UCF Solar Powered Beach Buggy Challenge

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Abstract — This **paper describes the design process behind the creation of an automated vehicle which satisfies the conditions laid out for the UCF Beach Buggy Competition. Specifically, it involves the creation of a system which will allow a vehicle to operate under pure solar energy while also being able to autonomously detect and avoid objects in its environment. This necessitates research and design effort put into the fields of circuit design, Lidar modules, and computational devices such as microcontrollers.**

Index Terms — Digital **signal processing, Environmental economics, Optoelectronics and photonic sensors, Photovoltaic effects, Signal analysis, Vehicular automation**

I. Introduction

In recent years, there has been a growing interest in both the public and commercial sectors with regards to the viability of automated motor vehicles. While there has been much research and prototyping done in the realm of converting traditional, on-road vehicles into self-driving cars, our team was unable to find anything concerning the automation of cars for non-standard terrain, such as sand. As a result, we have decided to create an automated, single passenger buggy for use on a populated beach. It will also be entirely operated on solar power, in order to demonstrate the viability and low power consumption of environmental detection and recognition systems.

The buggy will consist of a chassis, able to carry a passenger weighing a minimum of 120 lbs, across the beach at approximately 3 miles an hour. Through a combination of stereoscopic camera vision and Lidar, it will be able to conclusively detect and identify objects, communicate with an onboard Arduino unit, and through there affect the rotational speed of the wheels in order to turn the buggy away from a collision course with the object. Through the use of solar panels, as well as two onboard batteries, it will be able to operate for a minimum of 10 hours, assuming ideal weather conditions and functional components.

Lidar will be used as a primary method of surveying the landscape. Due to its basis in time-of-flight technology, it is an ideal method for quick and precise distance measurements to within one centimeter. It can generate a 'point cloud', or a series of data points with differing distances and angles from the origin, that are within its field of view and are constantly updated, and these data points can be fed into the Arduino in order to identify objects. The system will also utilize two stereoscopic cameras on the front of the buggy, giving us a rudimentary three-dimensional image, which can be analyzed by image recognition software running on the Arduino unit. Through the use of both systems in unison, we can be certain of any objects that could potentially obstruct the path of the buggy, and program the buggy to move around them.

In an effort to emphasize the general independent nature of the buggy, and with consideration to the bright environment it will be operating in, it will be powered by a solar panel placed on a platform located at the rear of the buggy. The panel selected will be chosen for its ability to operate at a maximum efficiency in the bright sunlight, and for the capability to output a sufficient level of wattage, so as to properly run the motors, Arduino, location and navigational systems onboard. The solar cell will be placed on a prominent position on the rear of the buggy, in order to achieve the most efficient angle with the noon-time sun and maximize the amount of power generated by it.

The primary goal of this project is to demonstrate the feasibility of both solar energy and automated vehicles, while simultaneously aiding beachgoers during their visit. The costliest aspects of our design will be the motors operating the wheels, and as a result we hope to showcase an efficient and cost-effective way to provide self-driving capabilities to conventional vehicles.

This project is of course being done in conjunction with a group of mechanical engineers. Their role in the project will be in designing the final chassis we will use as a basis for our electronic components, and in helping select the motors we will use to operate the buggy. Due to significant scheduling conflicts between the two teams, we will demonstrate our navigational and power systems using a miniaturized buggy that will not have been created by the mechanical engineering team. This buggy is a modified version of a commercially available toy and has been chosen as a simple tool to develop the electrical systems in conjunction with a functional vehicle.

II. System Components

In order to create a more concrete idea of what the buggy will be able to achieve, it is necessary to establish what technical milestones will be used as end goals for this project. To that end, this section will describe these technical specifications in significant detail, as well as the reasoning behind the methods chosen to achieve them.

