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DEVELOPMENT OF A LOW-COST AUTOMATED CRASH NOTIFICATION SYSTEM

Final Report
July 2001

Submitted by

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16. Abstract

The report describes the development of a Low-Cost Automated Crash Notification System for eventual field testing on New Jersey highways. The project was developed in response to national studies which show that nearly half of all traffic crash fatalities occur before the crash victim reaches a trauma center. Many of these deaths can be attributed to the inability of EMS personnel to locate and reach the victim during the so-called "Golden Hour" after the accident when emergency medical treatment is most effective. The goal of this project was to dramatically reduce EMS response time by developing and testing an advanced in-vehicle system which automatically transmits the location and severity of a crash to EMS personnel. Specifically, the project has designed, developed, and tested a low cost functional system that combines wireless communications and Global Positioning Systems with a network of inexpensive sensors for crash detection.

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1. SUMMARY

The report describes the development of a Low-Cost Automated Crash Notification System for eventual field-testing on New Jersey highways. The system was developed in response to national studies which show that nearly half of all traffic crash fatalities occur before the crash victim reaches a trauma center. Many of these deaths can be attributed to the inability of EMS personnel to locate and reach the victim during the so-called "Golden Hour" after the accident when emergency medical treatment is most effective. The goal of this project was to dramatically reduce EMS response time by developing and testing an advanced in-vehicle system that automatically transmits the location and severity of a crash to EMS personnel. Specifically, the project has designed, developed, and tested a low cost functional system that combines wireless communications and Global Positioning Systems with a network of inexpensive sensors for crash detection.

2. INTRODUCTION AND BACKGROUND

Figure 2-1. The Objective of Automated Crash Notification is to Improve Emergency Response Times.

With the advent of trauma centers, the fatality rate of persons reaching a hospital after a car crash has dropped dramatically over the last twenty years. However, nearly 20,000 crash victims die every year before ever reaching the hospital [NHTSA, 1999]. Undoubtedly, some fraction of these deaths result from catastrophic crashes. However, many of these deaths can be attributed to the failure of EMS personnel to reach the victim during the so-called “Golden Hour” after the accident when emergency medical treatment is most effective. National statistics clearly show that despite a growing wireless communications network and the availability of medivac transport, the time to notify emergency personnel of a crash and respond the crash victims can be quite lengthy. For fatal crashes in the U.S., the average pre-hospital time is approximately 30 minutes in urban areas and 1 hour in rural areas [NHTSA, 2000].

Currently, emergency personnel must rely on passing motorists, highway patrols, and traffic reporters to report crashes. Often the individual reporting the emergency may not know where he or she is, let alone be able to direct help to his or her location. These delays can be especially lengthy in rural, relatively unpopulated, areas where a crash site may go undetected for hours – and occasionally days.

Crucial to getting help to a crash victim is prompt notification that (a) a crash has occurred, (b) the location of the crash, and (c) some measure of the severity or injury-causing potential of the collision. Automated Crash Notification Systems capable of performing many of these tasks have been installed as expensive options on a limited number of high-end luxury cars. The OnStar System, for example, costs $700 for installation, carries a $200-400 annual fee, and is currently offered only for select General Motors models [Thomas, 2000].

The idea behind Automated Crash Notification is to equip cars with a crash sensor which can detect that an accident has taken place, and automatically notify the emergency medical personnel of the severity and precise location of the accident. Once activated, an Automated Crash Notification system would automatically transmit a signal to a 9-1-1 dispatch center, where an electronic map would pinpoint the signal location. Precise location of the traveler in trouble enables rapid emergency response. More advanced sensors can also estimate the injury-producing capability of the crash. The first estimates of the number of potential lives saved by ACN technology are 3000 lives per year [Champion et al, 1998].

The National Highway Traffic Safety Administration has sponsored a trial ACN system [Preziotti et al, 2001]. This program is in the process of installing ACN in 1,000 privately owned vehicles in upstate New York. The ACN system uses on-board sensors to identify that a crash has taken place. It then uses the Global Positioning Satellite (GPS) system and conventional cellular phone systems to deliver a message, based on the sensors input, directly to 911 operators. While promising, this system has proven to be extremely expensive. To date, the total Federal cost of the study has been about $3 million. The technical approach used in this project has resulted in an estimated $500 cost per unit – motivating a search for a lower-cost approach to Automated Crash Notification.

Objective

The goal of this project is to develop and test an advanced in-vehicle system that determines that a serious automotive collision has occurred and automatically summons Emergency Medical Services (EMS) response. Specifically, the proposed project will design, develop, and test a low cost functional system that combines wireless communications and Global Positioning Systems with a network of inexpensive sensors for crash detection. The purpose of the system is not only to shorten the time it takes to notify authorities of the crash event, but to improve the quality of the response.

This project will perform limited field tests of a prototype automated collision notification system (ACN). A follow-on phase of this effort will seek to conduct an operational field test of the ACN system using up to 1000 privately- or publicly-owned cars in a representative cross-section of the State of New Jersey.

3. System Requirements/Architecture

The Automated Crash Notification system developed under this project is referred to as the Automated New Jersey Emergency Locator (ANJEL). ANJEL is composed of two major subsystems: (1) the Mobile Unit which is installed in the occupant compartment of the vehicle, and (2) the Base Station which is responsible for receiving distress calls from the Mobile Units and reporting their location to emergency response dispatch personnel. This section describes the requirements of each of these subsystems.

Mobile Unit

The Mobile Unit is responsible for detecting a crash, determining the location of the crash, and communicating crash severity and crash site location to the Base Station. Figure 3-1 presents the system architecture of the proposed device. The system consists of a single chip embedded microcomputer which is connected to a crash sensor, a Global Positioning System (GPS) sensor, and an embedded wireless modem. In the event of a crash, the crash sensor(s) will detect the vehicle impact, and output a signal proportional to the deceleration of the vehicle. The crash sensor signal output will be continuously monitored by the microprocessor which will decide whether or not a crash has taken place. Upon detecting a collision, the microprocessor will poll the GPS sensor to determine the final resting position of the car. The microprocessor will then use its wireless modem to establish a communications link with the Base Station. Once a link has been established, the Mobile Unit will transmit crash site location and the crash severity to the Base Station. Ideally, the entire process, including linkup, will be completed within 30 seconds after the crash occurred – giving EMS personnel a crucial edge in rapidly reaching the crash victim.

The Mobile Unit will be installed either under the driver's seat or in another occupant compartment location. Locating the Mobile Unit in the occupant compartment will provide an accurate measure of the deceleration experienced by the occupants in a crash, and will protect the Mobile Unit with the same structural cage which protects the occupants.

Note that there is some degree of overlap between the Mobile Unit and components in late model cars. Since the early 1990's, all passenger vehicles sold in the U.S. have been required to have airbags. Increasingly, the sensors used in these systems are electronic sensors of the type used in this program. However, modification or connection to the airbag or any other safety systems of the car has been strictly avoided in the Mobile Unit for liability reasons. Eventually, automakers may choose to use the airbag sensor to drive an ACN systems of the type described here. However, the Mobile Unit has been designed to be completely independent of all in-vehicle systems with the exception of the car battery.

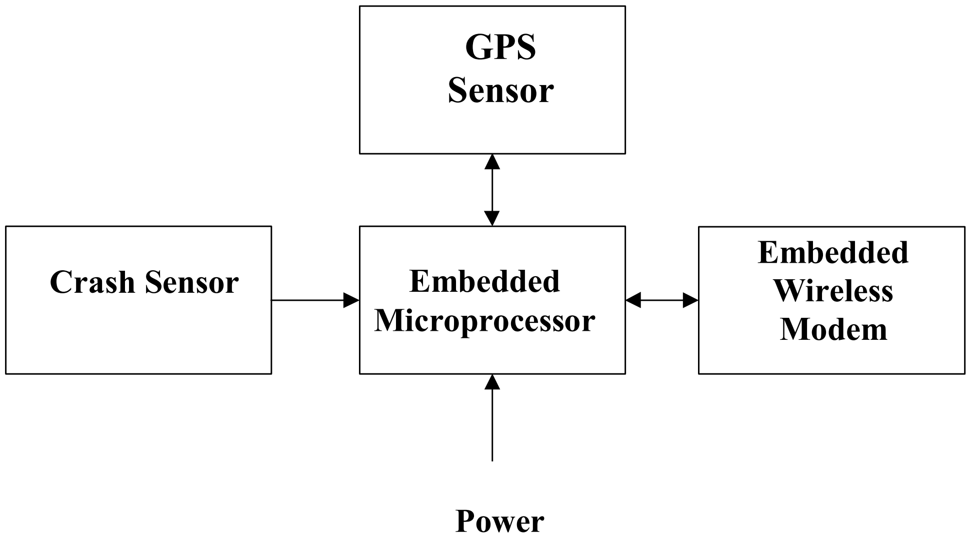


Figure 3-1. System Architecture

Base Station

The Base Station system will (1) receive the emergency call over the Mobile Unit, (2) receive GPS data and the crash pulse from the crash site, and (3) display the location and severity of the crash using computerized maps for Emergency Response Team dispatch. The prototype Base Station will (1) serve as a test bed for later development into a full-featured Base Station in later phases of the project, and (2) for checkout of the prototype in-vehicle device proposed here. Note that this system is intended only for laboratory use: it is not intended for use as a production system.

Mobile Unit Functional Requirements

Crash Detection. Crash detection will be performed with an array of accelerometers. Detection of frontal impacts requires an accelerometer aligned with the longitudinal axis of the car (x-axis) while detection of side impacts requires an accelerometer aligned with the lateral axis of the car (y-axis). Note that the x-axis accelerometer will detect rear impacts in addition to frontal impacts, and a single y-axis accelerometer will detect both driver and passenger side impacts. Angled impacts or frontal offset impacts would detect accelerations along both axes.

A minimum of two sensors is required to detect front, side, rear, angled, and offset impacts. In the U.S. these accident modes account for the majority of all accidents. The system developed under this program is a two-axis system. Depending on system cost constraints, additional sensors could be added to the system to complement this minimal sensor set. Other sensors such as a third sensor in the vertical direction (z-axis) would provide a complete acceleration time history including vehicle pitching during impact. However, a review of NHTSA frontal, side, and frontal-offset crash test data suggest that z-axis acceleration is negligible compared with the x-axis and y-axis acceleration. It should be noted that the two-sensor system cannot detect rollovers. Either a dedicated roll sensor, or a second sensor in the z-axis, separated from the first z-axis sensor by a known distance would allow detection of rollover.

The system uses a newly developed low-cost crash sensor – the Analog Devices ADXL-250. These crash sensors are inexpensive silicon based accelerometers which were initially developed for airbag systems, and cost two orders of magnitude less than conventional accelerometers.

GPS Sensor. The system uses a newly developed low-cost GPS sensors – the Trimble ACE-II system and the Conexant Zodiac System. These sensors can provide location resolution under 30 meters. Two options were investigated for GPS data processing for the mobile unit. The first option was to use a turn key single board system which processes the raw GPS data on board to determine the position of the car. The second option considered was to transmit the raw GPS data directly to the Base Station that will compute crash site location using a more powerful computer. However, early concerns that the computationally more intensive first option might introduce unacceptable time delays proved to be unfounded. All prototype development used the onboard GPS option.

Wireless Communications Transceiver. The system uses Cellular Digital Packet Data (CDPD) wireless transmission technology. CDPD is a cutting edge wireless communications protocol which allows direct connection of the remote devices to the Internet.

Embedded Microprocessor. System performance is controlled by an embedded single chip microcomputer. Single chip microcomputers such as the MicroChip PIC series, Z-World series, or Motorola 68HC12 series combine onboard memory, reasonable clock rates, and onboard A/D capability into a low-cost package which is readily interfaced to sensors such as those used in the ANJEL system.

Power. Power for this system is provided by the passenger car 12-volt electrical system. Note that per our design guidelines this is the only interconnection between Mobile Unit and the passenger car. Power from the car battery will be conditioned as necessary before input to the Mobile Unit electronics. Storage of backup power in a small onboard battery permits successful operation of the Mobile Unit even if car battery power is lost as a consequence of the crash.

Crash Algorithm. A crash algorithm, a software module in the microprocessor, was developed to detect a crash while avoiding false alarms. The Mobile Unit must be able to distinguish between actual crashes and low-severity crashes or non-crashes such as panic braking or backing into a shopping cart. To detect a crash, the microprocessor samples the accelerometer output at 1000 Hz (1 sample per millisecond). Based upon examination of National Highway Traffic Safety Administration crash tests coupled with crash test modeling, the crash detection algorithm was designed to signal that a crash has occurred if a 10-miles/hour change in velocity occurs in under 50 milliseconds. To put these time intervals in perspective, the typical frontal-barrier crash has a duration of approximately 150 milliseconds while panic braking requires over 1000 milliseconds.

Message Content. When a crash is detected, the Mobile Unit must transmit a message to the Base Station which describes the crash location and severity. Knowledge of the crash location allows the EMS center to dispatch EMS crews to rescue the crash victim. Knowledge of the crash severity provides the EMS center with an early snapshot of the seriousness and potential injury consequences of the accident. The message to the Base Station must include both these data facets as well as information detailing the time of the crash and a description of the car. Crash location can be as straightforward as the GPS location longitude and latitude. Crash severity will be provided for each crash sensor, and will be either the change in velocity or the crash pulse along each axis. It should be noted that while the crash pulse requires transmission of a longer message, the crash pulse typically provides sufficient information to infer whether the car struck a tree or another car (which may require additional EMS personnel). Inclusion of crash severity for each axis allows the Base Station to distinguish between frontal and the potentially more serious side impacts.

Crash Survivability. The Mobile Unit must be capable of surviving and properly functioning after a crash. The unit, its enclosure, and necessary antennas must be designed to survive crash loadings (typically 30 G in a 35 mph crash) and potential of power after the crash. Antennas for GPS and wireless transmission must survive the crash so that the crash location can be determined and notification of the crash event can be transmitted to the Base Station. As not all transmissions between the Mobile and Base Unit may be received, the Mobile Unit must be designed to transmit multiple times. Crash survivability can be increased through several means including (1) backup battery power, (2) locating the Mobile Unit inside the occupant compartment ‘cage’, (3) taking GPS measurements repeatedly during normal driving, and transmitting the last known location to the Base Station if the GPS lock is lost. The post-crash operation of the system was evaluated in laboratory testing at Rowan University.

Base Station Functional Requirements

The Base Station system must (1) receive the simulated emergency call over the Mobile Unit, (2) receive GPS data and crash severity from the simulated crash site, and (3) display the location and severity of the simulated crash using computerized maps for Emergency Response Team dispatch. Design concerns include how to best present crash location and severity to the Base Station operators, and how to ensure that large numbers of calls can be handled simultaneously.

The long-term objective of the ACN system, which will not be conducted under this research effort, will connect the Mobile Units with existing or expanded 911 systems. However, this effort will require coordination with existing 911 system operators and careful attention to how best to present crash information graphically to operators who are more accustomed to receiving voice-only calls. The Base Station developed here will provide an early evaluation of possible 911 operator user interfaces. The Base Station may also be suitable for limited field testing of the system for captive fleets such as the State Police or NJDOT vehicles.

4. DEVELOPMENT APPROACH

The ANJEL system required the development of two major components: (1) a Mobile Unit and (2) a Base Station. This section describes the development strategy to design, build, and test each of these components.

4.1 Mobile Unit: Development Approach

The development strategy was to develop the Mobile Unit in two stages. The first stage was to demonstrate proof of concept. The second stage was to explore designs which would lead to a lower cost Mobile Unit. While important, reduced cost was to be attempted only after successful proof of concept. To attack these two design criteria, a series of prototype Mobile Units was planned for development. The first prototype, Rev. A, would be designed to demonstrate proof-of-concept. The second prototype, Rev. B, would extend Rev. A, and would be designed to explore consumer cost reductions.

Proof of concept required the design, fabrication, and testing of a prototype Mobile Unit which could a) detect a crash, b) determine crash location, and c) transmit crash severity and location to a Base Station. These were the primary design objectives for the first prototype, i.e. to demonstrate functionality. Although other design considerations, e.g., cost, size, power requirements, ease of installation, and crash survivability, would be important in the eventual production Mobile Unit, these design criteria were relaxed during pursuit of the first prototype.

