AC 2011-611: ENHANCING THE SAFETY, SECURITY, AND CONVENIENCE FEATURES OF AN AUTOMOTIVE VIA A CELLULAR INTERFACE

Lei Miao, The University of Cincinnati
Denis Fedorov, University of Cincinnati

Receive a bachelor degree (BSEE) cum laude from University of Cincinnati in 2010.

James O. Everly, University of Cincinnati

James O. Everly is an Associate Professor in Electronic and Computing Systems at the University of Cincinnati's College of Engineering and Applied Science. He received a BSEE and MSEE from The Ohio State University in 1969 and 1970, respectively. He is a Senior Member of the Institute of Electrical and Electronics Engineers (IEEE) and a registered professional engineer in the state of Ohio. He is a member of the IEEE Cincinnati Section, and in 1997 he received the IEEE Professional Achievement Award. He has held several research and management positions in industry working for such companies as Battelle's Columbus Laboratories, Rockwell International, and Claspan Corporation. He joined the University of Cincinnati in 1985.

Max Rabiee, University of Cincinnati

Max Rabiee earned his Ph.D. in Electrical Engineering from the University of Kentucky (UK) in 1987. He has taught electrical engineering and electrical engineering technology courses full-time & part-time for 28 years; and he is currently Professor and ECET Program Chair in the School of Electronics and Computing Systems in the College of Engineering and Applied Science (CEAS) at the University of Cincinnati (UC). Dr. Rabiee is a registered professional engineer (since 1988), and a senior member of the Institute of Electrical and Electronic Engineering (IEEE). He is also a member of the American Society of Engineering Education (ASEE), the Eta Kappa Nu Electrical Engineering Honor Society, and the Tau Beta Pi Engineering Honor Society.

Enhancing the Safety, Security, and Convenience Features of an Automotive via a Cellular Interface

Introduction

According to the National Highway Traffic Safety Administration (NHTSA), there were nearly 6,500,000 auto accidents in the United States in 2009 [1]. Being involved in a car accident is a nightmare, and the victims are often disoriented, upset, and unsure of what to do after the accident. In the worst case, the victims may be injured too badly to call for help. But what if the car can call for help automatically right after the accident? More than 1 million motor vehicles are stolen each year in the U.S. Losing a car is surely an unpleasant experience, but what if the stolen vehicle can report its geographical location to the owner or the police? Fortunately, commercial security and safety services, e.g., OnStar and LoJack, are available today on the market to address the above two concerns. However, these services require either a high installation fee or a high monthly/yearly service fee.

This paper presents a senior design project which utilizes cellular and microprocessor technology to provide similar and better services at lower cost. The project also enhances the convenience features of motor vehicles. The outcome of the senior design project is a complete electronic system assembled on a printed circuit board, and it is ready to be mass produced for the unit price under $100. When the system is installed on an automotive, the following functionalities can be achieved: i) a user may turn on and turn off the engine remotely; ii) the car may turn the engine off automatically after the desired temperature is reached; iii) a user may inquire the cabin temperature of the vehicle; iv) remote keyless entry; v) accident monitoring and notification; and vi) vehicle location tracking. All these functionalities do not have any limitation on distance, as long as the cell phone signal is available. The system is also very easy to operate: a user simply sends the commands as short text messages from his cell phone.

System Components and Methodology

The system that the student designed and built in the senior design project is shown in Fig. 1.

