Electric Vehicle Economy Mode Control Unit (EV-EMCU)

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ABSTRACT — **The purpose of this project was to create an intelligent control system for a fully electric vehicle. A series of microcontrollers are used in the design of this control unit. The data microcontroller takes in readings from sensors around the vehicle and stores them. The power microcontroller calculates optimum current and outputs a voltage to the motor controller, which is representative of that current. A safety microcontroller works to prevent runaway acceleration. In order to control the different modes of performance, a switch is located on the dash board for the driver to select when to use economy mode.**

Index Terms — **Data storage systems, differential equations, electromechanical sensors, flash memory, intelligent vehicles, microcontrollers, power system control.**

I. INTRODUCTION

Most vehicles on the road today are still running on fossil fuels. Their emissions are pollution that fills our air, affecting our environment. Many agree that these fossil fuels should be replaced with cleaner technology. Electric vehicles are on the rise, but they are not very efficient. Our project is to design a control unit that goes into an electric vehicle that can monitor the flow of current and voltage, and force the vehicle to drive at an optimized speed.

In this senior design project, a vehicle from Tecta America is used. See a picture of this vehicle in Fig. 1. This vehicle will already be a fully electric car but needs to be upgraded with a control unit. After researching the parts contained in the already converted car, we determined it was best to stay with the Warp 9 DC electric motor already installed.

Fig. 1. Picture of the 2004 fully converted Ford Ranger that worked with during the course of this project. The vehicle is owned by Tecta America.

The truck, provided by Tecta America, has a manual transmission, which is expected because most electric vehicle conversions are manual transmissions because of their efficiency. Manual transmissions provide greater range, require less motor torque, and require no transmission cooler, and are easier to convert. The problem with an automatic transmission is that it shifts at about 2000 rpm; the electric motor is usually designed to operate efficiently between 4000-5000 rpm. An electric vehicle conversion does not become idle, since when the vehicle stops the motor does too. Electric motors usually spin faster than gasoline engines, so they don't need to shift into high gear. Though there have been many different projects for electric cars, some with manual transmission and some with automatic, we can see that the new electric or hybrid gas/electric cars don't use any transmission at all. The primary motor on these cars is electric, and it operates under a much wider range of speeds, so a transmission isn't necessary.

The make and model of batteries that are already in the electric truck is a Discover® Clean and Green™ Series EV 12A-A. There are twelve of these twelve volt batteries; they are connected in series for a total of total of 144 volts. This battery has Valve Regulated Lead Acid technology, and specifically is an Absorbed Glass Mat battery. Like all AGM batteries, this battery is completely sealed and valve-regulated. This battery is also considered to be a dry cell battery. That is another way of explaining that the electrolyte in the battery is not a liquid, it is immobilized inside the battery container [1].

Also, the thermally welded case covers bonds to eliminate the possibility of leakage. Therefore, there is no danger or spilling the electrolyte. The valves are specially