To facilitate demonstration of proof-of-concept and retain maximum design flexibility, Rev. A was envisioned as a ‘research prototype’. Rev. A was intended to serve as a test bed for potential ACN technologies – including crash sensors, GPS chip sets, and wireless communication components. Rev. A was designed to be as modular as possible so that alternate components, e.g. GPS boards, could be readily swapped into and out of the prototype Mobile Unit to investigate improved performance. Rev. A was also designed with numerous internal diagnostics to track and allow debugging of system performance during operation in the field. Finally, because this was to be a research prototype, cosmetic packaging concerns were postponed until the development of later prototypes. This allowed antennas, for example, to be placed where convenient for testing as opposed to attachment points more aesthetically pleasing to a consumer. Similarly, this approach allowed power for the Mobile Unit to be obtained from the car cigarette lighter adapter rather than directly connecting to the car’s electrical system.

The second prototype, referred to as Rev. B, in this document, would be designed using a fully functional Rev. A prototype as a starting point. While maintaining the functionality of Rev. A, Rev. B would explore the possibility of lower cost approaches to Automated Crash Notification. The objective was to design, build, and test a second prototype which could be fabricated in quantities suitable for field testing in New Jersey.

4.2 Base Station: Development Approach

To test both of these prototypes, a Base Station was developed which could field calls from the Mobile Units, and simulate the operation of a future automated crash notification 9-1-1 center. A key objective of the Base Station was to provide a means to test Mobile Unit wireless communication, i.e., to receive ACN messages from the Mobile Units, and to plot the location of these Mobile Units on a computerized map. A second objective was for the Base Station to serve as the test bed for evaluating automated mapping products. To limit development costs, the research team sought to use commercial-off-the-shelf software and mapping products whenever possible.

Note that the Base Station developed under this project was intended solely as a means to test correct operation of the Mobile Unit. While it is hoped that our Base Station design may provide some guidance for future 911 centers, the current Base Station is in no way intended to serve as a replacement for current 911 dispatch centers.

4.3 Crash Determination

One of the key functions of an ACN system is its ability to determine whether a crash has occurred or not. This makes the design of this sub-system very critical. One possibility would be to monitor the airbag sensor in the car, and trigger the crash notification system in the event that the airbag deploys. However, modification or connection to the airbag or any other safety system of the car was avoided for liability reasons. While automobile manufacturers may eventually choose to use the airbag sensor to drive an ACN system, it was decided to monitor the vehicle's acceleration profile to determine whether or not a crash had occurred.

An Analog Devices ADXL250 dual axis accelerometer was chosen to monitor the acceleration felt by the car. This accelerometer was chosen for a number of reasons. One main reason was the small size – a mere 0.4" x 0.3". Moreover, the fact that it is a dual axis accelerometer allows us to monitor the acceleration in both the x and y directions. This allows the system to detect both frontal as well as side impacts. Also, the accelerometer has a range of +/- 50 g. Even in 30 mph accidents, the passenger compartment often feels up to 30 g's. Hence, it is important to make sure that the range of the accelerometer is sufficiently broad to avoid saturation.

During normal operation, the acceleration values from the accelerometer will be logged by the micro-controller, which will then integrate these values over a 40 ms time interval to determine the change in velocity of the vehicle. This change in velocity is then compared to a predetermined threshold, which allows the microcontroller to determine whether or not a crash has occurred.

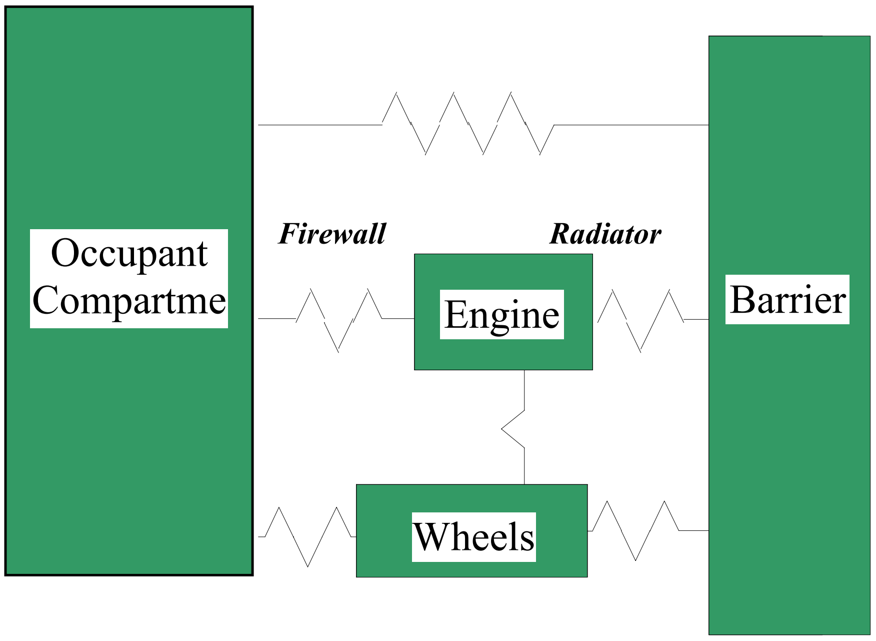


Figure 4-1. Extracted Lump-Mass Model for a 1999 Dodge Intrepid

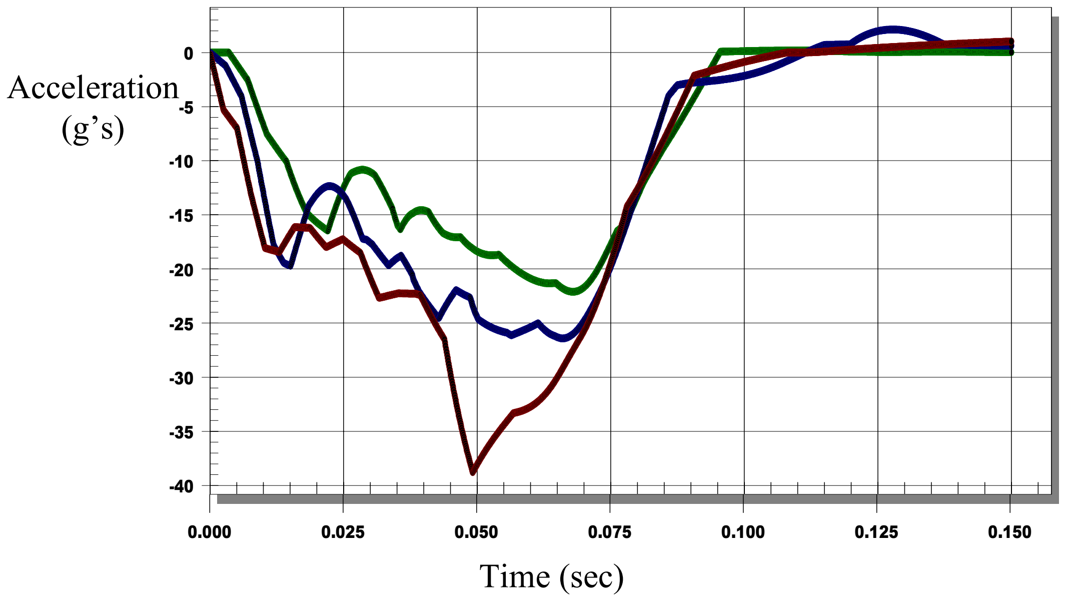


Figure 4-2. Acceleration time history for 1999 Dodge Intrepid during a frontal barrier crashes at 25, 30, and 35 mph impact speeds

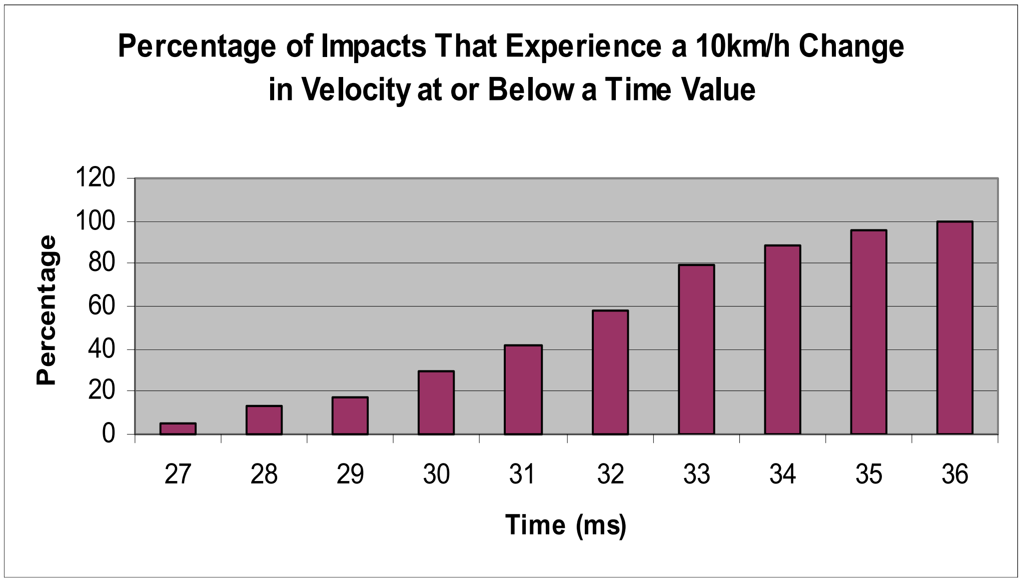


Figure 4-3. Time required for a 10 km/hour change in velocity during a crash under various circumstances

To determine the different possible threshold values for a crash, numerous crashes were simulated using the SISAME impact simulation code developed by NHTSA [Mentzer, 1999]. First, a model of a 1999 Dodge Intrepid was extracted using crash test data available from the NHTSA Vehicle Crash Test Database. The detailed SISAME model file is provided as an appendix to this report. As shown in Figure 4-1, this model uses a system of non-linear springs and lump-masses to simulate a vehicle's structural response during a collision. Using this model a crash simulation was conducted. Figure 4-2 shows the outputs from the program in terms of acceleration pulses for the impact. These pulses were integrated to find the change in velocity of the vehicle. These simulations were then repeated using a range of speeds varying from 25-70 mph. By analyzing the results from each simulation, the time for a 10 km/h change in velocity during a crash was found. Figure 4-3 shows that for the simulations run, the maximum time required for a 10 km/h change in velocity was 36 milliseconds. If the driver in a car traveling at 60 mph slams on the brakes, it takes about 500 milliseconds to undergo a 10 km/h change in velocity. Clearly, this method successfully differentiates between a crash-like situation (slamming on the brakes) versus an actual crash.

Although this algorithm should be adequate for field-testing of the ANJEL system, additional test and simulation data should be evaluated prior to development of an algorithm for a production ACN system. The final algorithm should set crash /no-crash threshold based on additional crash configuration, including different vehicle makes and models, side impacts, vehicle to vehicle impacts, and vehicle to rigid barrier impacts.

5. MOBILE UNIT SYSTEM DESCRIPTION

System Architecture

The goal for the initial prototype was to investigate the feasibility and workability of the concept involved with the ACN. As a result, the first prototype (also referred to as Rev. A) adhered to the baselines established for the overall design. No major flaws were found during the prototyping efforts, and no major changes were necessary. Rev. A hence manifests the same system architecture and functionality as outlined earlier in Section 3. An advanced prototype (Rev. B) has also been constructed based on the same architecture. Rev. B is a more advanced, slightly less expensive version of the Mobile Unit which corrects minor flaws detected in during Rev. A testing.

Crash Detection Subsystem

Silicon Accelerometer

The crash algorithm used in the ACN relies on measuring the acceleration of the vehicle (see "Crash Algorithm," Section 4). Consequently, the accelerometer becomes a key component of the crash detection subsystem. Several factors needed to be considered in determining which accelerometer to use:

- *Size*. The system should be as compact as possible, since it needs to be portable. Additionally, several physical and spatial constraints are imposed by the potential location of the system in existing cars.

- *Dual axis*. Although Rev. A focuses on the detection of frontal impact, the long-term goal of the ACN is to be a fully functional crash detection system. Consequently, the ACN would need to detect two kinds of accidents: frontal as well as side impacts. The accelerometer, then, needs to acquire data in two directions as well.

- *Saturation*. Car accidents tend to take place over a wide range of impacts. For example, victims in 30 mph accidents may experience up to 30 g's. The range of the accelerometer needs to be wide enough to ensure the system does not saturate at low g's.

For Rev. A, it was decided to use an Analog Devices ADXL250 dual axis accelerometer. The component is small in size, measuring a mere 0.4" x 0.3". It possesses the ability to measure accelerations along both the X and Y axis, thereby enabling the system to detect both frontal and side impacts. Moreover, the accelerometer has a range of +/- 50 g. Since Rev. A is concerned with crashes to about 30 g, the system is in no danger of saturating.

Since Rev. A has been limited to the detection of frontal crashes, readings from the accelerometer are only considered along the X-direction. The process can be modified, however, to allow for inclusion of readings along the Y-direction.

Sample-and-hold Chip

The A/D converter is continuously connected to the onboard accelerometer. However, the A/D converter samples the accelerometer only at discrete time intervals. In addition, the analog-to-digital conversion process requires a finite amount of time. Since the voltage inputs to the A/D will change continuously, failure to "hold" a voltage sample during the A/D process may skew the data. To rectify such an error, the SMP04E (which is a sample & hold chip) is used between the accelerometer and the A/D unit. This will ensure all data points are properly recorded during the detection of a crash. Moreover, by setting a high sample rate (1000 times per second), we can account for the discreteness of the data.

A/D Converter (ADC)

The ACN uses an external voltage comparator to compare readings from the accelerometer to certain threshold voltage values. Whenever the voltage exceeds the threshold, the ADC chip (ADC0809CCNA) sends an interrupt signal to the microcontroller, which processes this data to determine if a crash has occurred or not. The ADC has 8 analog input channels. Using the address latch in the ADC, the desired input can be converted to an 8-bit digital stream. The stream is then assigned to the data bus and read to a particular address location on the micro-controller (the address used is 0x40C1). This acceleration data is stored in the RAM (Random Access Memory) in the form of a circular buffer of size 128. If the micro-controller detects a crash, the contents of the buffer are written out to the RS-232 output from where they can later be acquired by an external device. The 'C' code for this program is shown in the file "A_DACN.cpp," which is included in Appendix C at the end of this report.

Microcontroller

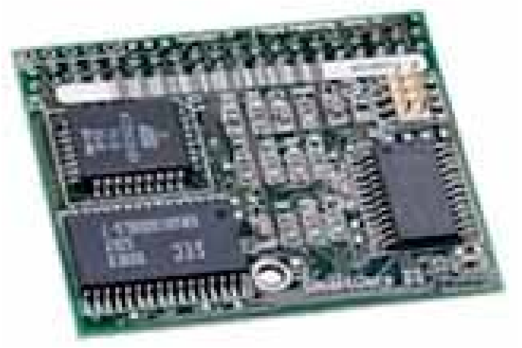


Figure 5-1. Z-World Microcontroller

A Z-World CM7200 microcontroller was used for Rev. A. The specifications are as follows:

Size	1.8” x 2.05”
Microprocessor	Z180 running at 9.216 MHz
SRAM	32 K
EPROM	128K flash EPROM
I/O	2 Serial Ports 2 DMA Channels 2 Programmable Timers

One of the main reasons that this microcontroller was chosen was the support it offered for programming in *Dynamic C*, which is a variant of traditional C. This along with the vast library support offered by Z-World has helped speed up development time.

The microprocessor used in Rev. B is the PIC17C756A processor. It has a clock speed of 33 MHz and is widely used in industry. The main features of the PIC chip as listed in the user manual are as follows:

Speed	33 MHz
Size	1.65” x 2.34” (68 pin PLCC)
Approx Price	$10.00
I/O	2 USART interfaces
Timers	4 + watchdog timer
A/D converter	12 channel 10-bit ADC
Brown-out	Yes

reset	
SRAM	902 bytes
EPROM	None

One of the main advantages of using the PIC micro-controller is that it is much less expensive than the Z-World processor. This makes it more suitable for applications such as the ACN where the cost of the final product is important. Additionally, the PIC17C756A has a 10-bit A/D converter which can be used to take in data directly from the accelerometer. This eliminates the need for an external ADC and reduces valuable board space requirements leading to a less expensive, more compact final product. Just as with the Z-World processor, the PIC chip uses C, a widely used programming language.