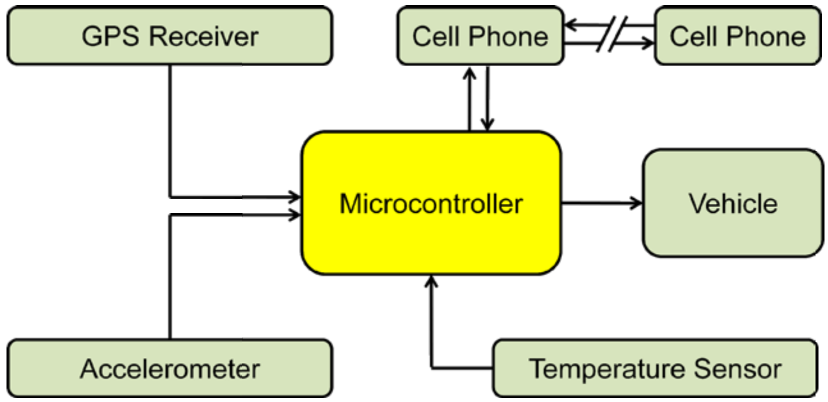

Fig. 1 System Components

The key system components include a microprocessor, two cell phones, a power supply (not shown), an accelerometer, and a temperature sensor. During all stages of the design, considerations were taken on the fact that the system would not be used in a LAB, but in a harsh environment where electronic components can be exposed to temperatures varying from -40^{0}F to 150^{0}F. All components selected for the system are able to withstand the wide temperature variation.

The user commands and system status are transmitted via a cellular network. In particular, a user sends some pre-defined text messages to a cell phone located in the vehicle. The cell phone is interfaced to a microcontroller via the RS232 serial port. Upon receiving the commands, the cell phone will notify the microcontroller, and the microcontroller will then perform the corresponding actions. Hardware-based serial interrupts are used to guarantee that the incoming text messages are never missed. On the reverse direction, the microprocessor can send the status of the vehicle back to the user, after it receives a query of system status.

It is obvious that the microprocessor is the core of the system. The student picked PIC18F2682, a microcontroller made by Microchip Technology Inc. This chip was selected primarily due to its large data memory capacity, which was required to process long text messages; another reason is that the chip is not expensive and has exceptional parameters; finally, it is also available in Dual In-line Package (DIP) and can be easily mounted on a printed circuit board. Below are the main features of the microcontroller:

- Program Memory 80 Kbytes
- CPU Speed 10 MIPS
- RAM 3,328 Bytes
- Idle mode currents down to 5.8 µA typical
- Sleep mode currents down to 0.1 µA typical
- Single-Supply 5V In-Circuit Serial Programming™ (ICSP™) via two pins
- In-Circuit Debug (ICD) via two pins
- Wide operating voltage range: 2.0V to 5.5V
- SPI and I2C™ Enhanced Addressable USART module

- 10-Bit 11-Channel Analog-to-Digital Converter module
- Price is $6.92 in quantities

The temperature sensor plays a key role in the system. In order to reduce fuel consumption and protect the environment when warming up or cooling down the air in the cabin, the system constantly checks the cabin temperature via the temperature sensor. Once the desired temperature is reached, the engine will be turned off by the microprocessor. The student used the TMP101 temperature sensor chip made by Texas Instruments. The microprocessor communicates with the TMP101 via the I2C protocol, which guarantees accurate readings and also allows multiple sensors on the same data bus.

The location of the vehicle can be tracked easily through the GPS module. The EM-406A GPS module made by USGlobalSat Incorporated was chosen. The module is based on the SiRF StarIII chipset and is shown in Fig. 2. The GPS receiver communicates with the microcontroller via the RS232 serial port.

Fig. 2: The EM-406A GPS module

The accelerometer is a critical component of the system. It is used for accident detection. The Freescale's MMA7260QT Micro-Electro-Mechanical Systems (MEMS) accelerometer with selectable sensitivity (1.5g/2g/4g/6g) was used in the project. Because the chip is only available in Quad Flat No leads (QFN) package, which is extremely hard to solder by hand, the breakout board from Polulu Electronics (shown in Fig. 3) was selected for the project. The breakout board basically makes it possible to use certain electronic chips and components in a non-industrial production environment.