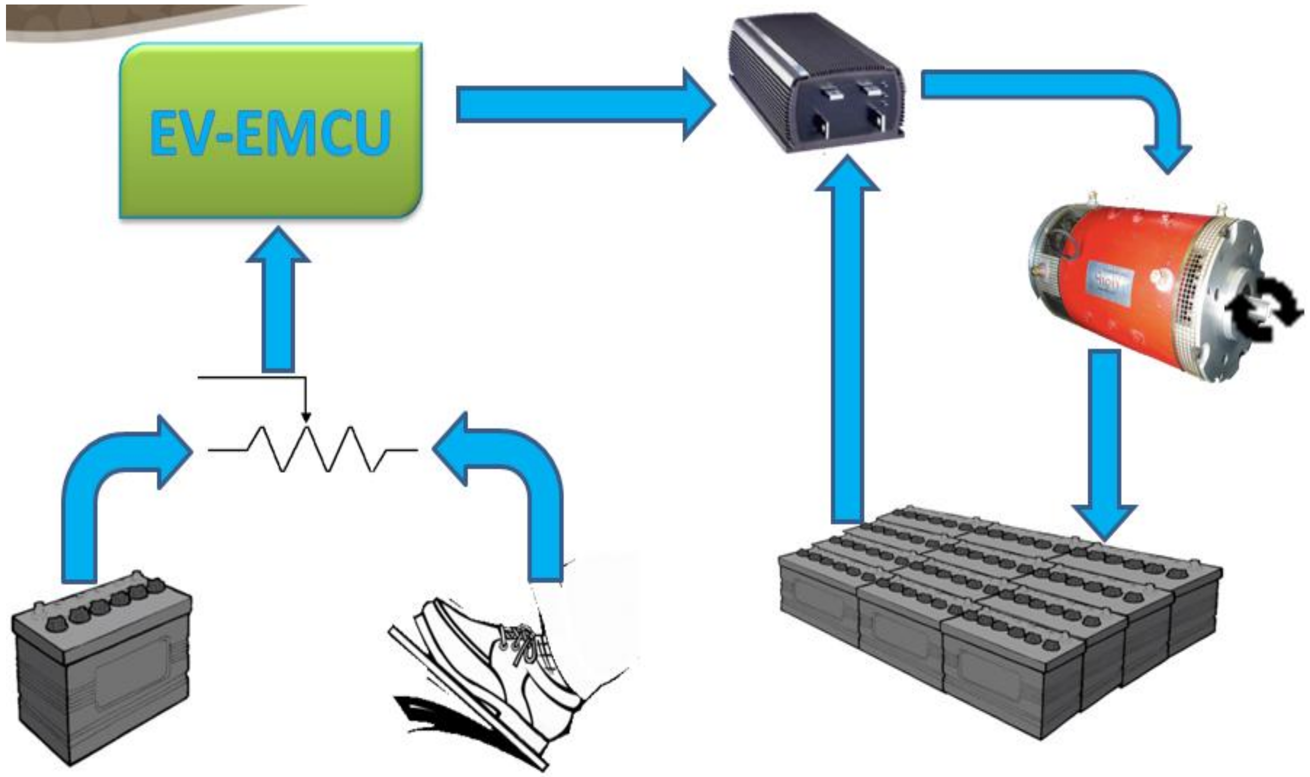

Fig. 2. Flow chart showing the control connected with the other major components of the vehicle.

engineered to improve overall safety, increase pressure management and protect against contamination. The grid design is 99.994% pure heavy-duty lead calcium. It also has anchored plated groups that work with the high impact reinforced strength copolymer polypropylene case to protect against vibrations. The glass fiber separators are double insulated, and the rate of self-discharge is as low as 1% per month when kept at 20-25°C and 3% per month when kept at 68-77°C.

The terminals and hardware are copper and stainless steel alloy. There are multi-terminal options, terminal protectors and removable carry handles. This battery can be installed in several different orientations, and has the ability to be located near sensitive electronic devices, since it is spill-proof and will not cause damage to these devices. This is a twelve volt battery that weighs approximately 89.5 pounds. We did research into replacing them, but we eventually decided against it. The project is supposed to focus on engineering design. Therefore, we did not want to spend the majority of our financial resources on battery replacement, with requires almost no engineering design. However, if we were going to replace the batteries, we would have chosen to use 24 6V deep cycle golf cart batteries. Using the 6V batteries will allow for more power output from the batteries.

To provide accuracy and safety in the control unit, four separate microcontrollers are used. There is a data microcontroller that reads all of the signal inputs from the sensors, convert them to digital, and then send them to a USB drive for storage. The second microcontroller is the power microcontroller. It uses the power equations that are programmed to determine the correct voltage to be delivered to the motor controller. The microcontroller takes in a reading of the voltage applied from the potentiometer and determines from a percentage of the maximum voltage, how much of the output there should be.

A safety microcontroller is also used. The purpose of this controller is to prevent runaway acceleration, in other words to make sure what goes in to the control unit does not excess what goes out of the control unit.