Functionality

As mentioned earlier, the Rev. A microcontroller receives input from the A/D converter to a specific memory location (0x4104). The micro-controller then assigns a value of ‘1’ to this address. This assignment serves as instruction to the ADC to hold the voltage sample that it currently sees on its X-axis input. Following this, a value of ‘0’ is written to the address 0x40C1, which initiates analog to digital conversion. When the conversion is completed, the ADC sends an interrupt signal to the microcontroller. It should be noted that the value on the data bus will hence represent the acceleration reading at that particular instant of time. After the interrupt signal, a value of ‘1’ is reassigned to the address 0x4104. This tells the ADC to release the held value of voltage. The acceleration reading acquired by the micro-controller is then stored in the circular data buffer. It is compared with preceding values to ascertain whether a crash has occurred or not. If a crash is detected, the data buffer is written out through the microcontroller’s serial I/O channel; if no crash has occurred, the above loop is repeated. The ‘C’ code for algorithm is shown in the file “crastest.cpp,” included in Appendix C at the end of this report.

The microcontroller continuously logs acceleration values from the accelerometer every millisecond. It monitors the data in 40 millisecond pieces to determine if a crash has occurred. It also updates the vehicle’s location from the GPS unit every second. The software implemented for this is primarily interrupt-driven. Both the A/D unit and the GPS unit generate interrupts when the microcontroller needs to read a value. In the event that the microcontroller detects that a crash has occurred, it proceeds to wake up the wireless modem from sleep mode, and instructs it to begin emergency transmissions.

Crash Site Location Subsystem

GPS System

System Description

GPS is one of the only systems available today that can pinpoint one's exact position on the earth anytime, in any weather, anywhere. Twenty-four GPS satellites continuously orbit the earth at a height of 11,000 nautical miles. These satellites transmit signals that can be detected and used by anyone with a GPS receiver to determine one's location with great precision. Consequently, the GPS system is an integral part of a crash notification system, as it is needed to determine the location of the vehicle during a crash.

Various companies were researched before a GPS receiver was selected. These companies include Motorola (www.motorola.com), Trimble (www.trimble.com) and SiRF (www.sirf.com). Important considerations in the purchase of the GPS receivers include their accuracy, locking time for a signal and their ruggedness to vibrations, g-force and so on. All three companies have a host of GPS products that could be used for this application.

After much consideration, the Trimble ACEII GPS core module was chosen for Rev. A. Since the ACEII is a core module, it is designed for OEM applications. The specifications of this GPS module are as follows [Trimble, 1999]:

Figure 5-2. Trimble ACE-II GPS Unit

Channels	8-channel continuous tracking receiver
Update rate	NMEA @ 1 Hz
Accuracy	25 m (50%) without S/A
Acquisition (typical)	Cold start: < 130 seconds (90%) Warm start < 45 seconds (90%) Hot start: < 20 seconds (90%)
Reacquisition after signal loss	< 2 seconds (90%)
Velocity	515 m/sec maximum
Operating temp	-40 C to +80 C

Power consumption	Primary: 5 V DC, +/- 5% GPS board only; 155 mA, 0.78 watts With antenna: 180 mA, 0.9 watts
I/O protocols	TSIP (binary data) NMEA 0183 v2.1 (ASCII data) TAIP (ASCII data)

The GPS board is capable of outputting coordinates using various I/O protocols. For our application, we will be using the NMEA protocol, as this protocol has been standardized. One issue of concern here is the power consumption for this unit. However, since the unit will be running off the car battery, this is not a major concern. The acquisition times as well as the accuracy of this unit are reasonable.

Functionality

The GPS unit is triggered by the microcontroller as soon as the car is turned on. Within minutes, the GPS receiver locks onto the satellites and is able to pinpoint the location of the car. Thereafter, the GPS unit updates the position of the vehicle every second as long as the car is on. As a result, even if the GPS antenna is damaged and the satellite lock is lost during a crash, the microcontroller will have the position of the car to within a second before the crash.

For testing purposes in Rev. A, the GPS output is read into a computer using RS-232. However, as the GPS actually outputs TTL logic levels, once the GPS unit is embedded into the system, no interface will be required between the GPS unit and the microprocessor. The ‘C’ code for this operation is shown in the file “CDPD_GPS.cpp,” included in Appendix C at the end of this report.

Antennas

A major concern related to the usage of GPS is its antenna. While special care can be taken to ensure to crashworthiness of the antenna, there is always the possibility that the antenna may be destroyed in a crash, thereby rendering the system useless. To combat any such issues, it was decided that the GPS unit should automatically update the vehicle location every second. As a result, even if the GPS antenna is lost in a crash, the system will still be able to transmit the last known position – which, given the sample rate, will be to within a second before the crash. Note that two antennas are required for the system: one fore the GPS, and one for CDPD communication. For Rev. A, the two antennas received from the GPS and CDPD vendors were used in their modified form.

Rev. B
To achieve lower costs, a Conexant Zodiac GPS receiver was used in Rev. B. The Zodiac receiver provides performance similar to the ACE-II receiver in a comparably sized package.

Wireless Communication Subsystem

Communication Technology

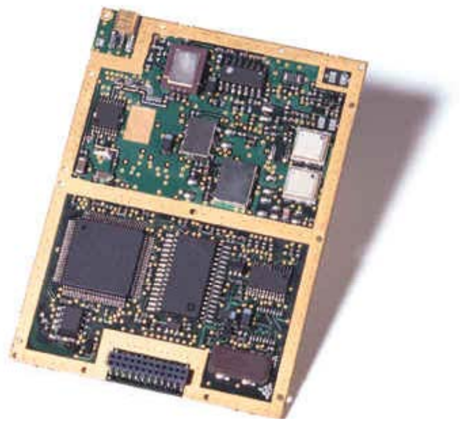


Figure 5-3. Novatel CDPD wireless modem

There are a number of possible wireless technologies that can be used for the transmission of the vehicle's location. These technologies include Radio Frequency (RF), cellular and Cellular Digital Packet Data (CDPD) modems among others. Rev. A, uses a CDPD modem manufactured by Novatel Wireless. It is a 0.6 W full duplex wireless modem. It supports maximum transfer rates of up to 19,200 bps and uses a mere 8 mA in sleep mode. This is important because in a crash, if the ACN unit is operating on backup batteries, the system should use as little power as possible.

While this approach seems sufficient, other possible communication means are possible and should be considered for a production system. An important issue in determining the technology to use will be the available coverage for the given technology versus related cost. While CDPD performs satisfactorily, it would require consumers to purchase a monthly plan in order to use the ACN. Cellular seems to be advantageous in this sense because with the new E911 standards being enforced, any carrier that detects a 911 call must accept it. This would save the consumer the cost of having to purchase a monthly plan of some sort with a cellular provider in order to use the crash notification system.

Antenna

The cellular antenna is of even greater concern than the GPS antenna, for if this antenna is lost, no transmissions will be possible. Multiple antennas for the cellular unit, possibly in the front and the back of the car would be advantageous, as this would give maximum antenna survivability in a crash. However, there are other issues related to the number and location of antennas. Wires must be run from each antenna to the crash notification box, and an excessive number of antennas would intensify the associated labor, thereby reducing the ease of installation of the system. Moreover, aesthetics is also a very important issue. The presence of antennas in safe but obscure locations might actually have an adverse affect on the marketability of the product as far as the consumer is concerned. More studies need to be conducted in this area to determine the consumer's preferences.

Power Requirements

Rev. B

The ACN power system consists of a power conditioning system of the various filters and regulators required to convert the 12V DC from the car battery into the necessary DC voltages vital to the internal circuitry. The power system also includes a back-up battery pack complete with its own charger and a mechanism for switching between primary and back-up power consumption modes.

All of the circuitry relies on 5V DC with the exception of the CDPD modem for which 3.6V DC must be supplied. In addition, a 5V analog reference is needed for the A/D converter onboard the microcontroller. To provide each of these required voltage levels, a voltage regulator is used. Each regulator is supported by an EMI (electromagnetic interference) filter and bypass and bulk capacitors. An LM2940 linear voltage regulator provides the 5V DC supply, while an LM4040 provides the 5V analog reference. An LT1098 sources the 3.6V DC supply.

The back-up battery system is composed of 5AA NiCd batteries and the supporting charge system. Each battery has a cell voltage of 1.2V giving the total battery pack a voltage of 6V. The 12V input from the car battery and the battery pack outputs are both connected through power diodes to the to the inputs of the three regulators. When the 12V from the car battery is removed, the battery pack diode becomes forward biased and continues delivering power to the regulators. Specifically, Schottky diodes are used such that there will be a minimal voltage drop across the diodes.

A p-MOS switch, installed between the battery pack and its diode, is the means for switching battery pack power into and out of the rest of the circuit. The p-MOS switch is closed when presented with 0V at its gate and open when 5V is present at the gate. In this way, battery pack power is conserved when not needed.

Under operating conditions, there are two circumstances that would result in the loss of the 12V supply to the circuit. Either the car has been turned off, or the car battery has been disconnected as the result of a crash. When the microcontroller senses the loss of the 12V supply, it checks to see if it is a valid crash state. If it is not, the microcontroller leaves the p-MOS switch open and the battery pack does not supply power to the circuit (system shutdown). If the microcontroller is in a valid crash state, the p-MOS switch is closed and the battery pack provides power to the circuit so that there is still power to continue transmitting the crash coordinates.

The actual control of the p-MOS switch is accomplished through the use of a D-type flip-flop. The clock and the D input are directly connected to port D of the microcontroller. A state change operation in the D-type flip-flop requires two occurrences. First, the data bit at the D input must be set (0V for on, 5V for off). Second, the clock must receive a rising edge. On start-up, the microcontroller sets the output of the D-type flip-flop to 0V, closing the p-MOS switch, and checks to be sure that back-up power will be available in the event of 12V supply loss. To prevent any leakage current from flowing into the microcontroller, 10kΩ resistors are installed between the flip-flop inputs and the port D terminals.

As stated previously, the battery pack is supported by a charging network. The MAXIM 1640 charging chip is employed to PWM (pulse width modulate) a 1mH inductor to provide a constant current level for charging the battery pack. The charging chip has a two-bit interface with the microcontroller at port C. This allows the charging mode to be set by the microcontroller as outlined in the following table:

Table 5-1. Charging Modes

D1	D0	Mode	Output Current (A)
0	0	Off	0
0	1	Top-Off	$V_{SET}/(13.3R_{sense})$
1	0	Pulse-Trickle	$V_{SET}/(13.3R_{sense})$ 12.5% Duty Cycle
1	1	Fast Charge	$V_{SET}/(13.3R_{sense})$

The only mode that will be used in this design is the pulse-trickle mode, where V_{SET}= 1.145V and R_{sense}= 0.56Ω so the output current is 154mA with a 12.5% duty cycle. This mode can be set during start-up of the microcontroller.

Conclusion

Figure 5-4 shows a photograph of the completed Rev. A prototype. Figure 5-5 presents a overall schematic of the system. Table 5-1 provides cost estimates for the Rev. A system. A similar calculation of costs for Rev. B estimated Mobile Unit costs in quantities of 1000 at $400-450 per unit.