A. Requirements

This project has many objectives set forth by the client, Duke Energy. Namely, they are: To create a vehicle capable of traversing a beach while autonomously detecting moving and inanimate objects; To have the buggy travel at a maximum speed of 3 miles per hour, travel 10 miles in a single journey, and to do so while carrying a weight of approximately 120 lbs; To have it run entirely on solar power; To do no harm to the environment, or any beachgoers; and to be produced with a budget that does not exceed $2000. These design goals ensure that the buggy will be a positive addition to the beach going experience and can demonstrate the viability of low-cost Lidar and solar systems for autonomous transportation purposes.

A key feature of the buggy is its ability to automatically detect objects and move around them, and for that purpose we chose to incorporate a Lidar system into our design. While other autonomous vehicles chose to incorporate traditional rangefinders into their designs as a way of detecting objects, the ability of Lidar to generate a point cloud and recognize individual objects makes it a superior, if more complex, choice. It also allows us to continuously scan an entire field of view, as opposed to simply measuring distances along a single vector.

In the interest of safety, several design decisions have been implemented. The primary safety feature will be several ‘kill switches’ placed in easily accessible areas of the buggy. One will be reachable by the passenger, another on the side of the buggy so as to be available to a passerby, and a remote ‘kill switch’ available to us as we monitor the buggy. For safety reasons, the maximum speed of the buggy is also limited to 3 miles per hour, so as to give us time to react in the event of some unforeseen design failure.

The primary purpose of this project is to create a novel mode of transportation that will stoke the public interest in the capabilities of both solar power and autonomous navigation. To this end, we intend to have a large solar panel on the rear of the buggy, which will provide power into one of two on-board batteries. The batteries will power the motor and electrical systems, and they will each alternate between powering the buggy and receiving a charge from the solar cells.

B. LIDAR Module

This section will discuss the implementation of the Lidar system onto our buggy. This will incorporate a laser diode and photodiode, as well as driving and receiving circuits that will operate the diodes. The output of this system will be fed into an Arduino and an analysis will be carried out on that data in order to determine distances and create a rudimentary point cloud which will allow us to identify objects in the path of the buggy.

The Lidar module consists, broadly, of two components: A laser emitter which will periodically emit a pulse of light out into the environment we wish to scan, and a receiver module, which will focus a portion of the laser light reflected directly back from the environment. By using a periodic step function as a method of time-keeping, the difference in time between the output of a pulse of the laser diode and the registered input of the photodiode can be recorded and converted into a distance traveled, which can in turn be fed into an Arduino for computational purposes. This method of laser range-finding is referred to as time-of-flight tracking, and for our purposes, we have chosen it as the most efficient and easily developed method of laser range-finding. A visual representation of this is shown in the figure below.

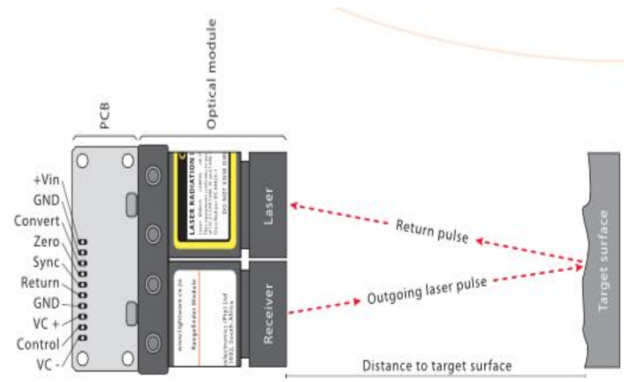

Fig. 1 Basic operation of a LIDAR module. Image courtesy of Lightware Optoelectronics.

C. Solar Circuit

Our basic system will consist of a monocrystalline solar panel, placed in prominent positions on top of either the buggy itself or a platform designed for the sole purpose of raising the solar panels to a safe altitude, where they can be made maximize their efficiency by achieving an angle flush with the incoming sunlight, and is unlikely to be blocked by any objects in the environment. From there, the current generated in the photovoltaic cells by the impact of the incident sunlight will pass through to a charge controller, which will limit the rate that the current is passed through to the batteries, ensuring safe operation and charge speeds. This current will pass through to one of two batteries, which will charge over time as the other battery discharges in order to power the necessary operational elements of the buggy. These batteries will switch roles as they get discharged, ensuring that the buggy is always operational, provided a bountiful and consistent amount of sunlight.