Fig. 2 depicts a general diagram of EV-EMCU and the most important parts of the electric vehicle. The 12V auxiliary battery and the foot pedal input go to the potentiometer. The potentiometer would normally feed into the motor controller, but it is interrupted by our control unit. EV-EMCU is connected in series between them. That way, it is able to replace the signal from the potentiometer with its own optimized output. The motor controller can be viewed as a dimmer switch that gives variable output to the electric motor. The 144V battery pack, consisting of 12 12V batteries connected in series, can also be viewed in Fig. 2.

This project is fully funded by Progress Energy. The original idea was proposed by Power Grid Engineering. The converted 2004 Ford Ranger is owned by Tecta America.

There were several specification set between our senior design team and our sponsors. The total range of the vehicle should be increased by at least 5 to 10%. Data recording should be able to take place for up to 90 minutes, though the current max drive time on the vehicle is 45 minutes per full charge. The control unit must have some sort of safety features. We are using individual microcontrollers and a dedicated safety microcontroller, which is programmed to prevent runaway acceleration. Also, there is a dash-mounted control switch that turns on EV-EMCU. This allows the user to conveniently turn on EV-EMCU. More importantly, the driver can quickly turn it off if they wish to regain full control of the vehicle. When the switch is flipped off, EV-EMCU will immediately surrender control of the vehicle.

II. POWER LOSSES

The main goal of the project is to reduce power loss is by implementing an economy mode. The main idea behind this option is to reduce power losses by heat in the motor and batteries due to high current and acceleration. These losses are called I^2R losses. This name also tells us how these losses are to be calculated.

The main objective of the economy mode is to limit power loss and conserve as much of the charge in the battery as possible. Since more current is needed for more acceleration, it is apparent that, ultimately, a sacrifice in acceleration must be made when implementing economy mode. The most obvious consideration to relate power loss to current and acceleration is the Law of Conservation of Power. This law states that the power that goes in must equal the power that goes out. Ideally, power is calculated by the electrical power equation

$$P = VI = I^2R \tag{1}$$

This equation presents an equation to calculate what are called the I^2R losses. Since the electrical power system in this project represents a series circuit, average current is the same throughout the circuit, and if the resistance for each element is known, these losses can be easily calculated. The I^2R losses calculated from the battery resistance will be the intermediate factor, since the main goal is to maximize efficiency. The minimum power needed to overcome frictional forces at constant velocity will be computed by the power microcontroller. A theoretical graph of the relationship between the two can be seen in Fig. 3.

The acceleration is attenuated dynamically as a function of vehicle speed. Less acceleration is required for higher velocities. And likewise, more acceleration is required for lower velocities. A preliminary graph of the relationship between acceleration and speed can be seen in Fig. 4.

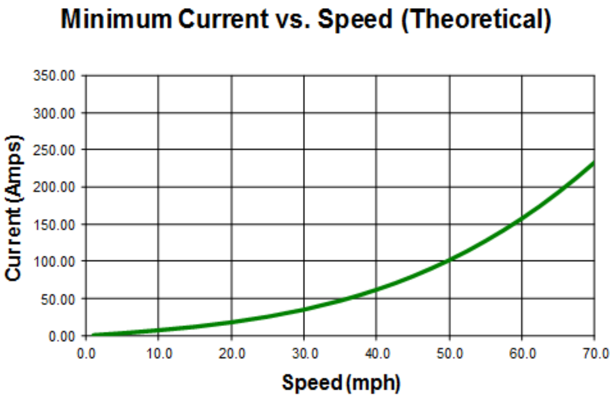

Fig. 3. Theoretical relationship between speed of a vehicle and the current that is going through the system.

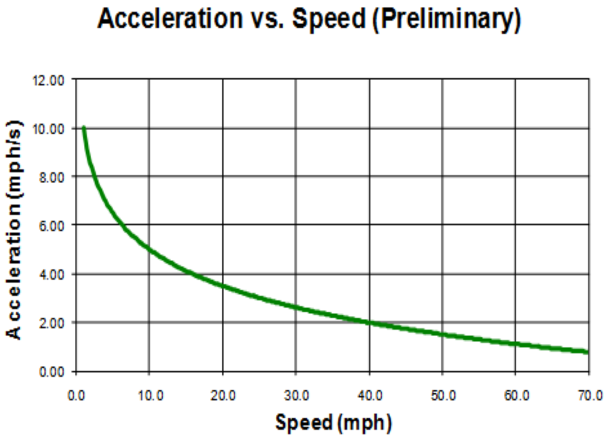

Fig. 4. Preliminary graph of the relationship between acceleration and speed.