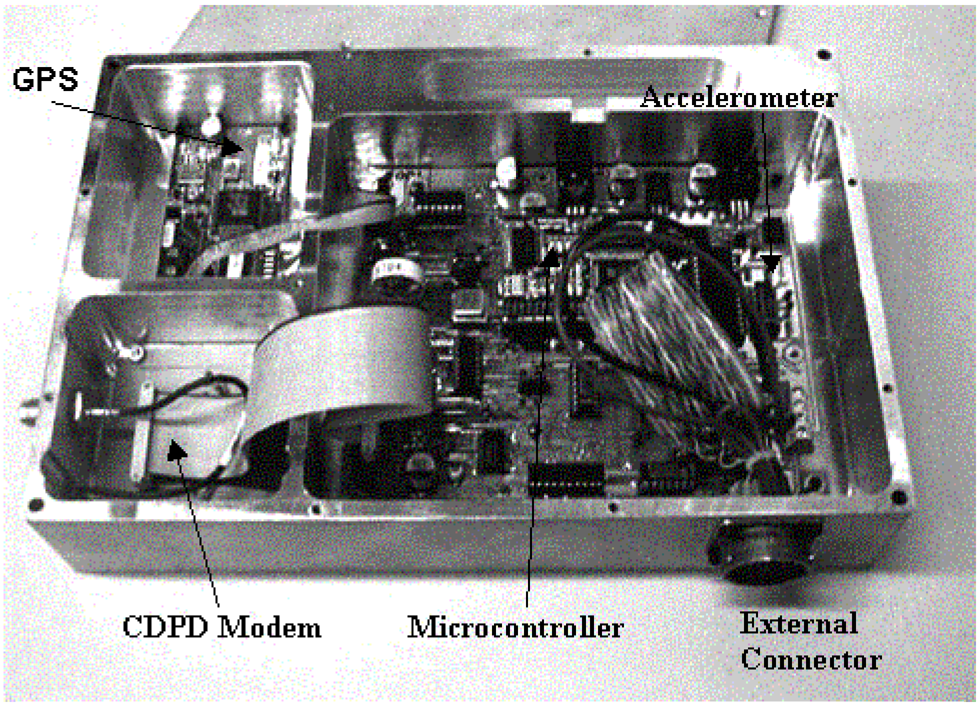


Figure 5-4. Completed ACN Rev. A unit

Figure 5-5. Basic Schematic of ANJEL Mobile Unit, Rev. A

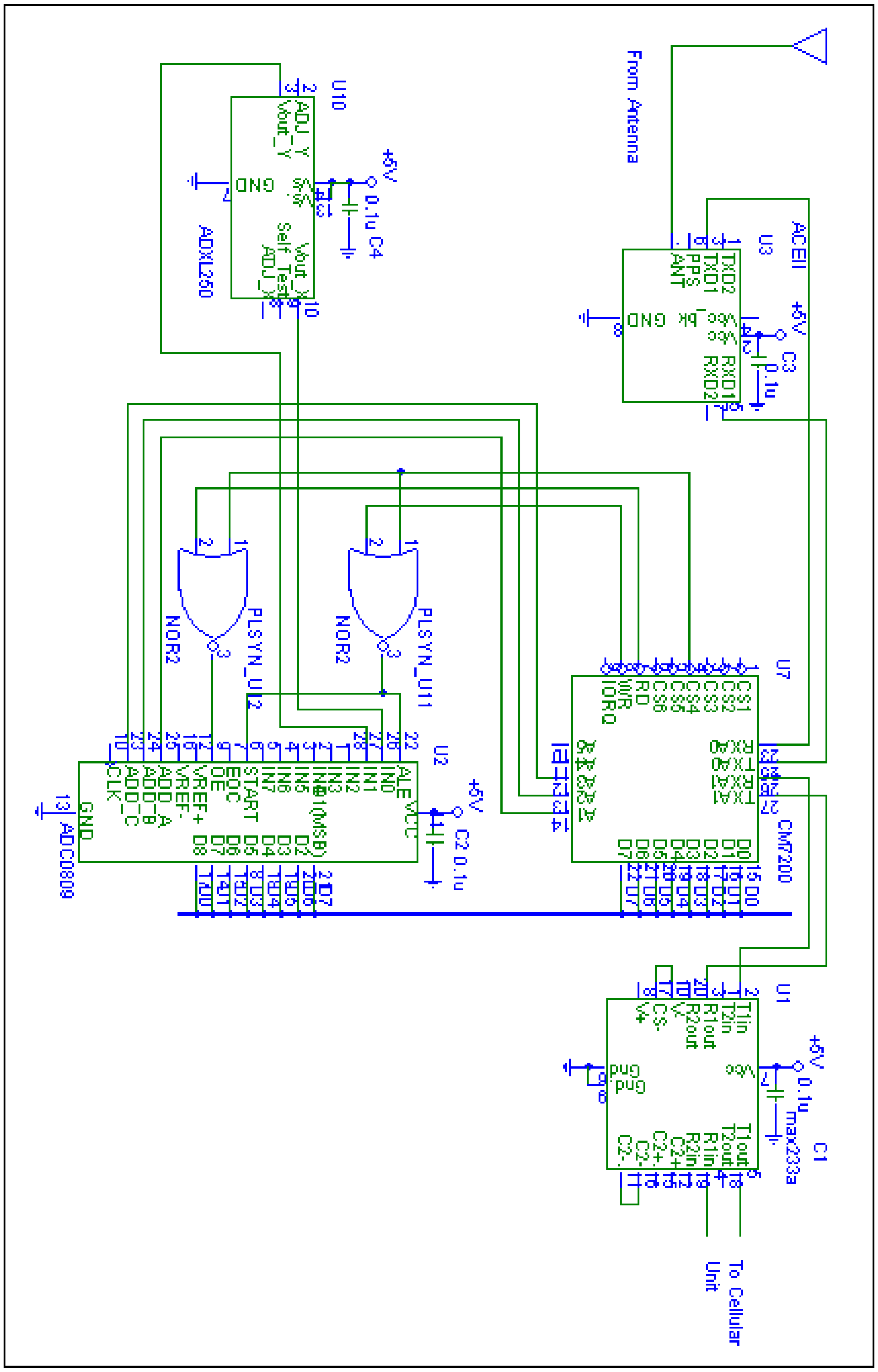


Table 5-2. Cost for ANJEL Mobile Unit, Rev. A

```
ACCEL Bill of Materials                    acn_design_b1.sch
==============================================================================================================================
Count  ComponentName   RefDes          PatternName     Value           Description                                  Cost ($)
------ --------------- --------------- --------------- --------------- ----------------------------------------------------
     1 CM7200          U1                                                  CM7200 Core module (Z180)              99.00
     1 EXPEDITE_MODEM  H2              IDC26M                              Novatel Expedite Modem                230.00
     1 ANTENNA CABLE                                                       Modem Antenna Cable                    19.99
     1 GPS_ACEII       U3              IDC8M_2MM                           GPS Unit                              160.00
     1 MAGMOUNT ANTENNA                                                    GPS Unit Antenna                       45.00

     1 74HCT02         U9              DIP14                               Quad 2-Input NOR                        0.39
     1 74HCT32         U13             DIP14                               Quad 2-Input OR                         0.41
     2 LMC662          U22, U25        DIP8                                Dual Operational OpAmp                  3.26
     1 LP339NA         U19             DIP14                               Ultra-Low Power Dual Comparator         1.40
     1 MAX232          U2              DIP16                               RS-232 Transciever                      3.31
     1 74HCT259        U12             DIP16                               8-Bit Addressable Latch                 0.85
     1 74HCT374        U8              DIP20                               Octal D-Type Register                   0.83
     1 74HCT541        U24             DIP20                               Octal Buffer/Line Driver                1.05
     2 74LVX4245       U20, U23        SOIC_24                             3.3V/5V Level Shifter                   3.34

     1 V33ZA2          U30             V33ZA2                              MOV - 26 V                              0.54
     1 LT1086          U15             TO-220                              3.6V/1.5A Low Drpt. Regulator           3.75
     1 LM2940          U16             TO-220                              5V/1A Low Drpt. Regulator               2.45
     1 NJM7809         U17             TO-220                              9V/1.5A Regulator                       0.63
     1 LM4040          U14             TO-92                               5V Precision Reference                  3.47
     3 EMI_FILTER      L1, L2, L3      SMT             10000pF             10000pf/50V EMI Filter                  2.10
     1 IND             L5              IND400          275 uH              High Current Toroid                     7.75
     1 1N5404          D1              267_03                              400V/3A Silicon Rectifier               0.05

     1 ADC0809CCNA     U4              DIP28                               8 Bit uP Compatible A/D                 6.90
     1 ADXL250_SOP     U7              SOIC_14                             Dual Axis Accelerometer                23.94
     1 SMP04           U5              DIP16                               Sample & Hold                           8.15
     1 LM34            U21             TO-92                               Temperature Sensor                      8.44
     1 MX7528          U26             DIP20                               DAC Unit                                7.11
     1 MXO45           U31             DIP8                                Crystal Oscillator (1 MHz)              2.78

     2 CAP100          C2, C3          CAP100          10 pF               10 pF/100V Ceramic Capacitor            0.38
    29 CAP200          C4,             CAP200          0.1 uF              0.1 uF/50V Ceramic Capacitor            3.48
                       C5, C6, C7, C8,
                       C9, C10, C11, C12,
                       C13, C14, C15, C16,
                       C17, C18, C19, C20,
                       C21, C24, C25, C26,
```

		C29, C31, C35, C37, C39, C42, C43, C45				
5	POLCAP	C32, C34, C41 C44, C49	CAP100RP	1 uF	1 uF/16V Tantalum	1.20
2	CAP_SMT_10UF	C48, C50	CAP_SMT_B	10 uF	10uF/16V Alum Elec. SMT	0.62
2	CAP_SMT_20UF	C27, C33	CAP_SMT_C	20 uF	20uF/16V Alum Elec. SMT	0.72
1	CAP_SMT_33UF	U27	CAP_SMT_D	33 uF	33uF/16V Alum Elec. SMT	0.42
6	CAP_SMT_100UF	C22, C23, C30, C36, C46, C47	CAP_SMT_G	100 uF	100uF/35V Alum Elec. SMT	4.80
3	RES400	R6, R7, R8	RES400	10k	Resistor 1/4W, 5%	0.18
1	RES500	R1	RES500	400	Resistor 1/4W, 5%	0.06
24	TEST_POINT	TP1, TP2, TP3, TP4, TP5, TP6, TP7, TP8, TP9, TP10, TP11, TP12, TP13, TP14, TP15 TP16, TP17, TP18 TP19, TP20, TP21 TP22, TP23, TP24	TEST_POINT		Test Points	3.52
3	JUMPER	H3, H4, H5	IDC8M_2MM		2mm 8 pin Header	2.49
1	CM7000	U1	CONN40M		40 Pin Connector for CM7200	3.63
1	26PIN_HEADER	H1	IDC26F		26 Pin Header for External Box	1.66
1	26PIN_CONN				26 Pin Connector for External Box	2.07
1	93F1233				Receptacle for outer box	30.40
1	91F8568				Plug for outer box	58.64
1	93F1233				Cable clamp for outer box	6.42
3					Heat Sink – TO220	0.96
6					Backup battery (1.2 V, 600 mAHr)	18.00
					SUB-TOTAL FOR ACN UNIT	**786.54**
3	906-3174				Square post receptacle	10.89
1	EG1957				3 pos switch	5.07
1	226-1011				Switch knob	4.55
1	APPP-001				Cigarette Adapter plug	2.25
1	EG1500				Rocker switch (Power)	1.78
					SUB-TOTAL FOR DEV UNIT	**24.54**
					TOTAL COST FOR ACN PROTOTYPE	**811.08**

ADDITIONAL COSTS INCLUDE PCB FABRICATION, RAW MATERIAL AND OTHER MECHANICAL COSTS (WASHERS, SCREWS, ETC.)

6. BASE STATION SYSTEM DESCRIPTION

In the event of a crash, the Mobile Unit will automatically notify the Base Station of the crash via a wireless communications link. The functions of the Base Station system are to (1) receive the simulated emergency call from the Mobile Unit, (2) retrieve GPS data and crash severity as transmitted by the Mobile Unit, and (3) display the location and severity of the simulated crash using computerized maps for Emergency Response Team dispatch. Design concerns include how best to present crash location and severity to the Base Station operators, and how to ensure that large numbers of calls can be handled simultaneously.

The discussion below will detail the Crash Notification Message Content, approaches for Crash location mapping, the wireless web communication strategy, and the software implementation.

Message Content

After detecting a crash, the Mobile Unit must transmit a message to the Base Station which describes the crash location and severity. Knowledge of the crash location allows the EMS center to dispatch EMS crews to rescue the crash victim. Knowledge of the crash severity provides the EMS center with an early snapshot of the seriousness and potential injury consequences of the accident. The message to the Base Station should include both these data facets as well as information detailing the time of the crash and a description of the car. Crash location can be as straightforward as the GPS location longitude and latitude. Crash severity should be provided for each crash sensor, and can be either the delta-velocity or the crash pulse along each axis. It should be noted that while inclusion of the crash pulse requires transmission of a longer message, the crash pulse typically provides sufficient information to infer whether the car struck a tree or another car (which may require additional EMS personnel). Inclusion of crash severity for each axis allows the Base Station to distinguish between frontal and the potentially more serious side impacts.

<u>Crash Location</u>
The Crash Location is the single most important data facet transmitted by the Mobile Unit. In order to extract meaning from the GPS messages sent from the Mobile Unit, the form of the data (i.e.: binary, ASCII, delimited, continuous, etc) and the interface it would require (i.e.: modem, serial port, etc) must be clearly defined. Current GPS devices provide several different options for GPS coordinate output. The most widely used format, however, is that set by the National Marine Electronics Association (NMEA). Of the three versions of the NMEA standards that were found, the NMEA 0183 was the most recent and workable. This standard, originally set for marine instrumentation, dictates both a

data and interface protocol. The NMEA transmissions consist of strings of printable ASCII characters, carriage returns, and line feeds. Comma delimited “sentences”, such as the one in Figure 6-1, are sent in succession through the serial port, typically at 4800 baud. [Trimble, 1999; Conexant, 1999]

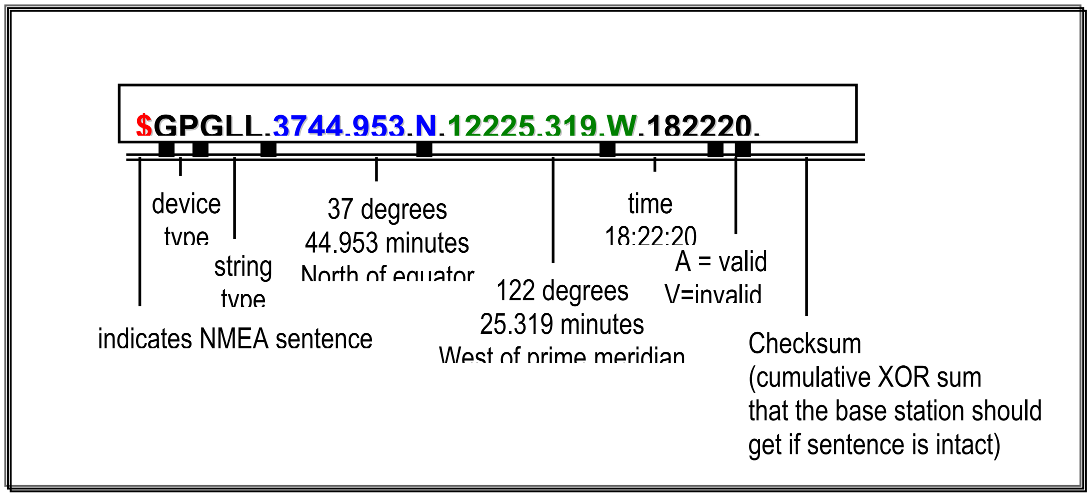

$GPGLL,3744.953,N,12225.319,W,182220,
device type
string type
indicates NMEA sentence
37 degrees 44.953 minutes North of equator
122 degrees 25.319 minutes West of prime meridian
time 18:22:20
A = valid V=invalid
Checksum (cumulative XOR sum that the base station should get if sentence is intact)

Figure 6-1. An NMEA 0183 sentence

A dollar sign indicates the start of each new sentence. It is followed by two letters indicating the transmitting device (in this case GP indicates a Global Positioning device) and then three more letters representing the sentence type. Each sentence type has specific fields of known length, separated by commas that remain in place even when a field is left empty. The GLL sentence shown here carries information about latitude in the second and third comma separated fields and longitude in the fourth and fifth fields. Initially, the first latitude field looks as if it is divided into two sections at the decimal point, when in fact, the division occurs after the second digit. This makes it read “37 degrees and 44.953 minutes.” The field directly following that indicates whether it is north or south of the equator (in this case, ‘N’ is indicative of north). The longitude fields behave in a similar way with the only major difference being that the separation comes after the third digit. So, for example, the longitude in fig. 6-1 reads “122 degrees and 25.319 minutes west of the Greenwich meridian.”

Crash Severity

One of the parameters most crucial to predicting crash victim injury level is crash severity. Crash severity is a direct measure of the mechanical forces which lead to human injury. The most important measure of impact severity is the crash acceleration / deceleration time history – frequently referred to simply as the crash pulse. If the crash pulse is known, both delta-V and other impact severity measurements such as average acceleration level can be calculated. Measurement of the crash pulse is a key instrumentation requirement of the majority of full systems laboratory crash tests.

Crash severity is computed by the Mobile Unit by analysis of the crash pulse read by the onboard crash sensors. It is this crash severity, in fact, which is evaluated to determine whether to initiate the emergency call from the Mobile Unit to the Base Station. Initial tests of the Mobile Unit have included the crash location alone. Future systems will include the delta-V and/or the crash pulse as read from each crash sensor. In these future systems, the Base Station operator will be presented with a display, not only of where the collision took place, but also with a separate display which shows the crash severity. Knowing the crash severity, the operator will then have an early warning of the expected level of injuries at the crash site.

Other Information

The message may also contain supplemental information to better identify the car to EMS personnel. Fields such as the car VIN, make, model, model year, and car color should be considered for future systems. It should be noted that many of these fields can be determined from the VIN. If VIN is available from the Mobile Unit message, future systems may be able to tie into state Vehicle Registration databases to identify the owner of the vehicle to expedite notification of family members.

Crash Location Mapping

Upon receipt of an emergency message from the field, the Base Station will present a map to the operator showing the location of the crash site. Numerous commercial GIS mapping products, e.g., ArcView, exist for providing this function. However, these packages tend to be relatively expensive. As a less expensive alternative, several consumer mapping products were investigated for their ability to provide this function. None of these packages are of course designed for Automated Crash Notification. However, they do provide a database of street-level maps for integration into a Base Station software package was written especially for this project.

Of these consumer products, the most promising programs for the Base Station application were Street Atlas, Version 8.0 by DeLorme and Mappoint 2002 by Microsoft. Both products provided the street level detail required for the Base Station operator to direct EMS teams to a crash site, and both products were capable of being controlled by an external program. Street Atlas is the mapping product used by the APRS-SA, shareware amateur packet radio location server. Mappoint 2002 provides a suite of Active-X controls which allow external program access to mapping display functions.

Wireless Communication Subsystem Design

One key enhancement of this system over existing ACN concepts is Mobile Unit-to-Base Station communication over the wireless web. Existing ACN systems are typically based upon circuit-switched communication in which the wireless network assigns a dedicated frequency to the call between the car and the Base Station. There are only a limited number of these frequencies. When they are expended, as many mobile phone users have experienced, the result is that phone calls do not connect. In the Rowan system, on the other hand, each car has a unique IP address and wireless communication is conducted using packet switching as shown in Figure 6-2. In packet-switching, the signal is divided up into individual packets of data, tagged with the address of the destination, and transmitted over a common channel shared with other users to the destination computer which reassembles the message. The result is a continuous Web connection between the Mobile Unit and the Base Station which avoids the dial-up delays which are inherent in circuit-switched designs. Unlike the circuit-switched design which has the potential for phone call contention problems, the number of accidents which can be handled by a Web based ACN Base Station is, in general, limited primarily by the bandwidth of the Base Station Internet connection.

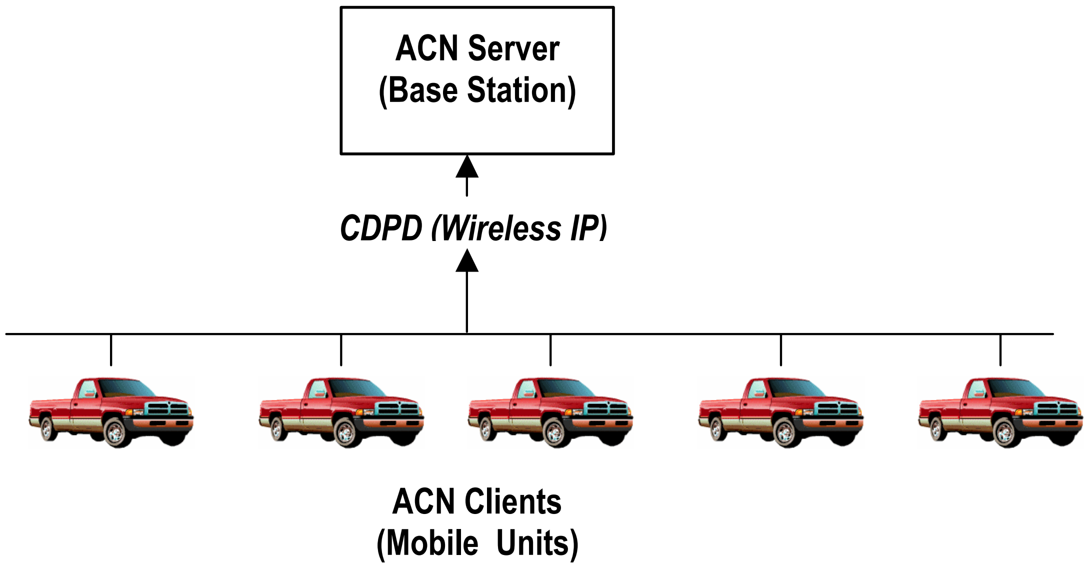


Figure 6-2. Automated Crash Notification via Wireless Web

Base Station

A Research Prototype Base Station was developed which implements the functional requirements described above. As shown in Figure 6-3, the Research Prototype consisted of a Dell Dimension 600 MHz Pentium III running Windows 98 equipped with a high speed Internet connection. In the event of a crash, the Mobile Unit and Base Station will communicate using wireless Cellular Digital Packet Data (CDPD) technology over analog cellular networks. CDPD is a new wireless Web access technology with widespread coverage in the eastern United States. CDPD allows a direct TCP/IP link to be established between the Mobile Unit and Base Station. Using CDPD, the Base Station is designed as a Web Server, and the Mobile Unit reports a crash to the Server via a wireless Internet connection. This approach allows the Base Station to monitor multiple vehicles involved in crashes without the requirement for banks of dedicated phone lines. When the Base Station receives a message from a Mobile Unit, the Base Station displays the crash location and severity on a commercially available mapping product.