From the battery that is being used to power the buggy, a current will pass through an inverter, which will convert the

DC current provided by the battery to an AC current which can be utilized by the various electrical components of the buggy to function.

D. Single Board Computer

In selecting the proper hardware system in providing a back-end for the software required to operate the robot, the following must be considered: its weight, its power draw, its processing power, and its architectural capabilities. The hardware should be powerful enough to be able to control and process the different sensors and imaging devices on the buggy without having too much overhead, allowing a real-time autonomous operation of the vehicle but at the same time, its power draw should be conservative in such a way as to not overdraw from the solar panels and the batteries as power might be needed elsewhere.

E. GPS Tracking Unit

While image and sensor processing alone can allow a robot to operate safely by avoiding obstacles, true autonomy can only be achieved if the robot knows where exactly it is. A GPS tracking unit is a device that allows just that. A GPS tracking unit uses the Global Positioning System (GPS) to track the device's movements at intervals to determine its location and, when attached to the vehicle, its carrier. A GPS tracking unit monitors multiple satellites and uses triangulation to determine its position along with its deviation from true time. It does this by receiving GPS signals (carrier wave with modulation) that includes:

- Pseudorandom bits that is known to the tracking unit. By time aligning a receiver-generated version and the receiver-measured version of the code, the time of arrival of a defined point in the code sequence, called an epoch, can be found in the tracking unit clock time scale
- A message that includes the time of transmission of the code epoch (in GPS time scale) and the satellite position at that time

The tracking unit measures the times of arrival of at least four satellite signals. From the time of arrival and the time of transmission, the tracking unit forms four time of flight values which are approximately equivalent to the distance between the tracking unit and the satellite. The tracking unit then calculates its three-dimensional position from this.

III. System Concept

Now that the basic demands of the system have been made, we can now create an idea of what the whole system will look like. The block diagram in Figure 2 below more closely describes what the completed system will look like, and how the separate components will feed into each other.

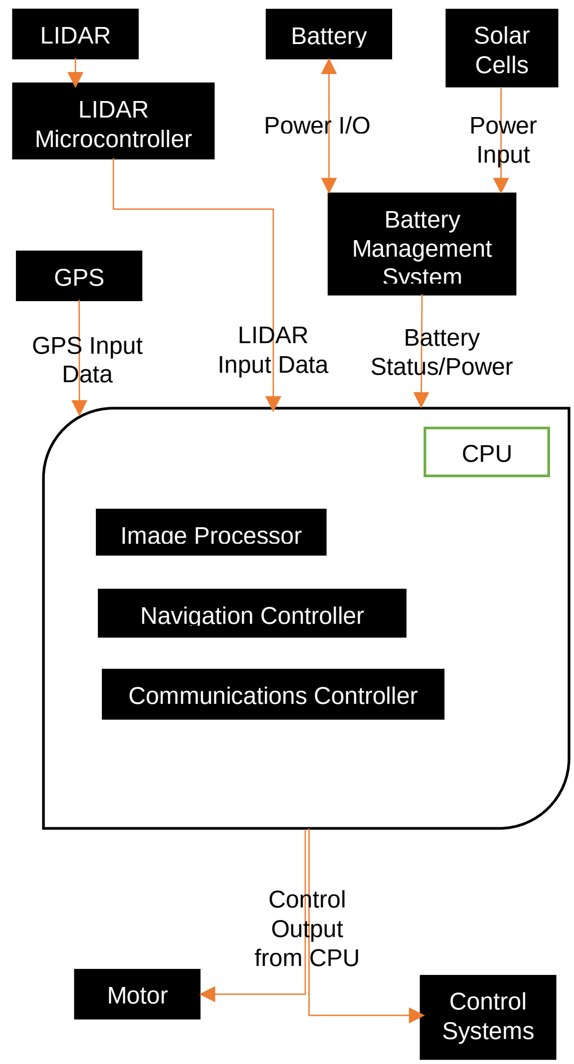

Fig. 2 A basic block diagram of the electrical system for the buggy.