The minimum acceleration needed to allow the vehicle to operate at the ideal speed must be determined to properly implement economy mode.

III. SENSORS

Several sensors are connected around the vehicle. They take different measurements from around the vehicle and feed these into the control unit. The sensors we chose are to measure current, battery pack voltage, state of charge of thee batteries, acceleration, rpm’s, and speed.

To measure the current we are using a Hall Effect current sensor. In the current sensor, there is a linear relationship between the measured current and the voltage output. The current sensor can measure a range of currents from 0 to ±500 Amps. The voltage output ranges from 1.5 to 4.5 Volts. The current sensor has an analog output.

The total voltage of the battery pack and the state of charge of the batteries is measured by a PakTrakr. The PakTrakr will determine the voltage of the 144 v supply located in the trunk of our vehicle. The PakTrakr uses a UART connection to deliver its 8 bits of data through to our microcontroller. The first byte is the letter that states what is the data following that. Digitally, the data will be delivered through the TX pin at 12 volts. The PIC controller we are using to analyze this data is the PIC 16F1823. Because the max voltage this PIC controller can stand is 5 volts, we have to use the MAX3232. This will receive the data and lower the voltage to an acceptable output the 1823 can intake. The 1823 well loop through the packs of data the PakTrakr sends out via the TX pin and then compares these stored values to the letter P. Once the correct letter is determine, will then wait to receive the next byte which will be the voltage of the 144 voltage supply. This information will be stored and the transferred to the Digital / Analog module to output this signal. The analog output will then be sent to the data controller for the information to be stored on the USB drive.

One PakTrakr can measure up to 6 batteries, so we purchased an additional remote to be able to measure all 12 batteries at once. The PakTrakr gives an analog output. A graph of the relationship between the open circuit battery voltage and the state of charge of the battery at 20°C can be seen in Fig. 5. It can easily be seen that they have a linear relationship.

The acceleration is measured by an accelerometer. This device is able to measure the static and dynamic forces of acceleration. Our selection of accelerometer is a PCB-based microelectromechanical-system (MEMS). They are designed to accurately respond to movements in very small increments so that the data can be converted to signals that are easy to interpret. The accelerometer measures movement with the use of a free floating mass. It then how hard and fast the free floating mass moves related to gravity.

It then converts that physical value into an electronic pulse. These pulses are then compared to gravitational force, or increments of gravitational force such as 1g, 2g or 5g forces. The output of an accelerometer is an electrical signal. The accelerometer is on its own printed circuit board. The output from the accelerometer is connected to the board and is then fed to the microcontrollers.

The main purposes for using an accelerometer is to determine the angle that a device is tilted or to analyze the way in which a device moving, such as up or down [2]. Fig. 6 shows a depiction of the direction in which the acceleration is measured for purposes of determining the angle that it is at. For this project, we are only concerned with the measurements in the x direction.

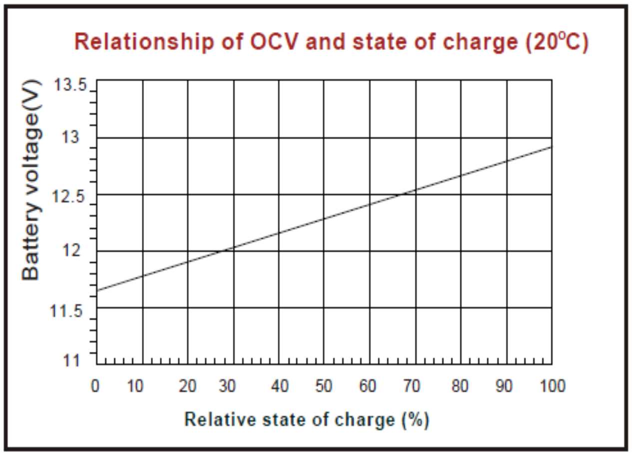

Fig. 5. Graph of the relationship between the open circuit battery voltage and the state of charge of the battery at 20°C.

