input and Feedback

Two different methods of motor feedback are implemented to accommodate the two motors and tie into the electronics. One provides absolute directional feedback within a single rotation of the steering motor shaft. This absolute encoder, chosen as the Avago AEAT-1060, has 10-bit resolution and is able to detect wheel position upon power-up within 0.35 degrees. The data is provided in binary to the MCU using serial bit stream.

A speedometer is also included to measure drive motor output speed. Each feedback loop is used to precisely adjust the PWM signals from the MCU through the motor driver to the motors. It is constructed from 8 magnets attached to the inner rim of the wheel hub and a reed switch, which shorts for every passing of a magnet. PID control is then implemented to accurately detect the speed with a timer.

IV. Sensor System

Using range finding and proximity sensors is a low cost and simple solution when designing and building an autonomous vehicle. Proximity sensors will play a key role because they will provide critical input that the vision system might not be able to capture, such as the distances away from the objects. The sensors need to be accurate and the technology needs to match the specific range in which the buggy should stop of about 1 foot (11 inches when considering a 3 mile an hour max speed).

Within the budget allocated to sensors, the sensors should be as accurate as possible to avoid causing the buggy to stop from false positives. For the design the important factors were weather, range, cost, and data output. Some technologies were automatically ruled out based on the budget constraints. The sensors selected include four SR 04 Ultrasonic range finders and one VL53L0X infrared time of flight sensor. This design is the lowest cost design and incorporates a

temperature sensor to be allow gathering more accurate calculations from the ultrasonic sensors in the beach environment. This is due to the fact that the distance calculation is based on the time it takes for the ultrasonic signal to return to the sensor, the air temperature and humidity may affect the signals speed throughout different times of the day in a beach environment. As shown below in figure 3, the temperature sensor is placed with the top center sensor to guarantee the temperature that will be used for the distance calculation will be the temperature of the surrounding area of the buggy, not within the buggy or near the motor. The top center sensor is the VL53L0X infrared time of flight sensor because it is more accurate than the SR 04 Ultrasonic sensors.

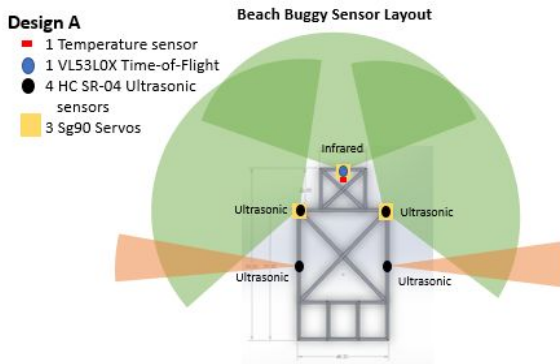


Figure 3: Final design chosen for the buggy sensor system.

The top center sensor and the two SR 04 Ultrasonic sensors to the left and right are mounted with servos that way there will be a greater coverage of the buggy. An additional two SR 04 Ultrasonic sensors will be placed on the side/rear of the buggy to aid the navigation system with merging and collision avoidance in the areas not covered by the stereo camera.

These sensors will be mounted to the frame about one fourth of the way up the frame. They need to be mounted on the lower part of the buggy because any obstacle on the beach that needs to be avoided has a greater chance of being identified there.

As discussed previously, the front three of the sensors will be rotating on servos with a 140-degree range for each scan each. This gives the sensors a good enough field of view, while at the same time staying within the servo limit of 180-degrees.

It is critical for the the beach buggy to be able to detect its proximity for any objects. Safety is a critical requirement for the beach buggy vehicle. Therefore, we must ensure that the beach buggy is able to detect if any objects are within its stopping distance and promptly stop itself. We designed the range finding system to be robust enough so that the beach buggy will likely stop for false positives, rather than for false negatives. The proximity range finding system is comprised of five ultrasonic sensors and an infrared sensor.