This diagram also serves to illustrate the basic flowchart of operation for the buggy; Once powered on, the solar cells will begin the process of charging the secondary battery, as the first one drains to operate the rest of the electronics on the vehicle. This includes the Lidar and GPS modules, the motors, the CPU, and the motor. The Lidar module will activate and begin scanning the environment in a 180-degree angle in front of the car. At the same time, the motor will activate, and the buggy will begin to move forward. Once the Lidar module detects an object within the distance that we have established as the minimum safe distance, it will feed that distance, along with the angle of the measurement, to the CPU, which will communicate with the motor and control systems in order to stop the vehicle, turn it to a sufficient extent to avoid the object it detected, turn again to resume its original course, and once it has gauged that there is no longer an object in its path, it will begin to move forward again. These systems will operate continuously for as long as the buggy is in operation and have been designed to be useful over the long stretches of time required by the project specifications.

IV. Hardware Detail

Now that we have established the basic framework of our system, this section will go into further detail on the technical aspects of each system. Specifically, it will describe the process by which the circuits and computing components which were incorporated into the final design were chosen.

A. Single Board Computer

For the buggy, a single-board computer provides the ability to satisfy our requirements as it has the ability to have an operating system installed, along with the ability to use the programs considered in operating our robot. With this in mind, we decided on the Raspberry Pi 3 Model B+, primarily for its low price and ability to adequately handle our software needs. It has also spent a longer time on the market, meaning that it has a larger amount of support from the manufacturer and the community, making computation hardware and software implementation less time and resource consuming.

B. GPS Tracking Unit

Two GPS trackers are in consideration: the Adafruit Ultimate GPS HAT for Raspberry Pi (Figure 17a) and the Adafruit Ultimate GPS Breakout (Figure 17b). Both of which are identical to each other except the HAT (Hardware Attached on Top) is an add-on board specifically for Raspberry Pi B+ that conforms to a specific set of rules that make life easier for users. A significant feature of HATs is the inclusion of a system that allows the B+ to identify a connected HAT and automatically configure the GPIOs and drivers for the board. The disadvantage is that the GPS HAT takes over the Raspberry Pi's hardware UART to send/receive data to and from the GPS module so if you the RX/TX pins are used with a console cable; this HAT cannot be used in conjunction. For this reason, our navigation system is based on two chips; an Adafruit Ultimate GPS Breakout v3 chip, and an Adafruit 9-DOF Absolute Orientation IMU Fusion Breakout INS chip.

The INS chip is primarily going to be used to verify GPS data- for example, if the GPS reports that the buggy has suddenly lurched 30 feet to the right, but the INS says it hasn't, that GPS data is discarded. The secondary use of the INS chip is to monitor the temperature of the single-board computer and turn on and off additional cooling fans as needed. The INS chip does have a magnetometer that could make available usable heading information, however the team is concerned that the amount of metal in the buggy would interfere with the magnetometer enough to make it unreliable.

The GPS chip is going to be the core of the general navigation system. The team plans to make a series of GPS waypoints hardcoded into the buggy, which will describe a "safe" general path. The waypoints will have a radius that the buggy will need to get within to count as having reached that waypoint, and it will travel between waypoints using a "travel" and "safe" corridor system.

C. Wireless Networking

While the buggy is intended to operate autonomously, being able to communicate with it is a priority considering that it is important to gather the buggy's telemetry data such as its current position, speed, and energy status when not near its vicinity. It is also imperative that the buggy's operation can be aborted should it pose a threat to itself, to property, or to others.

The implementation details of which wireless technology to use depends on the bandwidth, range, and power consumption requirements for the buggy. Three technologies are considered: WiFi, GSM, and Bluetooth Low Energy.