The static forces that are recognized by the accelerometer refer to the pull of gravity, and the dynamic forces refer to movements or vibrations. This technology can be used to help the operator of an electric vehicle better understand the environment that the vehicle is driving in and how the vehicle responds to that environment [3].

One of these MEMS devices will be used to measure the acceleration of the electric vehicle and also to determine when the vehicle is moving uphill or downhill. The accelerometer that will be used is this project is from Dimension Engineering. The parts description is DE-ACCM2G2 buffered ±2g accelerometer. We chose this particular accelerometer because it has a very simple layout, with only two input pins and two output pins. See this simple pin layout in Fig. 7. Also, it meets all of the requirements needed for our project. The third and final reason we chose to purchase from dimension engineering is that we received excellent technical support through email from this company. It is a two dimensional accelerometer, able to measure in both the X and Y directions, and has an acceleration range of ±2g. Its features include integrated op-amp buffers. These make for a simple direct connection to the analog outputs of the microcontroller.

The sensitivity of this accelerometer is 660 mV/g. Using this value, along with Vcc and the Xout reading from the accelerometer in (2), the acceleration in the x direction can be obtained. This is value that is used by the power microcontroller to obtain the optimized current output.

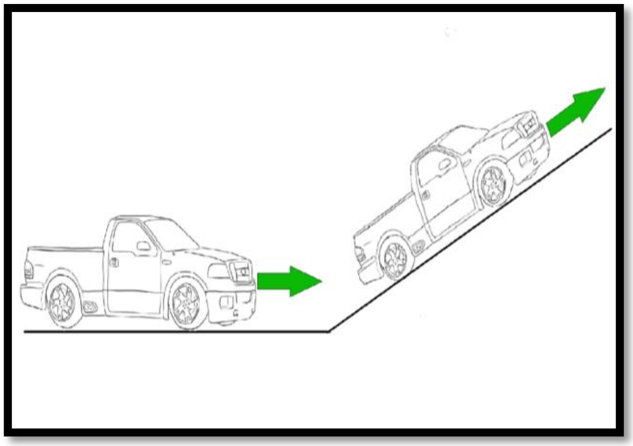

Fig. 6. Depiction of the direction that the accelerometer measures. Only the forward direction is needed for this calculation.

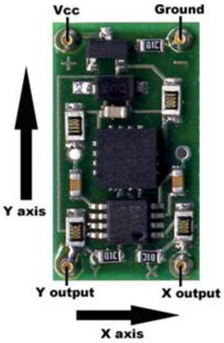

Fig. 7. Pin layout of Dimension Engineering buffered ±2g accelerometer.

$$\frac{\left[Xout-\left(\frac{Vcc}{2}\right)\right]}{sensitivity}=a_{\hat{x}} \qquad (2)$$

We are measuring the rpm's using a Hall Effect rpm sensor. It is attached to the tail end of the electric motor. This rpm sensor was recommended to our group by NetGain, the manufacturer of the electric motor already in the truck. This sensor operates under the 12V direct current power supply. The rpm sensor gives a pulse width modulated output signal.

The speed sensor posed a problem at first. The vehicle is 2004, but the transmission is 1994. 1994 Ford Rangers have mechanical speed sensors that do not give electrical outputs. In order for the signal to feed in the circuit board, there must be an electrical signal coming from the sensor. Therefore, we needed to purchase a new speed sensor, one that had an electrical output. It is a 9SS Ford 8 pulse speed sensor. The speed of this vehicle is measured from the rear differential.

The output from the potentiometer is not a sensor, but its output does feed into the board. This is the how the driver of the vehicle can most directly affect what goes into the control unit. The driver gives his input by pressing down on the pedal. This goes signal goes into the potentiometer, and comes out as a voltage from 0 to 12 volts. Normally, the signal would go directly to the motor controller. However, EV-EMCU is connected in series between the potentiometer and the motor controller. In this manner, our control unit is able to directly signal the motor controller how much current to send to the electric motor. The potentiometer was already installed when we began this project. It appeared to be in good working condition, so we did not attempt to replace it with a new one.