A. HC-SR04: Ultrasonic Sensor

The HC-SR04 is a ultrasonic ranging module capable of providing 2 cm – 400 cm non-contact measurement function, with a ranging accuracy of up to 3 mm [1]. The module includes ultrasonic transmitters, receiver and control circuit. Figure 2 shows the HC-SR04 ultrasonic sensor.

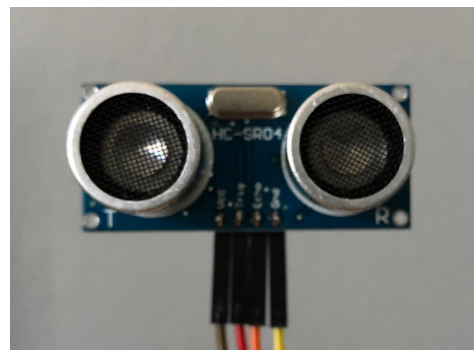


Figure 2: The HC-SR04 ultrasonic sensor

After being triggered, the HC-SR04 will emit a burst of ultrasound at 40 KHz and raise the echo pin. The ultrasonic pulses will travel outward until hitting an object. The object will cause the ultrasonic waves to be reflected back towards the unit. The ultrasonic receiver would detect the reflected waves and put the echo pin to low. The time between sending the ultrasonic waves and receiving the reflected waves will allow us to calculate the distance between the buggy and the object. Since we know the velocity of the ultrasonic burst is 340 m/s in air, the formula to calculate the distance from the sensor to the object can be expressed as:

$$D = C \times T/2,$$

where D is the calculated distance, C is the propagation velocity of the sound median (in this case, ultrasound which travels at 340 m/s), and T is the amount of time between sending the ultrasonic waves to receiving the reflected waves. We must

divide time by 2 because the ultrasonic sensor is taking the time the ultrasonic waves is sent and received. Dividing by 2 will give us the time the ultrasonic waves hits the object. Table 2 shows the electrical specifications of the HC-SR04 Ultrasonic module.

Electrical Parameters	HC-SR04 Ultrasonic Module
Operating Voltage	DC 5 V
Operating Current	15 mA
Operating Frequency	40 KHz
Max. Range	4 m
Min. Range	2 cm
Measuring Angle	15 degrees
Input Trigger Signal	10 us min. TTL pulse
Output Echo Signal	TTL level signal, proportional to distance
Board Dimensions	1-13/16" X 12/16" X 5/8"
Board Connections	4 X 0.1" Pitch Right Angle Header Pins

Table 3: Electrical specifications of the HC-SR04 Ultrasonic module

Five ultrasonic sensors are fitted on the beach buggy. Each of the posts holding up the solar panels will be a mounting point for the sensor. The fifth ultrasonic sensor will sit on the front of the beach buggy. This layout will help to detect for any objects that may be in range of the vehicle.

B. VL53L0X: Infrared Sensor

We used an additional range finding sensor. The VL53L0X is a Time-of-Flight laser-ranging module manufactured by Pololu [2]. The VL53L0X is a fully integrated miniature module of size 4.4 x 2.4 x 1.0 mm.

It is able to measure absolute range up to 2 m. The reported range is independent of the target reflectance. As safety is an important factor in designing the beach buggy, the VL53L0X is safe for the eyes. The module is a class 1 laser device compliant with the latest IEC 60825-1:2014 - 3rd edition. The VL53L0X sensor shall be mounted on the front of the beach buggy. Figure 2 shows the HC-SR04 ultrasonic sensor.

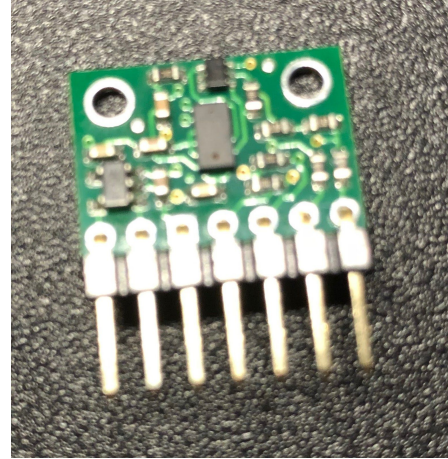


Figure 2: The VL53L0X sensor

The manufacturer has provided a programming library with the infrared module. The library allows us to configure the sensor and read range data from the module via I2C. The programming library is available for the Arduino IDE.