Wi-Fi is a technology based on IEEE 802.11 standards, with 802.11ac as the latest standard as of writing. It is a trademark of the Wi-Fi alliance. Depending on standard implementation, Wi-Fi can reach a single-link theoretical throughput of at least 500 Mbit/s (802.11ac). Both 802.11n and 802.11ac have similar maximum ranges of around 230 feet. While 802.11ac and 802.11n do not differ much when it comes to range, 802.11ac provides superior throughput in longer ranges than 802.11n. Wi-Fi has a modest power consumption rate which averages around 0.5-2 W.

Global System for Mobile Communications, or GSM, provides a virtually unlimited range where the buggy can be communicated from anywhere around the world. However, GSM is subscription based and requires a subscriber identification module (SIM) for both the buggy and the human operator. Current devices primarily communicate on the subscriber network over the Long-

Term Evolution (LTE) standard, which is based on GSM. LTE has a theoretical net bit rate capacity of up to 100 Mbit/s in the downlink and 50 Mbit/s in the uplink, with realistic bit rates of half of that. LTE has the most consumption rate of the technologies considered, which averages around 1 — 3.5W.

Bluetooth Low Energy, or Bluetooth LE, is a wireless technology designed and marketed by the Bluetooth Special Interest Group. Bluetooth LE is based on the “classic” Bluetooth but is not backwards compatible. Compared to Classic Bluetooth, however, Bluetooth LE is intended to provide considerably reduced power consumption and cost while maintaining a similar communication range. Bluetooth LE has a max theoretical range of 330 feet and has an over the air data rate of up to 0.27 MBit/s throughput. While its throughput is nowhere compared to Wi-Fi or LTE, it shines the most in its power consumption-- a mere 0.01-0.50 W with peak current consumption of 15 mA. After careful consideration, we decided to go with Wi-Fi, mainly due to the throughput superiority it carried over Bluetooth, while also having a lower power consumption than the GSM.

D. Voltage Regulator Circuits

In this design, a switching regulator will be used since it offers the advantages of higher power conversion efficiency that we are looking for. A boost converter will be used to lower the input voltage from the battery or solar panel to 5V and 3.3V to power the microcontrollers, IR sensors, LIDAR, and cameras. For the 5V, the LM2596 will be used. Although it costs more than the other chips that are in consideration, its efficiency makes it the best choice. On the other hand, the LM3940 will be used for the 3.3V. Figures 3 and 4 below show the circuit diagrams for two voltage regulators which will lower the 12V solar output voltage to 5V and 3V respectively.

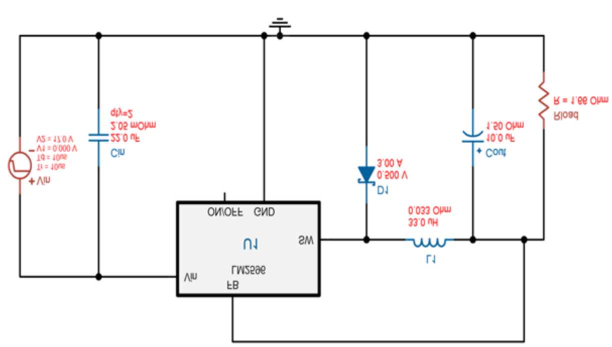

Fig. 3: Buck converter voltage regulator circuit with a 5V output. Reprinted with permission from Texas Instruments.

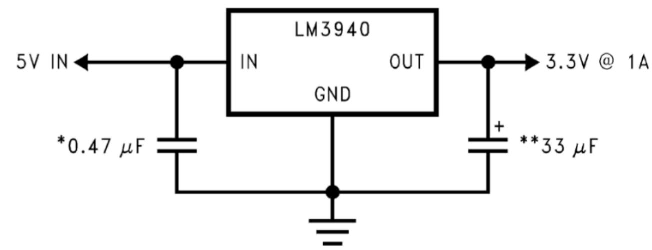

Fig.4: Buck converter voltage regulator circuit with a 3.3V output. Reprinted with permission from Texas Instruments.