Fig. 3: MMA7260QT accelerometer breakout board

The accelerometer is connected to a separate microcontroller (Microchip Technology Inc.'s PIC16F684) via an analog to digital converter module of the microcontroller. This design decision was dictated by the need for reliable and independent operation of the accident detection algorithm and also by the limitation of the number of the input/output channels on the main microcontroller. The primary job of the PIC16F684 chip is to take the G-force readings from the MMA7260QT accelerometer periodically. The simplicity of operation on MMA7260QT determines that its programming code is very robust and runs fast; this, in turn, leads to desired sensitivity and reliability of the operation. If a spike in G-force is detected, an accident may have happened. The PIC16F684 chip then sets one of the inputs on the main microcontroller to high and triggers the external interrupt. This principle of operation guarantees that accidents will never be missed. After an accident is detected, the corresponding code will be executed, and an accident notification (a text message) will be sent to the emergency contact phone number.

One of the goals of the senior design project is to make the system a final product that can be mass produced and can benefit people. Soon after some proof-of-concept testing is done on the breadboard, the student started to produce a printed circuit board for the system. The printed circuit board was designed using the Eagle 5.7 software suite. The design was sent out for fabrication to BatchPCB, a company specializes in printed circuit board production. The final printed circuit board used in the project is shown in Fig. 4, and the circuit schematic is available in the Appendix. All the system components were hand-soldered onto the printed circuit board.

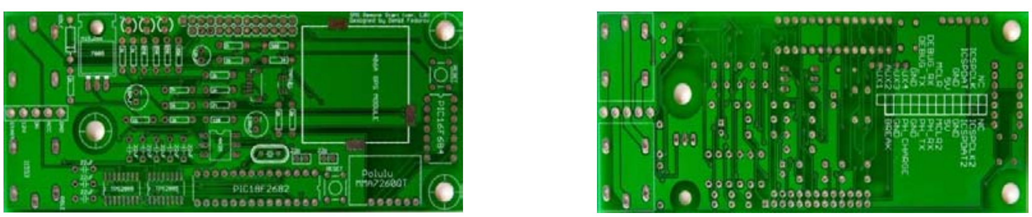

Fig. 4 The Printed Circuit Board designed by the student

Finally, the system is connected to a vehicle via five wires: +12 volts, Ground, Ignition, Accessories, and Starter. All these wires are standard and can be easily accessed at the ignition lock connector of any vehicle. The stock wires remain uncut; instead, the wire tap splice connectors, shown in Fig. 5, are used. This ensures that the car's functionality is not affected and the system can be easily installed and removed.

Fig. 5: Wire tap splice connectors

Budget and Timeline

Table I below shows the budget of the senior design project.

ITEM	COST
Motorola C168i cellular phone (used)	$5.00
MMA7260Q 3 axis accelerometer	$15.00
GPS receiver	$45.00
Printed circuit board fabrication	$20.00
Discrete components	$20.00
PIC 18F2682 Microcontroller	$0.00
PIC 16F684 Microcontroller	$0.00
TI TPS2085 SSR	$0.00
PTH08080W power module	$0.00
TI TMP101 Temperature sensor	$0.00
TOTAL	**$105.00**

Table 1: Project Budget

Notice that there were a number of parts that were received at no charge through the sampling programs of Microchip Technology Inc and Texas Instruments. In case of mass production of the system, the cost for those parts, around $15.00, will have to be added to the system cost; however, the cost of other components may be reduced dramatically. The rough estimate of the cost per unit in case of mass production is shown in Table 2.

ITEM	COST
Cellular module	$20.00
MMA7260Q 3 axis accelerometer	$2.38
GPS receiver	$15.00
Printed circuit board fabrication	$1.14
Discrete components	$5.00
PIC 18F2682 Microcontroller	$6.33
PIC 16F684 Microcontroller	$1.32
TI TPS2085 SSR	$1.34
PTH08080W power module	$5.80
TI TMP101 Temperature sensor	$1.05
TOTAL	**$59.36**

Table 2: Mass Production Budget

The senior design project was completed by one student, and lasted for about six months. Fig. 6 depicts the Gantt chart of the project.