Each sensor makes its own contribution to the calculation of the efficiency of the truck. Knowing how to control these sensor inputs is done by microcontrollers which run a program written to determine the optimized current.

IV. HARDWARE DESIGN

The microcontrollers will control all aspects related to the operation of the 144 Volt systems. The main function of the microcontrollers is to determine the output voltage to the motor controller. The software will run different equations to determine the total voltage output. The electric vehicle printed circuit board has four microcontrollers. This is done to minimize microcontroller processing load, and to simplify the design, as to not having one microcontroller doing everything. The function of the microcontroller is separated into different modular parts, as to minimize the risk of a domino effect in failing. There are dedicated microcontrollers for data, power, safety and one for the PakTrakr interface. Sensor signals go into the board and then the microcontrollers. The data microcontrollers accept the analog signals, convert them to digital and then send them to USBwiz for data storage.

The USBwiz is a PCB with the USB port as well as a SD port soldered to it. The PCB is then connected to the microcontroller. The connection uses UART, which is a type of serial communication protocol. The USBwiz run on a FAT file system, which most flash drives are configured to run this way. The USBwiz can also run on I^2C and SPI which are serial communication protocols.

The USB controller will interface with the flash drive and record data to it. The data recorder will then send necessary data to the LCD to display to the user. This is the same data that can be accessed later from the flash drive. The microcontroller takes this input and takes an average of the information sensed. This includes current, rpm, velocity, voltage, and the state-of-charge.

The power microcontroller is responsible for taking in a voltage signal from the potentiometer and deciding if that voltage needs to be attenuated or not while in economy mode. It makes this decision based on factors such as vehicle speed, road incline, resistive forces from the air and tires, power input to the motor and power loss due to internal battery resistance. It takes in measurements and process these inputs through calculations programmed into the power microcontroller's software.

The power microcontroller uses its programmed equations to determine how much current should be sent from the motor controller to the motor. The power microcontroller calculates the optimum current, and outputs a voltage that is representative of that current. In order for our microcontroller to take in this voltage a non-inverting amplifier well be added. The microcontroller can only receive a maximum of 3.3 V but the voltage being delivered will range between 0~12 V. Our amplifier does not amplify the voltage but reduce the input voltage to an acceptable amount for the microcontroller. There is another non-inverting amplifier that will amplify the output signal up to a maximum of 12 Volts. This signal makes the vehicle's pulse width modulator take current from the batteries, which it will send to the motor.

The purpose of this controller is to prevent runaway acceleration. This controller will never output anything larger then what the user applies on the gas pedal to the electric motor. The safety controller simply takes in two inputs; the pot box and the power controller. These two input are analog signals will be taking in by the pic16f1823. It will use the A/D module to change this signal into digital so that these two values can be stored and compared. The two values are subtracted, so that we can determine which input is greater by checking the status bit. If the carry bit is set to 1, then the power is the larger of the two values. Now, by using the D/A module we can then output the analog signal to motor controller then leading to the electric motor. The safety microcontroller will take in the inputs from the applied voltage of the accelerometer and the output voltage from the power microcontroller. It will compare them and then output the correct voltage to the motor controller. This allows the safety microcontroller to serve its purpose of preventing runaway acceleration.

The vehicle's 12 volt auxiliary battery is fed into the board. Then the signal is split between two voltage regulators. It goes into a 7812 voltage regulator and a 7912 voltage regulator to obtain +12V and -12V signals. Third, a switching regulator is used to step the + 12V down to +5V. The microcontrollers are powered by this +5V signal. The LF351 op amps are powered by the +12 and -12 volts sources. This board requires op-amps to lower the input voltage to the microcontrollers' requirements. Also the output voltage needs to be increased to operating levels. This will require op-amps capable of delivering the necessary voltage. The group members all have personal experience on a frequently used op-amp, as well as other varieties of op-amps. Op-amps are used in this project mainly as buffers and to step voltage up or down. We have chosen to use LF351 op-amps because we are the most familiar with them, from electronics lab, and because they fulfill all requirements for the project.