Table 3 shows the general specifications of the VL53L0X infrared module.

V. Sensor Microcontrollers

We decided to use the MSP430F5529LP [3] and Arduino UNO microcontrollers [4] to control the proximity range finder sensors.

A. Arduino UNO

According to Arduino.cc, the Arduino UNO is the best board to get started with electronics and coding. The programming library for the VL53L0X made it simple to program the Arduino UNO to read in the range data from the sensor. We utilized another serial communication protocol UART to send the range data from the infrared sensor measured to the MSP430F5529LP.

B. MSP430F5529LP

We used the MSP430F5529LP microcontroller to read in range data from the HC-SR04 ultrasonic sensors. It should be noted that the pins of the MSP430F5529LP can only take in 3.3V. Since the HC-SR04 sensor's echo pin outputs 5V, a voltage divider must be implemented to reduce the voltage from 5V to an acceptable 3.3V. After the MSP430F5529LP has read the data, the MSP430F5529LP then sends the range data to the Raspberry Pi for further processing. We utilized the

serial communication protocol SPI for this communication task.

General Parameters	VL53L0X infrared module
Operating Voltage	2.6 V – 5.5 V
Operating Current	10 mA
Operating Frequency	40 KHz
Max. Range	200 cm
Interface	I2C
Board Dimensions	0.5" × 0.7" × 0.085"

Table 4: General specifications of the VL53L0X infrared module

VI. Other electrical components

It is generally good practice to include the use of fuses when working with expensive circuits. We used the ATC Blade Fuse Block manufactured by SuperDroid Robots to help protect against any electrical faults and short circuiting. The battery will be attached to the fuse block. Depending upon the current threshold, properly picked fuses would be inserted into the fuse block. From the fuse block, the electrical components of the beach buggy vehicle will be connected to it. Figure 4 shows a picture of the ATC Blade Fuse Block. The ATC Blade Fuse Block will help ensure that power is safely and easily distributed to the electrical components of the beach buggy vehicle.

VII. Software and Hardware Controls

A. PCB Design

The main control units (MCU) primary function is to be the interface between the navigation boards, which will be doing the path finding algorithms and peripherals such as the motors and sensors. It will need to be able to interpret the signals from the feedback devices and other components so that it can send the relevant information to the navigation boards. The MCU will then have to be able to take

the output from the navigation boards and translate those into the necessary PWM signals to control the motor.

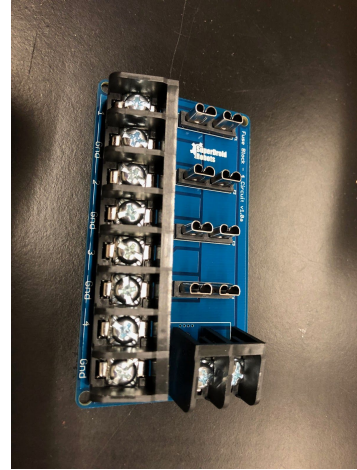


Figure 4: The ATC Blade Fuse Block

From the initial design it was decided that the MSP430 FR5529 Development kit board would be a good design base for this project and this is what was eventually used. Being a MSP430 board, it has the benefits of being low power and supported by Texas Instruments.

Another great feature that is provided by the TI RTOS is being able to use semaphores to keep critical areas of memory safe from two tasks accessing and changing the memory at once. This is a feature that is useful especially if there is a packet that is constantly being updated by several different peripherals.