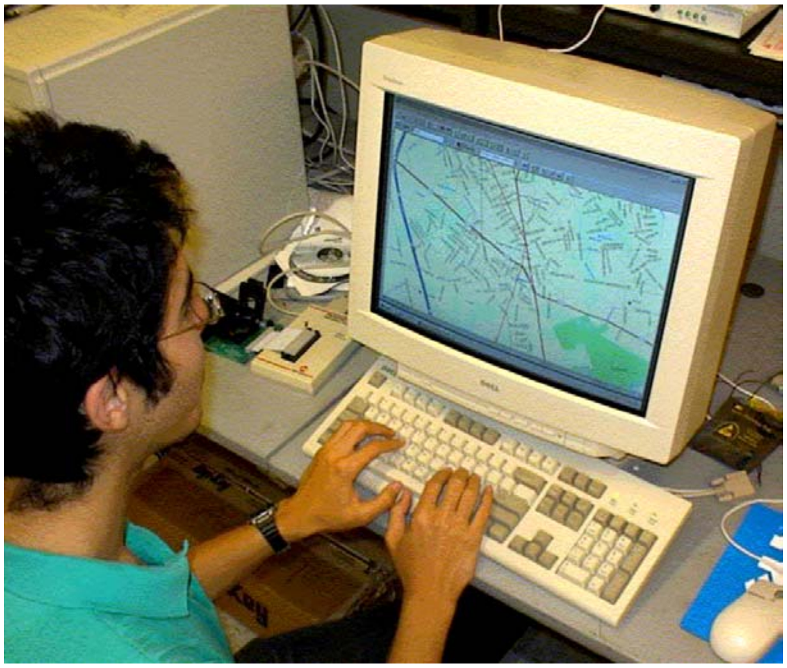


Figure 6-3. Base Station: Research Prototype

The system will use Cellular Digital Packet Data (CDPD), sometimes referred to as a Wireless IP connection, to transmit data between the Mobile Unit and the Base Station. CDPD is a cutting edge wireless communications protocol which allows direct connection of remote devices to the Internet. In addition to CDPD, the Mobile Unit has been designed for adaptation to other wireless communications options, including CDMA (Code Division Multiple Access) Data, GSM (Global System for Mobile Communications), and emerging third generation wireless protocols, e.g. GPRS (General Packet Radio Service) and W-CDMA (Wideband Code Division Multiple Access).

Software Implementation

The Research Prototype Base Station was implemented using the APRS-SA Packet Radio Location Software. APRS-SA is a shareware software package which automatically plots the location of a transmitted GPS string on maps displayed under Street Atlas 8.0. Figure 6-4 shows a map displayed by the Base Station running APRS-SA during a tracking test of the Mobile Unit near Rowan University.

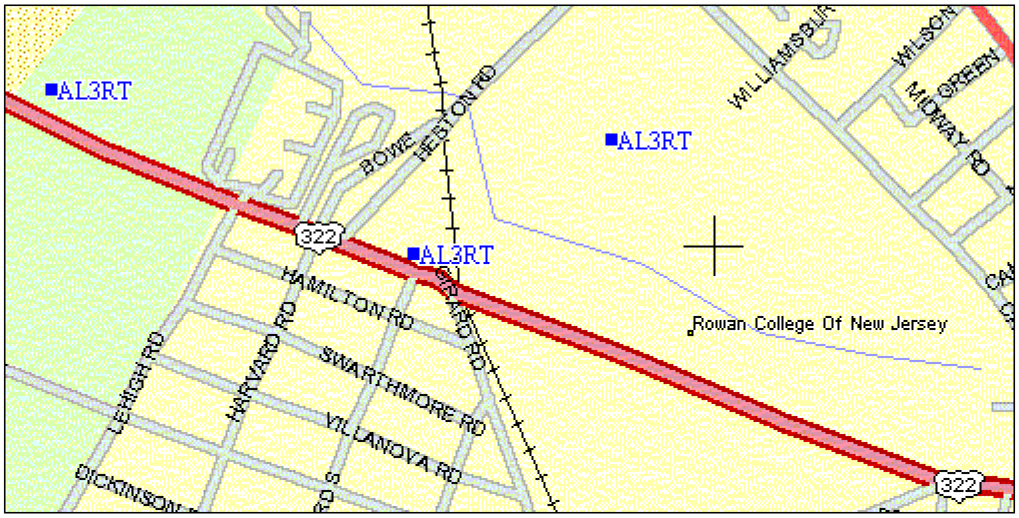


Figure 6-4. Sample Base Station Display

Normally the APRS-SA client software receives GPS strings from an APRS server via the TCP/IP protocol. In setting up APRS-SA, the user is given the option to select their APRS Server of choice. For the prototype Base Station, our approach was to develop an APRS Server look-a-like that received messages from the Mobile Units from a UDP port and served those messages to the APRS-SA client from a TCP/IP port. The messages, which were passed to APRS-SA, were formatted by our program to look like messages which would normally be received via packet radio. This approach allowed the APRS-SA program to believe that it was receiving packet radio messages when in actually it was receiving messages from a Mobile Unit.

The UDP protocol was selected for the wireless communications link between the Mobile Unit and the Base Station instead of the more typical TCP/IP. The UDP protocol does not require verification of the transmitted message packets, and hence is a faster protocol than TCP/IP. This approach removes the computational burden of verification on the limited computing resources of the Mobile Unit, and allows the Mobile Unit to transmit repeatedly to the Base Station without having to pause after each transmission and wait for an acknowledgement.

The Base Station software was initially written as a Perl script, and later rewritten as a Java application. The TCP/IP port was set as 9110, and the UDP port was 9111. The code for both versions is provided as an appendix to this report.

Future Work

The long-term objective of the ACN system is to connect the Mobile Units with existing or expanded 911 systems. However, this effort will require coordination with existing 911 system operators and careful attention to how best to present crash information graphically to operators who are more accustomed to receiving voice-only calls. The Base Station developed here will provide an early evaluation of possible 911 operator user interfaces. The Base Station may also be suitable for limited field testing of the system for captive fleets such as the State Police or NJDOT vehicles.

7. TESTING

To evaluate the performance of the ANJEL system, the Mobile Unit was subjected to a battery of tests during development. The tests included both non-impact vehicle tracking test as well as low-severity impact tests. This section describes the test strategy, test procedures, test apparatus, and test results.

Tracking Test

To check the communication between the Mobile Unit and the Base Station, the completed prototype was tested in tracking mode. In this test, the Mobile Unit and associated antennas were mounted in a car, and the Mobile Unit was switched to its special diagnostic-tracking mode. When in tracking mode, the Mobile Unit automatically reads the GPS and transmits its location every second. Note that tracking mode is a research diagnostic only: this mode will not be included in the production prototype. During the test, the car with installed Mobile Unit was driven on a 10-mile circuit around Rowan University. From the continuously updated map on the Base Station, we were able to track the student team as they drove from street to street, and were able to even identify which lot they parked in upon their return.

Low-Severity Impact Testing Objectives

The ANJEL Mobile Unit was tested in an impact test for two purposes:

(i) To check if the unit can detect a crash,
(ii) To ensure the system can survive a crash.

The goal was to evaluate the performance of the Mobile Unit in low-severity crashes. For this project, low severity was defined as that impact speed at which the airbag would normally deploy – approximately 12-15 mph. Higher severity crashes, such as the NHTSA full-barrier 30 mph crash tests are expected to result in peak decelerations of 30G or higher. Although the contractual requirements of the current project are limited to evaluation of the Mobile Unit at low-severity crashes, it is recommended that follow-on projects test the unit in higher-severity crash tests.

Micro-drop Test

A micro-drop tower design was chosen as the first impactor because of the simplicity of its design and ease of fabrication. The micro-drop tower, shown in figure 7-1, was constructed by cantilevering a rope and pulley system from the top of the Rowan Drop Tower. The Rowan Drop Tower, normally used in aircraft seat crash testing, allows freefall drops from heights up to 6 meters. The Mobile Unit enclosure was fixed to a wooden platform which could be hoisted to the desired drop height via a rope-pulley system. During free fall, the platform and attached Mobile Unit was constrained by four guide cables which passed through four eye hooks attached to the corners of the platform.

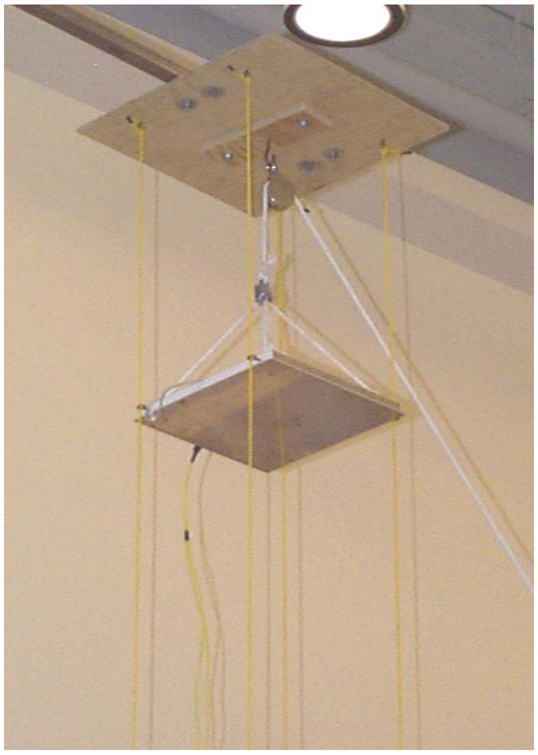


Figure 7-1. Micro-drop Tower Apparatus

Instrumentation

The fixture holding the Mobile Unit during testing was instrumented with an external accelerometer as a check against the internal Mobile Unit accelerometer. The major challenge was determining a location for the accelerometer so it would not get damaged. A second concern was how the accelerometer on a moving system would be connected to a stationary data acquisition system. The accelerometer required a constant power source and a cable for transmitting data back to the A/D board. The cable was mounted in a manner to avoid tangling during the drop tests.

Experimental Setup

The accelerometer was connected to a signal-conditioning unit through the use of an umbilical cable. The signal-conditioning unit provided the required excitation voltage to the accelerometer. The signal-conditioning system also provided signal filtering and amplification prior to input to the data-acquisition board. To implement the data acquisition system a PC was used with the DasyLab data acquisition software.

Procedure

The experimental procedure was drop the plate with accelerometer, from various heights on to different surfaces at the base. The plate was dropped from three different heights: six feet, eleven feet, and seventeen feet. Three different densities of foam, ranging from very soft to very dense, were used for the impact surface. A total of eighteen drops were performed. To evaluate test repeatability, two drops were performed for each height onto each of the foams. During testing, the accelerometer plate was pulled up to the required height, and the data acquisition system was started. The plate was then allowed to freefall onto the foam. The acceleration was recorded for each drop and plotted versus time.

Results

As shown in Figure 7-2, the drop tower was able to produce realistic accelerations when tested with the Mobile Unit enclosure. However, while the absolute acceleration levels were realistic, the results of the test were not entirely representative of an actual crash. For example, Figure 7-3 shows the results of a 1999 Dodge Intrepid frontal crash test. Comparison of the two types of tests shows that while the acceleration levels are similar the pulse shapes are quite different. This would suggest that the way the forces are applied to the test articles differs in some manner. Moreover, in the drop test, the impact speed is limited to a terminal velocity of approximately 20 miles per hour – which is at the lower range of real world injury-producing automotive crashes. Consequently, a second impactor was explored to attempt to produce more “real world” impact conditions.

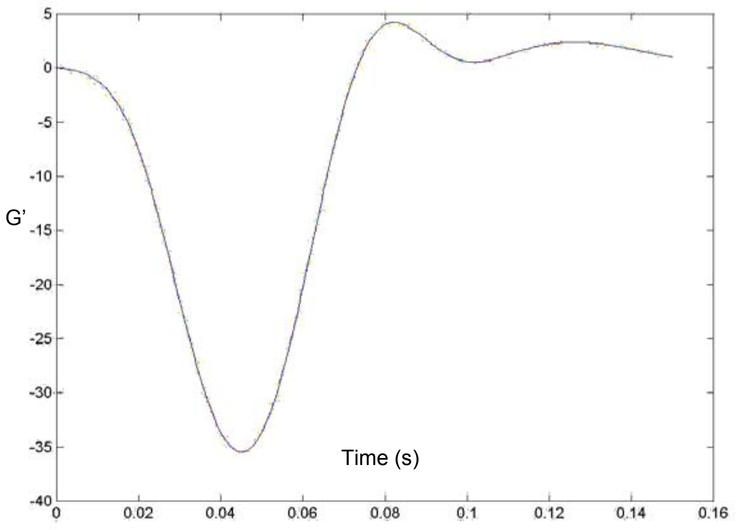


Figure 7-2. Drop tower results.

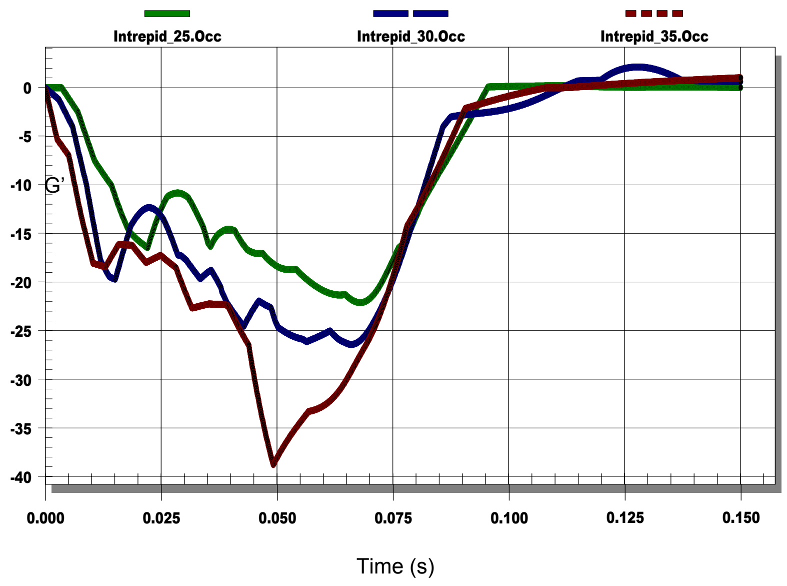


Figure 7-3. 1999 Dodge Intrepid crash pulses in Full-frontal barrier collisions at 25, 30, and 35 mph impact speeds

Mini-Sled Impactor System

To produce higher speed impacts, a bench-scale pneumatically driven sled was designed and evaluated for possible Mobile Unit testing. To accelerate the Mobile Unit enclosure, the casing was mounted on a carriage placed between two guiding rails as shown in Figure 7-4. A pneumatic cylinder was selected to generate sufficiently high forces to rapidly accelerate the Mobile Unit at target speeds up to 35 mph. Once the ACN unit had been accelerated to sufficiently high speeds, it was crashed into a stationary wall at the end of the slide. The design and construction of the required apparatus is described below:

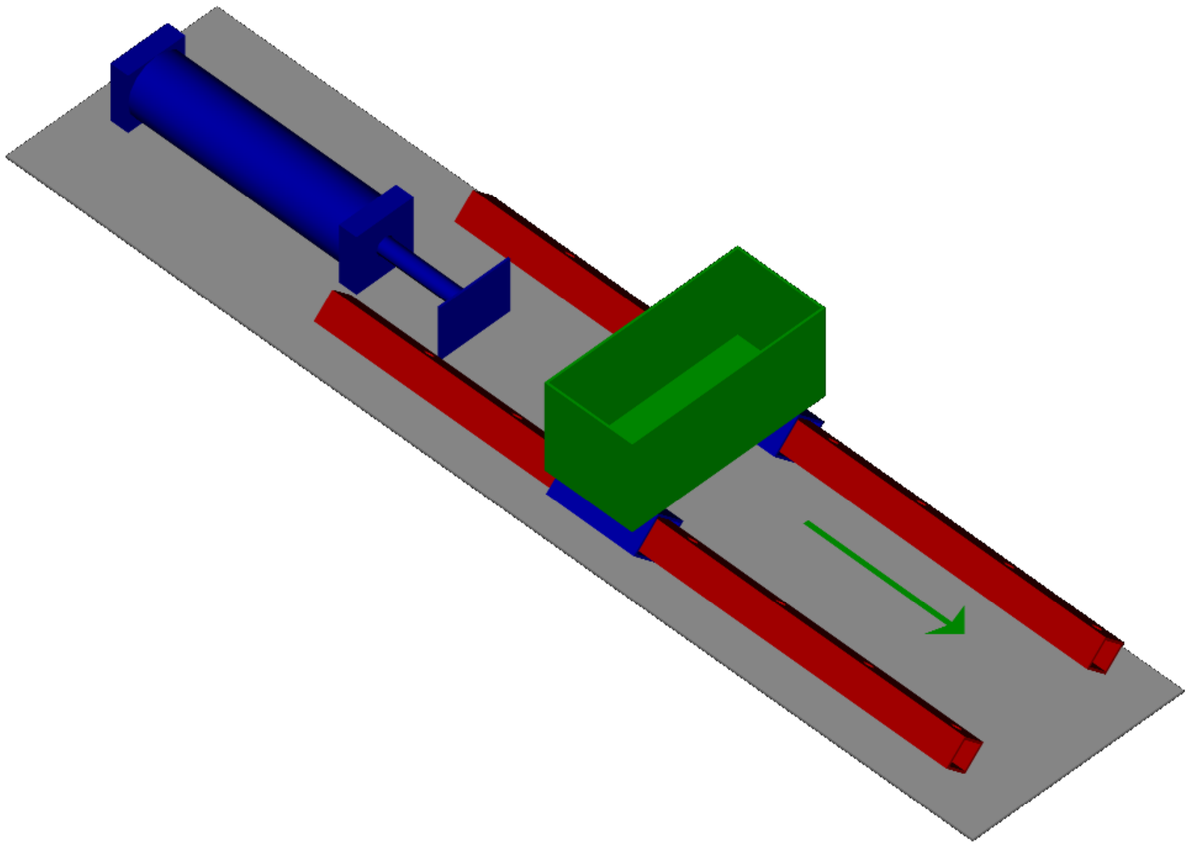


Figure 7-4. Concept Model of the Benchscale Impactor

Air Cylinder
In the design of the impactor, the biggest challenge was discovering how to accelerate the Mobile Unit until it reached a speed of about 35-mph. An air cylinder was used to accomplish this task. In choosing an air cylinder there were two selection factors: the bore size of the cylinder, and the stroke length of the piston. In the current design, the stroke length was fixed at 12 in, and the bore

size was adjusted accordingly. The major factor affecting the bore size would be the force to accelerate the load of the carriage. Using Newton's second law (F=ma), with an assumed Mobile Unit mass of 7lb$_m$ and an acceleration of 12454.28in/s^2 (30 G's), the required force was found to be 225.6 lb$_f$. In other words, the air cylinder must be able to produce a force of at least 225 lb$_f$.

The next task was accounting for any losses in the system. The work requirements for the pneumatic cylinder were computed as follows:

$$m = 7lb$$
$$V = 546.72\, in/s$$
$$W = Fx = 1/2\, mV^2$$
$$W = 2707.453 lb \cdot in$$

To account for frictional and other losses in the system, a cylinder work effiency of 50% was assumed. The process was then re-analyzed assuming polytropic work:

$$k = 1.4$$
$$v_1 = 2\pi\left(\frac{d}{2}\right)^2$$
$$v_2 = 3\pi d^2$$
$$p_1 = 110\ psia$$
$$p_2 = p_1\left(\frac{v_1}{v_2}\right)^k$$

$$\frac{W}{2} = \frac{p_2 v_2 - p_1 v_1}{1-k}$$

$$\frac{2707.453 lb \cdot in}{2} = \frac{110psia\left(\dfrac{2\pi\left(\dfrac{d}{2}\right)^2}{3\pi d^2}\right)^{1.4} * 3\pi d^2 - 110psia * 2\pi\left(\dfrac{d}{2}\right)^2}{1-1.4}$$

$$d = 2.475$$

However, in addition to accelerating the carriage up to 30g and overcoming frictional losses inside the piston, the cylinder must also ensure that the air can be evacuated prior to the next stroke (any backflow would prevent the process from being polytropic, a key assumption in the analysis above). Consequently, a larger 3-inch bore diameter cylinder was used to ensure adequacy over the test. Figure 7-5 shows the air cylinder used for the apparatus.

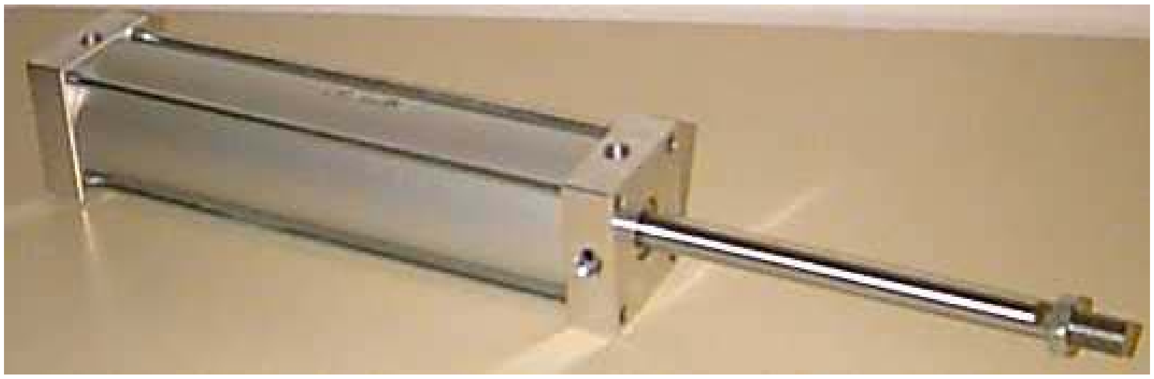


Figure 7-5. Air cylinder with a 3” bore diameter

Despite the conservative design described above, initial testing of the apparatus revealed insufficient acceleration of the Mobile Unit. To improve the impactor performance, the inside of the front plate was bored out to enhance air escape from the non-pressurized side of the cylinder. This allowed the cylinder to let out the maximum amount of air, and completed the construction of a fast acting cylinder.

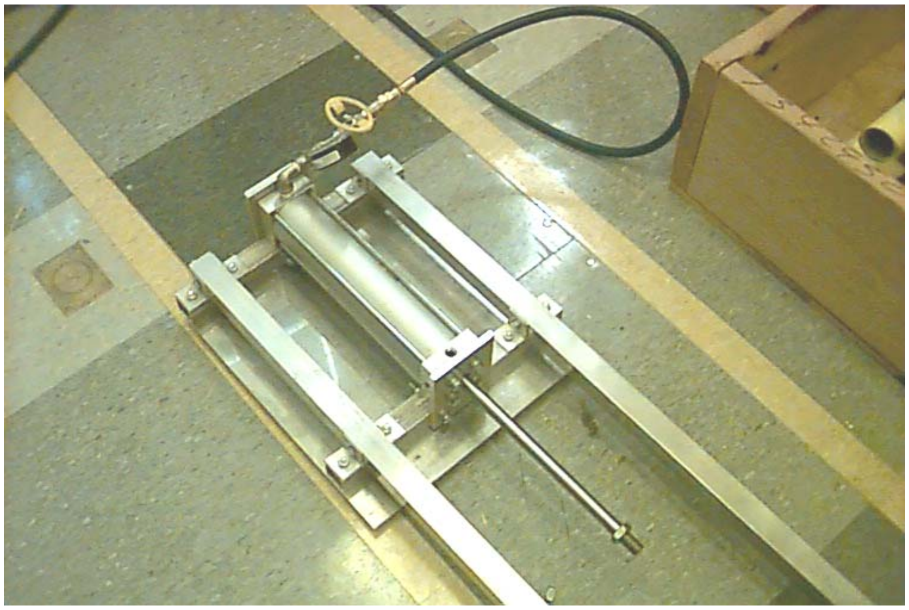


Figure 7-6. Test stand with mounted piston

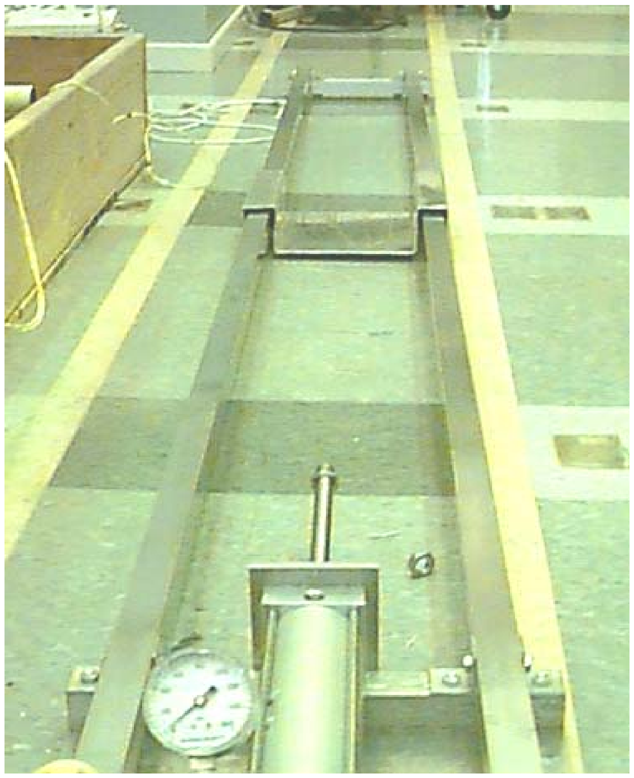


Figure 7-7. Rails mounted to test stand

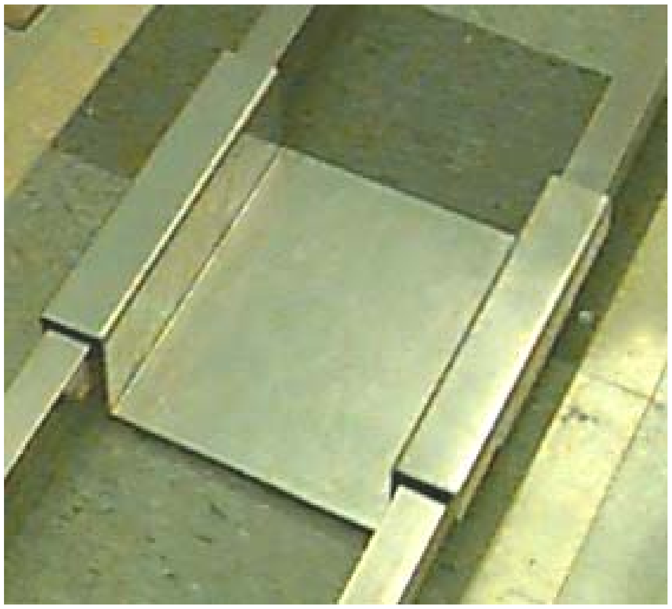


Figure 7-8. Carriage on rail system

Test Stand and Rails

The test stand is one of the most integral parts of the impactor setup. It is approximately 11 feet long, thereby allowing for 10-foot rails and a 1-foot wide cylinder. As shown in Figure 7-7, the test stand holds the cylinder in place and absorbs the recoil from firing. During testing, the test stand is constrained so that the platform does not slide along the floor. Aluminum was chosen as the material of construction. In order to ensure that the box experiences the proper acceleration forces, it is necessary to guide and support the box with as little interference as possible from the rails. Owing to its simplicity and ease of operation, a dry rail system was used. For better lubrication, the rails were polished to a smooth finish. To further reduce friction, Teflon pads were mounted on the inside of the carriage brackets.

Carriage

As shown in Figure 7-8, the carriage is supported by two brackets on either side. A common base connects the two brackets. This platform is approximately 12 inches long, and as wide as the rails dictate it to be. to reduce the friction between the support brackets and the polished rails, “felt” is glued to the inside. A wall is attached to the rear of the carriage so the ACN does not come in direct contact with the piston rod. Moreover, at the end of the rails, there will be a wall so the carriage will not experience a “metal on metal” collision.

Instrumentation

The data acquisition system consisted of the following components:

- Analog Device: ADXL150 single axis accelerometer (Figure 7-9)
- Metraplex Series 300 signal-conditioning system
- Iotech DBK11a screw terminal card
- DasyLab data acquisition software
- PC Workstation

The carriage was instrumented with an ADXL150 single axis accelerometer. The ADXL150 accelerometer was used to measure the acceleration experienced by the Mobile Unit during the impact. This accelerometer was connected via an umbilical cable to the Metraplex signal conditioning system. The signal conditioning system provides power for the accelerometer and amplifies the return signal. The output from this device will then be fed to the Iotech DBK11A screw terminal card. This is the device that will receive the conditioned, amplified signal, and in turn connect with the computer via a parallel port, sending the data to DasyLab. This data was then imported into Matlab for display. Figure 7-10 shows a block diagram of the complete system.

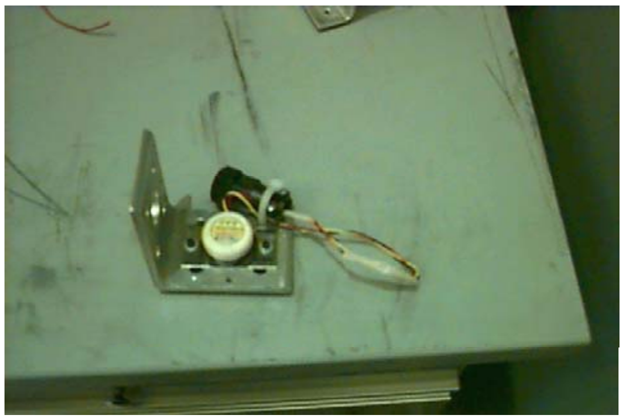


Figure 7-9. Accelerometer mounted to testing plate

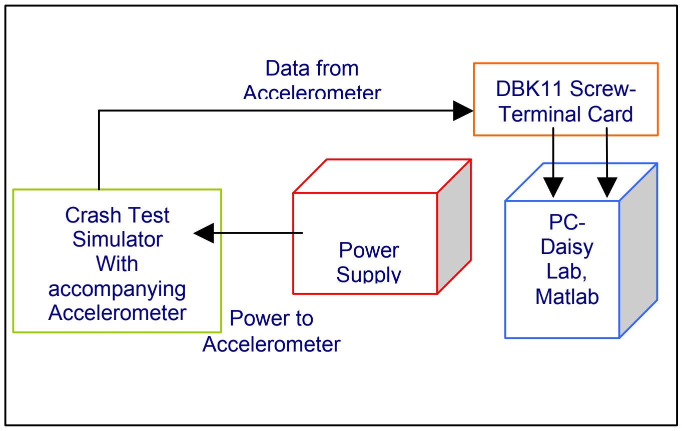

Data from Accelerometer
DBK11 Screw-Terminal Card
Crash Test Simulator With accompanying Accelerometer
Power Supply
PC-Daisy Lab, Matlab
Power to Accelerometer

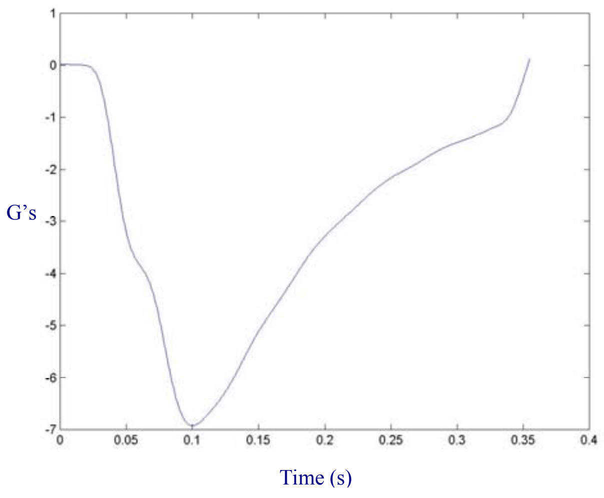
Figure 7-10. Schematic for data acquisition

<u>Results</u>

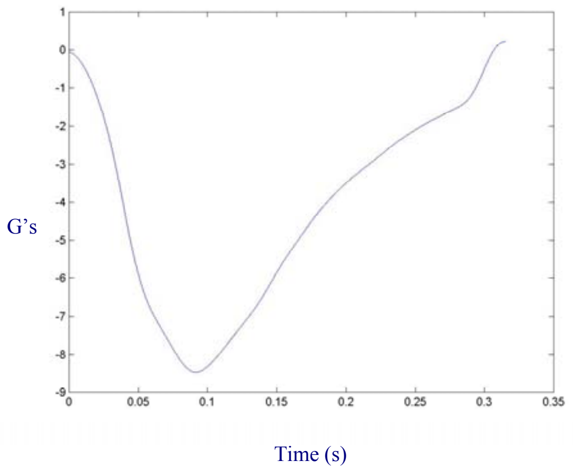
After construction of the system, a series of twelve tests were conducted. Tests were conducted with and without Teflon pads, and with and without the Mobile Unit Enclosure. A table documenting all the tests is shown in Table 7-1. An “X” denotes the use of the part, an “O” denotes the lack of the part.