D. Motor Controller

For this application, finding a motor controller capable of providing sufficient power to the motor was very important. First, it must have a dual driver motor; second, it has to be able to handle a motor with at least 700W of power. After a careful consideration of the available options, we decided on the Sabertooth Dual 32A Motor Driver. The Sabertooth dual 32A can supply two DC brushed motors up to 32A of continuous current each and up to 64A peak currents per channel for a few seconds. In addition to a dual motor driver, the controller comes with thermal and overcurrent protection. This is an important feature for a controller to have since an overheating board can have a negative effect on other electrical components. The motor controller allows the control of the two motors using analog, radio, serial and packetized serial control. The controller also has a build in switch mode converter that can supply power to a 5V DC source like microcontrollers, receivers, as well as up to 4 analog servos.

E. Solar Charge Controller

The charge controller plays a critical role in our system, as it is what allows the input voltage received by the solar cells to be lowered to a level which is usable by the electrical components in our system. After careful consideration of the available options, we decided on the ZHCSolar PWM charge controller.

PWM controllers work by lowering the input voltage they receive from the solar panel to charge the battery bank. Their charging features are very basic compared to the MPPT. When the battery voltage is low, the controller pulled down the voltage of the panel from 18 V to the battery voltage. Due to loss in power, PWM charge controllers are only 75-80% efficient. PWM is suitable for small systems and provide low cost solutions. The ZHCSolar in particular boasts a relatively low cost; the controller can provide four times more current to the battery bank than the other's that was in consideration. Unlike other options we considered, the ZHCSolar is a fully assembled board with enclosure and is available to purchase. Although alternative charge controllers can be designed and assembled for less than $30, other readily available products on the market can be purchased for less and still provide more output current to the battery.

F. Lidar Module

As stated above, the Lidar module will consist of two major components: The laser emitter and the photodiode receiver. The laser emitter is a fairly simple set up, being driven by a laser driving circuit that produces a regularly pulsed signal, which is kept in sync by the sequential equivalent time sampling circuit. This pulse is sent to the laser diode and produces an output which is then passed through a collimating lens before being sent out into the environment. The photodiode receiver is also a relatively simple circuit design, as it only needs to incorporate a detector that is sensitive enough to receive the minute amounts of light reflected off of the surfaces in the environment, and an amplifier to turn the received signals into a useful pulse waveform. A rough block diagram for our system is displayed below in figure 5.

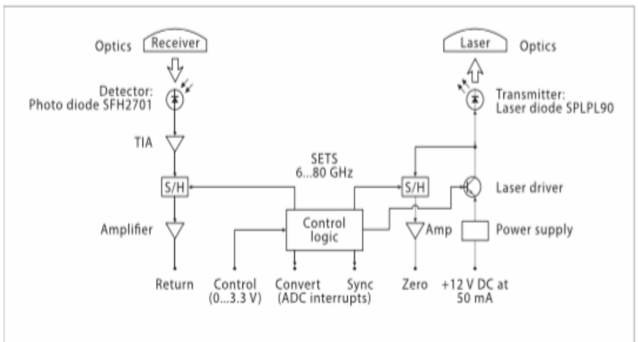

Fig. 5 A basic block diagram of the Lidar system. Courtesy of Lightware Optoelectronics.

One of the most important aspects of our Lidar set up is the timing circuits, referred to as the sequential equivalent time sampling circuit. Given the high frequency at which light pulses need to be generated, received, and calculated, an efficient and dependable timing circuit is vital to the successful operation of our device. As we are dealing with a system that would require clocking speeds on the order of 15 GHz to maintain a resolution of 1cm, it would be impractical to incorporate a direct timer to track our pulses. In order to design around the expensive equipment that a direct sampling method would require, the sequential equivalent time sampling circuit operates by establishing a discreet time-based of our own choosing, which can then be used to sample the outgoing and incoming pulse waveforms and convert high speed signals onto the slower time-based that we have established, thereby allowing the computations to be done with less expensive, power intensive hardware. The slowed down signals operate on a time-based that is around 100,000 times slower than the real-time signals, and the amount of time-based expansion can be modified to change the resolution of the measurements and the update rate.