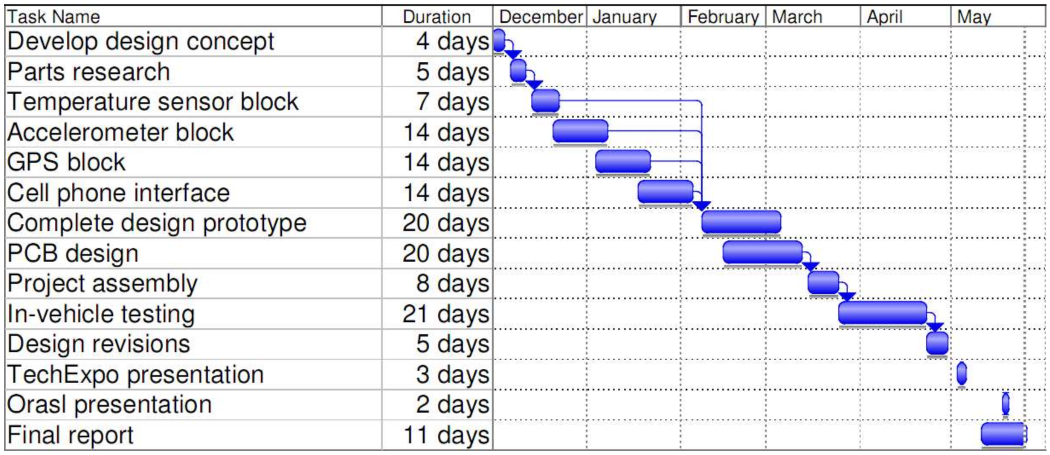

Fig. 6: Gantt chart

Problems Encountered

During the final testing of the system, a serious problem was encountered. The power supply component of the design was based on a regular low dropout (LDO) linear voltage regulator – the UA7805 chip from Texas Instruments. Although the unit worked well in the LAB environment, it failed during the first in-vehicle test. The problem was that the UA7805 radiated a lot of heat and a sizable radiator was necessary. Furthermore, the low efficiency of the LDO regulator led to discharge of the car battery if the car is not driven for a period of two or more days.

This problem was solved by replacing the UA7805 LDO with a buck DC to DC voltage converter. Texas Instruments offers convenient drop-in modules. The PTH08080W miniature power module with maximum current of 2.25 A was selected. This module has 92% efficiency. It does not get hot and there is no excessive leakage current drawn from the car battery.

The revised design worked flawlessly. The power unit stayed cold, and its temperature is close to the ambient temperature. This made the system much more reliable and versatile in terms of the possible installation places in a vehicle, since the air flow is no longer required for cooling purposes.

Assessment

The outcomes of the senior design project, including a poster, were demonstrated to the faculty members, as well as to the general public of the city of Cincinnati in an annual Tech Expo event. Judges from the local IEEE section evaluated all the senior design projects in the Tech Expo, using criterions such as novelty, quality, cost, etc. Among near 100 senior design projects, this senior design project won the 2nd place IEEE prize.

Conclusions

This paper presents a recent senior design project conducted by a student at the University of Cincinnati. The goal of the project is to develop a user-friendly and low-cost electronic system that can enhance the security, safety, and convenience features of a motor vehicle. The communication between a user and the system is achieved via a cellular interface. In particular, commands and system status are transmitted as simple text messages.

The system has several attractive properties, including: (1) it can provide the geographical location of the vehicle in real-time in case that the vehicle is stolen; (2) it can monitor the vehicle and report to an emergency contact number in case that the vehicle is involved in an accident; and (3) it enhances several convenience features of the vehicle, for example, it can turn on the engine and warm up or cool down the cabin air until the desired temperature is reached.

The outcome of the project is a complete system mounted on a printed circuit board. The estimated unit cost for mass production is less than $60, at least an order of magnitude less than the existing commercial services such as OnStar and LoJack. The system developed by the student also outperforms these services in certain extent.

On the educational front, this senior project is a nice practice for a student to integrate several electronic devices and components, such as cell phones, microcontrollers, temperature sensors, accelerometers, GPS receivers, and printed circuit boards into a complete and working system. We hope that the idea, the design, and the implementation of this senior design project are helpful to other educators and senior students.

References

[1] National Highway Traffic Safety Administration
National Center for Statistics and Analysis
http://www.nhtsa.gov/people/ncsa/

Appendix

System Schematic