Table 7-1. List of Mini-Sled Tests Performed

Trial	Teflon Pads	ACN Box
1	O	O
2	O	O
3	O	O
4	X	O
5	X	O
6	X	O
7	X	X
8	X	X
39	X	X
10	O	X
11	O	X
12	O	X

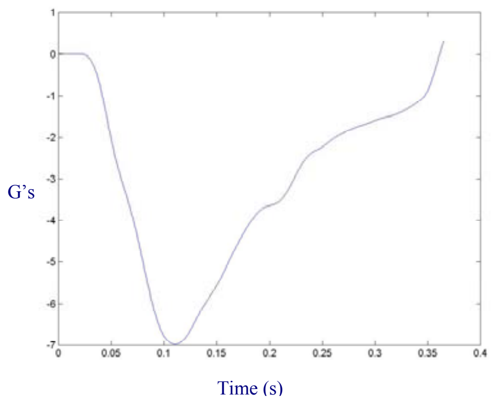


(a) Without Teflon Pads.

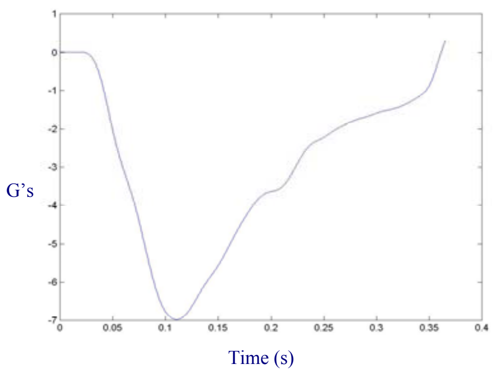


(b) With Teflon Pads.

Figure 7-11. Acceleration Pulses without the Mobile Unit Enclosure



(a) Without Teflon Pads.



(b) With Teflon pads

Figure 7-12. Acceleration Pulses with the Mobile Unit Enclosure

Graphs were obtained of the deceleration-time history of the carriage at the impact point at the end of the rails. The first two graphs were taken without the Mobile Unit Enclosure (Figure 7-11). The same tests were performed twice – first with the Teflon padding, then without. These show that only about 8 g's total acceleration was obtained. Note that the use of Teflon pads produced only moderate increases in peak acceleration. The procedure was then repeated with the ACN box (figure 7-12). Figure 7-12 shows that similar results were obtained. In all cases, peak deceleration was below 10 G.

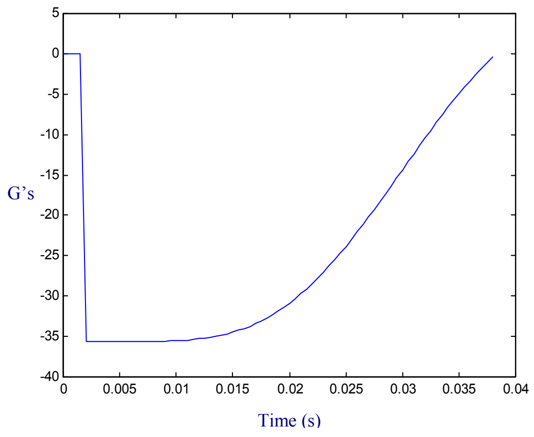


Figure 7-13. Acceleration Pulse of the Air Piston

In addition to these impact tests performed on the rails, tests were also performed on the air cylinder piston. Figure 7-13 shows that the peak acceleration of the air cylinder piston was about 35 g's. The peak was attained early in the test when air cylinder pressure was at its highest. As the piston shaft extended, the acceleration dropped back to zero as the cylinder air pressure dropped. The entire event was observed to take place in approximately 35 milliseconds.

After tests on the Mobile Unit enclosure itself were completed, a test was performed with the Rev. A Mobile Unit in place. When the Mobile Unit was plugged into the PC and slammed into the wall, the word "CRASH" appeared on the screen when appropriate, indicating the success of the system in detecting a crash. Peak deceleration during the test was observed to be 9 Gs.

Future Work

Testing of the a Mini-Sled Impactor System showed the potential for improved performance, especially in three areas:

- Rails Modifications. If an air cushion were used to carry the system, friction could be greatly reduced.

- Carriage Modifications. Bearings and rollers/wheels should be added to facilitate motion of the Mobile Unit.

- Air Cylinder Modifications. To improve the speeds achieved, more air flow should be allowed to leave the piston on the outstroke.

8. CONCLUSIONS

This project has developed a Low-Cost Automated Crash Notification System for eventual field-testing on New Jersey highways. The system was developed in response to national studies which show that nearly half of all traffic crash fatalities occur before the crash victim reaches a trauma center. Many of these deaths can be attributed to the inability of EMS personnel to locate and reach the victim during the so-called “Golden Hour” after the accident when emergency medical treatment is most effective. The goal of this project was to dramatically reduce EMS response time by developing and testing an advanced in-vehicle system that automatically transmits the location and severity of a crash to EMS personnel. Specific accomplishments of the project include:

- The project has designed, developed, and tested a low cost functional system that combines wireless communications and Global Positioning Systems with a network of inexpensive sensors for crash detection. The project has developed two Mobile Unit prototypes which have been demonstrated to communicate vehicle location to a remote Base Station via a Wireless Web communications link.

- The project has developed a Base Station based upon commercially available mapping software which has been successfully demonstrated to communicate via wireless modem with Mobile Units in the field, receive vehicle coordinates from the Mobile Unit, and automatically indicate Mobile Unit location on the Base Station system.

- Two impactors were developed for testing of the Mobile Unit: (a) a Drop Tower and (b) a Pneumatic Benchscale Impactor. Of the two the Drop Tower was found to be the more promising. The Drop Tower was found capable of producing up to 100 G’s and produced crash pulse shapes which were observed to be similar to actual rigid barrier crash tests with production passenger cars.

- In low severity impact tests, the research team has successfully tested the Mobile Unit at severities up to 9 G. These tesst were designed to evaluate the survivability of the electronics to impact as well as testing the ability of the system to detect and report collisions of this magnitude.

9. RECOMMENDATIONS

This project has successfully demonstrated the feasibility of a Low-Cost Automated Crash Notification System. The performance of both a Mobile Unit prototype and a prototype Base Station has been successfully tested in a series of laboratory low-severity impact tests. Although system performance has shown unusual promise, it must be emphasized that the systems tests have been conducted solely in a controlled laboratory setting. Prior to development of a production system, the following additional tasks are recommended:

- **Field Testing.** Future work should include a second research phase which will perform operational field testing of the ACN system. A fleet test would evaluate the performance of the system in both crash and non-crash modes, and would provide important consumer acceptance feedback from the motorists. A fleet of 1000 ACN-equipped cars could be expected to incur approximately 10 collisions per year for evaluation of the system under crash conditions. The location of the cars should be chosen to produce a fleet mix representative of the New Jersey's mix of urban and rural highways. Captive fleets such as those maintained by the New Jersey Department of Transportation or the New Jersey State Fleet would be ideal for such a field test.

- **Higher-severity impact testing.** Although the system has been demonstrated to be crashworthy in low-severity tests, we recommend that follow-on projects should conduct additional laboratory performance testing of the system at the higher impact severities attainable in staged crash tests and HyGe sled tests.

- **Integration of ACN into existing New Jersey Emergency Response Systems**. One of the most challenging and important questions confronting deployment of an Automated Crash Notification system is determining how to integrate an ACN system into existing 9-1-1 systems. Follow-on research should actively consult with the representatives of the emergency response community to address this issue.

- **Lower Cost Wireless Communication.** New 3rd Generation Wireless communications protocols will be introduced to the market in the coming months which should be actively investigated in follow-on studies. Currently, the Wireless Modem accounts for half the cost of the Mobile Unit. These newer wireless protocols have the potential to tremendously wireless communication performance and further reduce the costs of the wireless link between the Mobile Unit and the Base Station.

10. REFERENCES

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8. Conexant Systems, Zodiac GPS Receiver Family Designers' Guide (February 1999)

Appendix A: SOURCE CODE FOR THE BASE STATION PROTOTYPE

A.1 Base Station in Java

Function. The following stand-alone Java server received UDP messages from the Mobile Unit and served these messages from a TCP/IP socket to an APRS-SA client.

```
import java.net.*;
import java.io.*;

public class ACN_Server
{

        public final static int MAX_PACKET_SIZE=65507;

public static void main (String args[])
{

        System.out.println ("Base Station Server\n");

        String hostname="localhost";
        int port=8080;
        byte[] buffer = new byte[MAX_PACKET_SIZE];


//*** Setup Datagram Socket.
        try
                {
                DatagramSocket soc = new DatagramSocket (port);
                DatagramPacket thePacket =
                        new DatagramPacket (buffer, buffer.length);


        //*** Read keyboard messages and send them to the UDP Socket.
                BufferedReader in = new BufferedReader (new
InputStreamReader(System.in));
                while (true)
                        {
                        soc.receive (thePacket);
```

```
                    String s = new String(thePacket.getData(), 0,
                            thePacket.getLength());
                    System.out.println (thePacket.getAddress()
                            + " at port " + thePacket.getPort()
                            + " says " + s);
                    // reset the length for the next packet
                    thePacket.setLength(buffer.length);
                    }
            }
        catch (Exception e)
            {
            System.err.println (e);
            }
}

}
```

A.2 Simulated Mobile Unit in Java

Function. The following code was developed to allow the Base Station to be tested from a simulated Mobile Unit. The simulated Mobile Unit was a Java program running on a separate PC. This program transmitted UDP messages containing GPS coordinates to the Base Station Server.

```
import java.net.*;
import java.io.*;

public class Key2UDP
{
public static void main (String args[])
{
        System.out.println ("Mobile Unit Simulator\n");

        String hostname="150.250.105.127";    // Address of ACN-Server
        int port=8080;

//*** Setup Datagram Socket.
        try {
                InetAddress dest = InetAddress.getByName (hostname);
            System.out.println ("Destination: " + dest);
                DatagramSocket soc = new DatagramSocket ();

        //*** Read keyboard messages and send them to the UDP Socket.
        BufferedReader in = new BufferedReader (new
InputStreamReader(System.in));
                while (true)
                        {
                        String msg = in.readLine();
                        if (msg.equals(".")) break;
                        byte msgbytes[] = msg.getBytes();
                        DatagramPacket theOutput =
                                new DatagramPacket (msgbytes, msgbytes.length,
dest, port);
                        soc.send (theOutput);
                        }
                }
        catch (Exception e)
                {
                System.out.println (e);
                }
}
}
```

A.3 Base Station Server in Perl

```
#!/usr/bin/perl
`mode COM2: BAUD=19200 PARITY=N DATA=8 RETRY=N STOP=1`;
$COUNTER = 0;
$logfile = 'C:/acn/crash.log';
$crashfile = 'c:/acn/crash.txt'; # Set to '2' when an alert happens
$nemafile = 'c:/acn/gps.nmea';  # Logs all valid NEMA with GPS data

$chr10 = chr (10);
$chr13 = chr (13);



# Takes a TCP connection, echos it back - but several now!
use IO::Socket;
use IO::Select;
   open (LOGGER, ">>$logfile") or &log ('WARNING - unable to log status
msgs');
    open (NMEA, ">>$nemafile") or &log ('WARNING - unable to log NEMA
string');
$listener = IO::Socket::INET->new(Proto=>'tcp', LocalPort=>'9111',
        Listen=>10, Timeout=>500)    # Normal connect timeout = 60
  or die ('Can not open port 9111 for listening!');

$selector = new IO::Select ($listener);

&log ("STARTUP: Listening to port 9111 TCP for APRS systems");

# Set up UDP port, Add to selector here

$udp = IO::Socket::INET->new (LocalPort => '9110', Proto => 'udp',
      Reuse=>1)
      or die "Can not open UDP socket";

$selector->add($udp);
&log ("STARTUP: Listening to port 9110 UDP for Alerts");

while (@consready = $selector->can_read) {
   for my $connection (@consready) {
       if ($connection == $listener) { # Is it a new TCP connection?
          my $newconn = $connection->accept;

        # Say hi to our new friend
        $newconn->autoflush(1);
        print $newconn "# ROWAN ECE ACN PROJECT EXPERMENTAL SYSTEM /
APRS RELAY$chr13$chr10";
        $newip = $newconn->peerhost;
        $port = $newconn->peerport;
        $time = scalar(localtime);
        &log ("INFO: TCP APRS Connection from $newip port $port");


         # Add new connection to selector
```

```
                $selector->add($newconn);

       } elsif ($connection == $udp)  { # UDP connection - possible
alert?
            $connection->recv ($udpdata, 250);
            # Code to verify valid alert goes here
            my @lines = split ('\n', $udpdata);
            for my $line (@lines) {
                $line =~ s/\r//go;
                system ('echo', $line, '>', 'COM2');
                } # End for line of lines
            if ($udpdata =~
/\$\w\wGGA,(\d\d)(\d\d)(\d[\d\.]+),(\d+.\d+),(\w),(\d+.\d+),(\w),(\d).*/
io)
            { # Begin if valid GPS data
                $hour = $1; $min = $2; $sec = $3;
                $lat = $4;  $ns=$5;
                $long = $6, $ew=$7; $quality = $8;
                $ns = uc ($ns); $ew = uc ($ew);
                my $ip = $udp->peerhost;
                my $port = $udp->peerport;
                &log ("ALERT - Alert Recieved $time from $ip port
$port");
                &log ("ALERT - $ip GPS Data $lat$ns $long$ew");
                &log ("ALERT - $ip GPS Data Recorded $hour:$min:$sec
GMT");
                &log ("ALERT - $ip GPS Quality Indicator: $quality");
               # Code to write to MS's stuff goes here...


                print NMEA $udpdata;
                if ($udpdata !~ /[\n\r]$/) {print NMEA "\n";}

#                open (FLE, ">$crashfile") or &log ('WARNING - unable to
trigger MS crash system via file!');
#                print FLE "2\n"; close (FLE);
                # Code to alert all TCP via APRS goes here
#                if (int ($lat) != $lat)
#                   {$lat = sprintf ('%02d', int($lat))
#                  . sprintf('%05.2f', ($lat - int($lat)) * 100/50*30);
}
#                  else {$lat = sprintf ('%07.2f', $lat * 100);}
#                if (int ($long) != $long)
#                   {$long = sprintf ('%03d', int($long))
#                   . sprintf('%05.2f', ($long - int($long)) *
100/50*30); }
#                   else {$long = sprintf ('%08.2f', $long * 100);}
$lat = sprintf ('%07.2f',$lat);
$long = sprintf ('%08.2f',$long);

    my ($sec,$min,$hour,$mday,$mon,$year,$wday,$yday,$isdst) =
gmtime(time);
   $zulu = sprintf ('%02d%02d%02dz', $mday, $hour, $min);

               my $string1 =
"ALERT>APZ100,TCPIP*:/$zulu$lat$ns\\$long$ew" . "'TEST EXPERIMENTAL
CRASH REP. SYS.$chr10$chr13";
print "\n$string1\n";
#               my $string1 = "AL3RT>APZ100,TCPIP*:!$lat$ns\\$long$ew" .
"'TEST EXPERIMENTAL CRASH REP. SYS.$chr10$chr13";


               my @aprssystems = $selector->can_write (1);
                for my $wrcon (@aprssystems) {
                   if (($wrcon != $listener)&&($wrcon != $udp))
                    {&log ("ALERT - Notifying APRS at ", $wrcon-
>peerhost);


   print $wrcon "# ROWAN ECE ACN PROJECT EXPERMENTAL SYSTEM / APRS
RELAY$chr13$chr10";
                      print $wrcon $string1;
                    } # End if not TCP or UDP listeners
                } # End For my wrcon of aprssystems
            } # End if GGA NEMA string
            else { &log ("WARNING - Wierd UDP string from " . $udp-
>peerhost. ":" . $udp->peerport);
                   &log ("WARNING - $udpdata");
               my @aprssystems = $selector->can_write (1);
                for my $wrcon (@aprssystems) {
                   if (($wrcon != $listener)&&($wrcon != $udp))
                    {&log ("WARNING - Notifying APRS at ", $wrcon-
>peerhost);

                    $udpdata =~ s/[$chr13$chr10]//go;
                    print $wrcon "# $udpdata$chr13$chr10";

                    } # End If
                } # End For
            } # End else wierd string
         }

        else { # For TCP connections
             $connection->recv ($a, 1);
             if ($a ne undef) { # Got one in!
                  $donothing = 1;
              } # End if $a not equal to the undefined value
             else { # Close connection

                my $temp = $connection->peeraddr;
                my $ip = $connection->peerhost;
                my $left = $selector->count - 1 - 2 ;
                &log ("INFO: Closing $ip port" , $connection->peerport);

             $selector->remove ($connection);
             close $connection;
             &log ("INFO: $ip:$port gone - $left APRS client(s)
remain.");

              } # End else close connection

       } # End else character or close
   } # End for
} # End while consready

print "\nI exited wrong - timeout waiting for users, maybe?\n";
close LOGGER;
close (NMEA);

sub log {
   $time = scalar (localtime);

   print "$time: @_\n";
   print LOGGER "$time: @_\n";


}
```