The original intent for the Lidar module was to create the transmitting and receiving circuits, as well as a timing circuit to maintain a measurable time difference between the incoming and outgoing pulses. In addition, these circuits would have been connected to a laser diode as well as focusing/collecting optics. However, due to time and budget constraints, as well as severe design difficulties, we were forced to opt for a commercially available module which fit our allocated budget and technical specifications. After an extensive analysis of existing Lidar modules, we ended up choosing the TF Mini, a small time-of-flight laser rangefinder. The TF Mini's maximum detection distance is 12 meters. TF Mini also supports 100Hz sampling resolution. Within 6 meters, its accuracy is within 4cm, and between 6~12 meters, its accuracy is within 6 cm. FOV of 2.3 degree. Its anti-interference is strong and can work in outdoor light; the overall weight is 4.7g. Though suboptimal, it is relatively inexpensive and easily modifiable, and is capable of functioning well for the limited purposes we intend to use it for.

V. SOFTWARE DETAIL

Having established the technical details of the hardware that will constitute this project, it is important to elaborate on the how the software will support the operation of this buggy.

ROS is fundamentally a full-featured message passing interface intended for use with robotics. Message passing interfaces are, as implied by the name, a system where one component can send information to one or more other components or make it available for other components to read. There are numerous predefined messages that can be used which can store data as simple as a single integer or as complex as a fully colored image. In addition, ROS offers the ability to create messages from a user made template if a suitable message type can't be found.

Every component in ROS is a "Node"; specifically, they are defined as a unit that does computation. They may additionally be publishers, subscribers, or both. Publishers can post messages of a specific type to specific topics, usually at a regular, fixed speed (although they can post as quickly as possible, or only in response to something else). Subscribers listen for messages posted to a specific topic or topics, and generally are event-driven.

For our system, the buggy will have three nodes, as shown in Fig. 6: a GPS Node, a Motor Control Node, and a Buggy Control Node. The Buggy Control Node is also the ROS Master which will receive and analyze all data it receives from nodes that communicate to it. The Buggy Control Node also receives input data from the Lidar. It also controls the servo to move only when the Buggy Control Node has received an input from the Lidar with the Servo's current position.

The GPS Node receives the raw input from the GPS module, parses it in to understandable, meaningful data and then publishes it for the ROS Master Node to process.

The Motor Control Node receives the directives of the ROS Master node and parses the commands such that it can output the required PWM signals for the motor controller in order to control the direction and speed of the two individual wheels of the buggy.

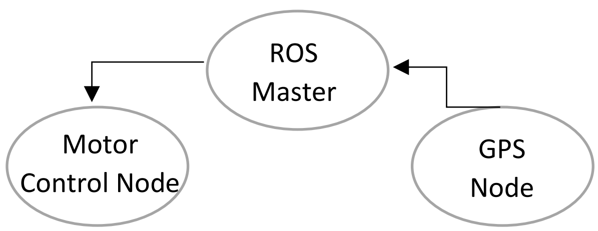

Fig. 6 A basic block diagram of the Lidar system. Courtesy of Lightware Optoelectronics.

In order to ensure parallelism for the function in the Buggy Control Node, threads and locks are utilized. This way, the Lidar, Servo, and GPS functions can receive, process, and publish data even when the main function in the Buggy Control Node is busy analyzing or sending directives to the Motor Control Node.

VI. Conclusion

Through the use of the systems we have established in this document, we believe that we should be able to create a system capable of managing the motors of a vehicle in order to allow it to autonomously avoid obstacles in its field of view.

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Biography

Jose Rosales is a 21-year-old, graduating Photonic Engineering student. He will be obtaining his Bachelors of Science in Photonic Engineering in the summer of 2018. He hopes to find a job working on optical systems in the commercial sector.

Jared Cozart is a 22-year-old, graduating Photonic Engineering student.

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Tony Jimogaon is a 22-year-old, graduating Computer Engineering student. He will be obtaining his Bachelors of Science in Computer Engineering in the summer of 2018. He hopes to find a job working for either the US Government or with the private sector such as Disney.

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