The accelerometer fits into a DIP 14 package, making placing it into the schematic simple. Also, the accelerometer's integrated op-amp buffers allow for a direct connection to the signal inputs.

The PakTrakr uses a serial connection port to connect to EV-EMCU. A serial connection sends out one bit of data at a time, as well as different control signals. This method of communication is preferred by the industry as it provides many benefits. In contrast with a parallel connection, in theory the parallel connection would be faster as there are more data cables, which transmit the data, but in reality, the parallel connection is slower as there is more noise interference. The clock on a parallel port also needs to be slower as there is more data going through.

There are several type of serial connections, the most important being the Universal Serial Bus (USB) and the RS-232 standard from the IEEE. RS232 is designed in such a way that it has to create different voltages for its control signals and its data signals. Some of these signals can be negative voltages during transmission. A max 3232 is used as an RS232 converter for the PakTrakr. The PakTrakr also has a dedicated PIC161823 microcontroller for interfacing.

V. SOFTWARE DESIGN

The two microcontrollers that are used in this project are the PIC16F886, and the PIC16F1823. Both microcontrollers are 8-bit devices made Microchip Technologies. The microcontrollers are programmed using the PICkit2 microcontroller programmer and the MPASM assembler.

The PIC16f886 is a 28-pin DIPP and was chosen for its 11 analog input pins, as well as its UART transmission capabilities, to accommodate the all of the sensors being monitored and UART transmission to the USBWIZ. The peripherals being used in this microcontroller are the analog to digital converter, EUSART module, and the timer module.

The PIC16F886 is used for the data controller. The analog to digital module is a 10 bit converter that runs at a frequency of 500 KHz. The module requires 11 acquisition periods to convert to 10 bit resolution. Since the chip runs at a frequency of 4MHz, and there are 10 bits to convert, the T_{ad} acquisition period is 2µs, therefore requiring a delay of 22µs for 10-bit resolution. Once the conversion is made, the 10-bit value is stored into two 8-bit registers. The rest of the sensors are polled through a looping algorithm and stored. The timer module is used to monitor the two pulse generating sensors. The time between pulses is measured and then stored into a register.

Before sending the sensor values to be stored on a USB drive, they must first be converted to ASCII characters in order for the USBWIZ to recognize them correctly. Also, any values larger than 8 bits must be separated into two bytes, high and low, for UART transmission. A hexadecimal conversion algorithm is used for this process. All values being sent to USBWIZ must be in hexadecimal format. This algorithm takes the high nibble of the byte, converts its hexadecimal value to its ASCII code, and then sent. The low nibble of the byte goes through the same process. Each sensor value is represented as a hexadecimal word, and is written to a file on the USB drive in CSV format. The commas and carriage return must be sent from code programmed into the microcontroller.

The EUSART module is set up for 8-bit, 9600 Baud, asynchronous serial communication to USBWIZ. In this configuration no CTS or RTS protocol is used. RX is only used for debugging purposes since only one-way communication is required from microcontroller to USBWIZ. After initialization, the code for the send process is only five lines of code, since all the EUSART module requires for transmission is to write a value to the TX register.

The PIC16F1823 is a 14-pin DIPP and was chosen for its digital to analog output, as well as the same peripherals as the PIC16F886. Three of these microcontrollers are used in this design, each one running at 4MHz. They are used for the power controller, the safety controller, and the PakTrakr interface.

The power controller is the main component of the EV-EMCU. This microcontroller uses the same algorithm to poll and store each sensor value as the data controller. Since it does not have a multiplication command, an algorithm was constructed to multiply 8-bit and16-bit values for a 16-bit product. Then calculations are made using speed, RPM, current, acceleration, and user input (potentiometer controlled by the gas pedal) to produce the optimized acceleration desired. It is then converted to a percentage of current needed for that acceleration. The digital to analog module is then implemented to output this value as a voltage, 0% being 0V and 100% being 5V. Since the digital to analog module is a 5-bit converter, the 8-bit value being sent out must shifted and masked before being written to the DA_{OUT} register.