B. Software Tools

Energia and Code Composer Studio were both adequate for embedded software development for the processor selected in the printed circuit board design. Code Composer Studio was used due to hardware support and extensive debugging tools that allowed tracking of flash memory that stores the main code, the 512 bytes of RAM, values of registers and expressions, etc. Additionally, Code Composer Studio supports TI Real Time Operating System that allows for easy multitasking and memory configuration and control on a one core 16 bit processor. TI- RTOS provided features to create tasks

that run based on priority and easy configuration and set up for communication protocols such as Serial Peripheral Interface used to communication critical information to the navigation system (raspberry pi) and Universal Asynchronous Receiver-Transmitter used to receive data from the GPS module.

C. Motor Controller

The connection to the motor controller requires both an digital direction control signal and a pulse width modulation (PWM) signal for each motor. The digital control signal in is on a scale of 0V to 5V which made it possible to use the MSP430FR5520's normal voltage to control. While the PWM will accept between 1.3V and 5V which was determined to need a step-up circuit. The PWM signal is controlled by its duty cycle so that a consistent 5v or 0v signal will be sufficient. The MSP430FR5529 provides hardware modules that will be used to create the PWM signal.

D. Encoder

The Avago AEAT-6010 encoder requires 3 data pins for operation. It has 2 control pins of CSn (chip select) and CLK (clock), with one output pin of DO (digital output). All of these are digital signals so that they can be controlled by the MSP430FR5529 GPIO pins. They all also operate on the range of 0-5V, so it was necessary to add step up circuits to the CSn and CLK connections and a step down voltage to the DO.

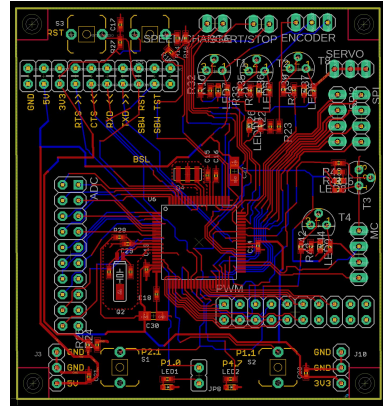
E. Speedometer

The speedometer was made by using a reed switch, for this reason, it was possible to use almost any voltage thus 3.3V was selected to power the reed switch so that it would be directly compatible with the MSP430FR5529. All that is required to connect the speedometer was a GPIO pin with interrupts support.

F. Board Layout

The major modifications that were made to the MSP430 FR5529 design were the removal of the emulator as this was only necessary for debugging and another board could be used to do this. The addition of transistor step up circuits that would allow

the MCU to be able to interface with the peripherals that required a 5v signal, and the addition of status LEDs that would simplify troubleshooting. Above is pictured the final board layout.



parsed and the three pieces of information is added to the packet that is sent over SPI.

IX. PCB communication

The MCU would be required to communicate with the Computer Science Raspberry Pi board to exchange information and receive commands. UART, I2C, and SPI were considered for this communication and SPI was selected for its full-duplex communication.

X. CONCLUSION

The beach buggy challenge produced an autonomous, solar power vehicle theorized and tested to endure the proposed competition requirements within the given budget using an array of technology encompassing sensors, microcontroller communication, PID control, an expansive solar array, and DC motor controls.

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Caroline Kamm is an engineering student at the University of Central Florida graduating in December 2018 with a BSME and a BSEE. She is engaged in research on the ENERGISE project for renewable energy grid integration and interns at C&S Companies as a consulting MEP engineer.



Patrick McBryde is a senior engineering student at the University of Central Florida graduating in December 2018 with a BSCpE. He will be pursuing a career in artificial intelligence and machine learning



Olesya Nakonechnaya is a computer engineering student at the University of Central Florida graduating in Spring 2019 with a BSCpE. She will be pursuing a career in FPGA and Space Systems.



William Zhang is a Computer Engineering student from the University of Central Florida. He will be graduating in the Spring 2019. He decided to delay his graduation in pursuit of a minor in Intelligent Robotics Systems and to complete an Honors Thesis.