In order for the EV-EMCU module to store data, we decided to use a device called USBwiz-OEM board. This board contains a programmed Philips LPC2141 microcontroller based on a 16/32-bit ARM processor core. The OEM board contains both SD and USB connectors which uses a fast FAT file system that permit the system to access storage media and open or create files and folders. Since these connectors are interfaced to the Philips IPS1160 USB controller, several USB devices can easily be connected to the device.

Along the sides of the board, is an 18-pin SIP header. This is called the user interface which allows "the User" to connect the device to a breadboard for testing. We bought the UMRS232 USB Adapter to quickly start communicating with the device to a computer. Once we have the USBwiz program working on the PC it can be used with any PIC or ARM controller. To communicate with USBwiz to the pc a terminal utility program is used called Tera Term. Programming the USBwiz is very simple because the command set is done in hex. Every USBwiz command must be followed by a CR code (ASCII 0Dh). After receiving a command and CR, the USBwiz returns a status code followed by a CR. A code of "!00" indicates success. For some commands, the USBwiz follows the status code with additional information, or the sender of the command sends additional information as described below.

VI. TESTING

Until testing can be completed from the control data test procedure, a preliminary algorithm has been constructed, in order to show design of concept. In this algorithm, the voltage signal from the potentiometer will be processed as a ratio out of 12, for instance a 12V signal will be interpreted as a 1, and a 6V signal will be interpreted as 0.5, and so on. From there, that ratio will be multiplied by the maximum current supplied by the battery pack, which is 500A.

As an example, 9V will be interpreted as a desired 375A. This current value will be compared to the maximum current limit set in economy mode. For now this limit will be 250A, or an output of 6V. If the desired current is less than 250A, the algorithm moves on to the next step, otherwise it clips the output voltage to 6V.

The next step in the algorithm will test to see if the power being sent to the motor is a maximum percentage over the resistive power needed to propel the vehicle at zero acceleration, due to the resistive forces such as aerodynamics and tire flexing and friction. Since voltage is a constant 144V, this calculation can be simplified in terms of current.

VII. CONCLUSION

This year-long project taught us many valuable lessons, beyond just hardware and software design. We learned how to write technical papers and how to present technical presentations. We also learned how to work as a team and how to put our ideas together to find the best solution to our problems.

If we could start this project over, we probably would have tried to find a way to swap out the batteries. They were about three years old, and they did not perform as well as we expected. We researched those specific batteries, and they were determined to be a great choice for this vehicle. The vehicle would have been easier to work with if it had fresher batteries.

ACKNOWLEDGEMENT

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We are grateful to the sponsors of this project. The original idea was proposed by Power Grid Engineering. They led us to Tecta America, who provided the fully electric truck that we worked with. This project would not have been possible without the financial support of Progress Energy. We would also like to thank Progress Energy for the opportunity to present our project in the third annual Progress Energy Senior Design Symposium in Sustainable & Renewable Energy.

BIOGRAPHY

Vanessa Baltacioglu is an Electrical Engineering student, with a minor in Mathematics. She will graduate from the University of Central Florida in August of 2011. Vanessa has been working as an intern in the Microelectronics Center at Lockheed Martin Missiles and Fire Control for almost two years. Also, she is currently working with Dr. Vikram Kapoor on a research project in biomedical nanotechnology. She is interested in microelectronics, digital signal processing, biomedical engineering and engineering management.

Christopher Chadman is a senior at the University of Central Florida, and will be graduating with his Bachelor’s degree in Electrical Engineering in May 2011. An alumnus of Brevard Community College and a U.S. Navy veteran, Chris will be pursuing a career in Electrical Engineering with an interest in signal processing and communications.

Shauntice Diaz is currently senior at the University of Central Florida and will receive her Bachelor's of Science in Electrical Engineering and a minor in Mathematics in December of 2011. Starting May 2011, she will apply her knowledge at an internship with General Electric in Bohemia, NY. She plans to join the Edison program offered by General Electric to continue growing her technical skills and earn credit towards an M.S. Degree in Engineering.

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