APPENDIX B: SISAME MODEL OF A DODGE INTREPID

The following SISAME model was used to develop the crash detection algorithm for the Mobile Unit.

```
SISAME Input File


Run Information

  RunID=INTREPIDFF  Title=INTREPID 1999 Full Frontal Model Weight Extraction
    DimSys=Metric
    DelTOut=.0001  FinTOut=.15


Model Information

  VehID=INTREPID  Make=DODGE  Model=INTREPID  Year=1999
    Wt=1749  IniVel=40.23

    MassID=OccComp  Descr=Occupant Compartment
      Wt=1331.278

    MassID=Engine  Descr=Engine
      Wt=267.7219

    MassID=Wheels  Descr=Front Wheels/Suspension
      Wt=150

    SprID=Occ-Bar  Descr=Occ-Bar
      NegMass=OccComp  PosMass=.Barrier
      StaType=SI  SU=15410.1  ST=0
        X=           0      39.47368      78.94737      118.4211      157.8947
             197.3684      236.8421      276.3158      315.7895      355.2632
             394.7368      434.2105      473.6842      513.1579      552.6316
             592.1053      631.5789      671.0526      710.5263           750
        F=           0      9266.408      26253.13      61447.73      95652.23
             114329.7      105060.7      89819.73      97692.63      119951.4
             128010.6      152992.9        179145        188187      218022.6
             317113.6      218785.2      203735.7        188647      173571.7
      DynType=AM  MSlp=.02251986  MMax=243.0128

    SprID=Radiator  Descr=Radiator
      NegMass=Engine  PosMass=.Barrier
      StaType=SI  SU=1028.647  ST=0
        X=           0      32.14286      64.28571      96.42857      128.5714
             160.7143      192.8571           225      257.1429      289.2857
             321.4286      353.5714      385.7143      417.8571           450
        F=           0             0             0             0             0
             403.2021      1381.185      2854.973      4759.486      7668.291
             11635.49      22504.78      22504.78      22504.78      22683.99
      DynType=AM  MSlp=1.244783  MMax=22.17755

    SprID=Wheels-Bar  Descr=Wheels-Bar
      NegMass=Wheels  PosMass=.Barrier
      StaType=SI  SU=21114  ST=0
        X=           0      39.28571      78.57143      117.8571      157.1429
             196.4286      235.7143           275      314.2857      353.5714
             392.8571      432.1429      471.4286      510.7143           550
        F=           0      .4361605      .4361605      3.291417      13.88973
             36.24468      76.82959      186.8221      186.8221      186.8221
             186.8221      249.3831      666.5682      666.5682      666.5682
      DynType=AM  MSlp=8.050754  MMax=3863.411

    SprID=Firewall  Descr=Firewall
      NegMass=OccComp  PosMass=Engine
      StaType=SI  SU=877.2985  ST=0  XSlk=92.60249
        X=           0      21.78571      43.57143      65.35714      87.14286
             108.9286      130.7143         152.5      174.2857      196.0714
             217.8571      239.6429      261.4286      283.2143           305
        F=           0             0             0             0             0
                     0             0             0             0             0
             768.7556      19880.03       38992.6      58105.17      76637.24
      DynType=AM  MSlp=0  MMax=1

    SprID=Occ-Wheels  Descr=Occ-Wheels
      NegMass=OccComp  PosMass=Wheels
      StaType=SI  SU=230.3747  ST=1066.072  XSlk=5.12806
        X=           0      7.276681      14.55336      21.83004      29.10672
             36.38341      43.66009      50.93677      58.21345      65.49013
             72.76681      80.04349      87.32017      94.59685      101.8735
        F=           0             0             0             0             0
                     0             0             0             0             0
                     0             0             0             0             0
      DynType=AM  MSlp=0  MMax=1

    SprID=Wheels-Eng  Descr=Wheels-Eng
      NegMass=Wheels  PosMass=Engine
      StaType=SI  SU=62.11453  ST=293.0707  XSlk=21.9767
        X=           0      8.851277      17.70255      26.55383      35.40511
             44.25638      53.10766      61.95894      70.81022      79.66149
             88.51277      97.36405      106.2153      115.0666      123.9179
        F=           0             0             0             0             0
                     0             0             0             0      244.4115
             794.2044      1343.997      1632.624      1632.624      1632.624
      DynType=AM  MSlp=1.417269  MMax=420.6391


Output Information

  OutClass=MassTS  Qty=AVD  Mass=*


Comments
```

APPENDIX C: SOURCE CODE FOR THE MOBILE UNIT PROTOTYPE

1. A_DACN.cpp

```
//This program tests the A/D and outputs the value read to the
//  serial port for reading with the hyper terminal

#define IBAUD0 4800/1200         // baud rate
#define IBAUD1 9600/1200
                      // with modem either 2400 or 1200
                      // without modem => 19200,9600, 4800, etc
#define TBUFSIZE 384             // size of transmit buffer
#define RBUFSIZE 384             // size of receive buffer

#define CS4 0x40C0
#define CS5 0x4100

char MODE = 4;                   // 8 data, no parity, 1 stop
char NO_MODEM = 0;               // we don't want modem
char ECHO  = 1;                  // we do want character echo

main(){

unsigned int input,upper,lower,i;
int j,h;
int  count;
char tbuf[TBUFSIZE];        // transmit buffer
char rbuf[RBUFSIZE];        // receive buffer
char buf[RBUFSIZE+1];       // dummy buffer for receiving a
                            //complete command
char buf2[RBUFSIZE+1];
char output[3];
char reference[16];

//allows serial port 0 to work.
#if ROM==0
     reload_vec(14, Dz0_circ_int);
#endif

Dinit_z0(rbuf,tbuf,RBUFSIZE,TBUFSIZE, MODE, IBAUD0, NO_MODEM,
ECHO );
Dinit_z1(rbuf,tbuf,RBUFSIZE,TBUFSIZE, MODE, IBAUD1, NO_MODEM,
ECHO );

reference[0] = '0';
reference[1] = '1';
reference[2] = '2';
reference[3] = '3';
reference[4] = '4';
reference[5] = '5';
reference[6] = '6';
reference[7] = '7';
reference[8] = '8';
reference[9] = '9';
reference[10] = 'A';
reference[11] = 'B';
reference[12] = 'C';
reference[13] = 'D';
reference[14] = 'E';
reference[15] = 'F';

input=0;

     for(;;){        // endless loop constantly monitoring for
                     // new command line
          runwatch();
          hitwd();

          //hold value
          outport(CS5+4 ,1);

          //begin conversion to A/D
          outport(CS4+3,0);

          //wait for A/D to finish converting
          for(i=0;i<1000;i++);

          //read A/D
          input = inport(CS4+3);

          //release held value
          outport(CS5+4 ,0 );

          //compute hex values
          upper = input/16;
          lower = fmod(input,16 );

          //assign hex values
          output[0] = reference[upper];
          output[1] = reference[lower];
          output[2] = ' ';

          //write value to serial port
          Dwrite_z1( output, strlen(output) );

          }

}
```

2. CDPD_GPS.cpp

```
//This program sends data through the CDPD
//This program takes the serial data from GPS in from port 0
//  and outputs it to port 1 for the CDPD to transmit.

#define IBAUD0 9600/1200          // baud rate
#define IBAUD1 9600/1200
                     // with modem either 2400 or 1200
                     // without modem => 19200,9600, 4800, etc
#define TBUFSIZE 384              // size of transmit buffer
#define RBUFSIZE 384              // size of receive buffer

char MODE = 4;                    // 8 data, no parity, 1 stop
char NO_MODEM = 0;                // we don't want modem
char ECHO  = 1;                   // we do want character echo

main(){

int  i,j,h;
int  count;
char tbuf[TBUFSIZE];         // transmit buffer
char rbuf[RBUFSIZE];         // receive buffer
char buf[RBUFSIZE+1];        // dummy buffer for receiving a
                             // complete command
char buf2[RBUFSIZE+1];

//allows serial port 0 to work.
#if ROM==0
      reload_vec(14, Dz0_circ_int);
#endif

// communication with Dynamic C is lost when the Z1 port is
// initialized

      Dinit_z0(rbuf,tbuf,RBUFSIZE,TBUFSIZE, MODE, IBAUD0,
NO_MODEM, ECHO );
      Dinit_z1(rbuf,tbuf,RBUFSIZE,TBUFSIZE, MODE, IBAUD1,
NO_MODEM, ECHO );

      for(;;){               // endless loop constantly monitoring
                             // for new command line
            runwatch();
            hitwd();

            if( Dread_z0(buf,ENTER) != 0 ){        // wait for
string terminated with CR
                  Dwrite_z1( buf, strlen(buf) );
            }
      }
}
```

3. crastest.cpp

```
//physical crash test code
//ACN Rowan University

// # define sets named constants
#define IBAUD 19200/1200   // baud rate
                      // with modem either 2400 or 1200
                      // without modem => 19200,9600, 4800, etc
#define TBUFSIZE 384             // size of transmit buffer
#define RBUFSIZE 384             // size of receive buffer

char MODE = 4;                   // 8 data, no parity, 1 stop
char NO_MODEM = 0;               // we don't want modem
char ECHO  = 1;                  // we do want character echo

#define CS4 0x40C0
#define CS5 0x4100
#define ticks 461                // (18.432 MHz/20)* 0.001
//#define ticks 921              // (18.432 MHz/20)* 0.001

void PRT0_init(int tc);

int status;

main()
{

      unsigned int input,upper,lower;
      char tbuf[TBUFSIZE];       // transmit buffer
      char rbuf[RBUFSIZE];       // receive buffer
      int circbuffer[50];
      int runningtotal;
      int index;

      int crash;
      int i;
// declare an array coordinate of size 1 greater than buffer
      char coordinate[RBUFSIZE+1];
      int time_index;
      int maxruntotal;
      int minruntotal;
      int maxruntotal_bk;
      int minruntotal_bk;
      char output[7];
      char reference[16];

      // fill reference array with some values
      reference[0] = '0';
      reference[1] = '1';
      reference[2] = '2';
      reference[3] = '3';
      reference[4] = '4';
      reference[5] = '5';
      reference[6] = '6';
      reference[7] = '7';
      reference[8] = '8';
      reference[9] = '9';
      reference[10] = 'A';
      reference[11] = 'B';
      reference[12] = 'C';
      reference[13] = 'D';
      reference[14] = 'E';
      reference[15] = 'F';

      //runningtotal = 0;

      runningtotal = 6375;
      maxruntotal = runningtotal;
      minruntotal = runningtotal;

      status = 0x0000;
      coordinate[0]='c';
      coordinate[1]='r';
      coordinate[2]='a';
      coordinate[3]='s';
      coordinate[4]='h';
      coordinate[5]=' ';
      coordinate[6]='\0';

      PRT0_init(ticks);
      // Initializes Port 1 of the Z180 for writing
      Dinit_z1(rbuf,tbuf,RBUFSIZE,TBUFSIZE, MODE, IBAUD,
NO_MODEM, ECHO );
      input = 0;
      index = 0;
      time_index = 0;
      crash = 0;
      for (i=0; i<50; i++)
      {
            circbuffer[i] = 128;
      }

      runwatch();

      while(1)
      {
            hitwd();

            //hold value
```

```
           outport(CS5+4 ,1);

           //begin conversion to A/D
           outport(CS4+1,0);

           //wait for interrupt
           while(status != 0x0100);

           //read A/D value
           input = inport(CS4+1);

           status = 0x0000;

           //release held value
           outport(CS5+4 ,0 );

           //place algorithm here
           runningtotal = runningtotal + input -
circbuffer[index];
           if (runningtotal > maxruntotal)
           {
                maxruntotal = runningtotal;
           }
           if (runningtotal < minruntotal)
           {
                minruntotal = runningtotal;
           }

           if (time_index == 2000)
           {
                // Reduce values to under 255
                maxruntotal_bk = maxruntotal;
                minruntotal_bk = minruntotal;

                maxruntotal = maxruntotal / 100;
                minruntotal = minruntotal / 100;

                upper = minruntotal/16;
                lower = fmod(minruntotal,16 );

                //assign hex values
                output[0] = reference[upper];
                output[1] = reference[lower];
                output[2] = ' ';

                upper = maxruntotal/16;
                lower = fmod(maxruntotal,16 );

                //assign hex values
                output[3] = reference[upper];
                output[4] = reference[lower];
                output[5] = ' ';
```

```
            output[6] = '\0';

            //write value to serial port
            Dwrite_z1( output, strlen(output) );
            Dz1send_prompt();

            time_index = 0;

            if (crash == 1)
            {
                Dwrite_z1( coordinate, strlen(coordinate));
                Dz1send_prompt();
            }
            maxruntotal = maxruntotal_bk;
            minruntotal = minruntotal_bk;
        }

        //if( (runningtotal < 110 ) || (runningtotal > 139) )
        if( (runningtotal < 5610 ) || (runningtotal > 7089) )
        {
            crash = 1;
        }

        circbuffer[index] = input;
        index++;
        time_index++;
        if( index == 50 )
        {
            index = 0;
        }
    }
}

void PRT0_init(int load_value)
{
    DI();
    outport( TCR,    inport(TCR) & '\B11101110');
    // inhibit TIMER0 interrupt
    outport( TMDR0L, load_value   );
    outport( TMDR0H, load_value >> 8);
    outport( RLDR0L, load_value   );
    outport( RLDR0H, load_value >> 8 );
    outport( TCR,    inport(TCR) | '\B00010001');
    EI();
}

#INT_VEC PRT0_VEC ISR_readAD

interrupt ISR_readAD()
{
    inport(TCR);
    inport(TMDR0L);
```

```
      status = 0x0100;
}
```

4. fullprog_mod.c

```
//ACN Rowan University
//this program is the first complete alpha prototype program for
//ACN
//Z1 writes Z0 reads

void PRT0_init(int tc);
void crashtransmission();

#define IBAUD 19200/1200   // baud rate
                      // with modem either 2400 or 1200
                      // without modem => 19200,9600, 4800, etc
#define TBUFSIZE 384             // size of transmit buffer
#define RBUFSIZE 384             // size of receive buffer

char MODE = 4;                   // 8 data, no parity, 1 stop
char NO_MODEM = 0;               // we don't want modem
char ECHO  = 1;                  // we do want character echo

#define CS4 0x40C0
#define CS5 0x4100
#define ticks 921 // ((18.432mhz/20)* 0.001)

char buf[RBUFSIZE+1];
// dummy buffer for receiving a complete command
int status;

main(){

      unsigned int input,upper,lower;
      int  i;
      int  j;
      char tbuf[TBUFSIZE];       // transmit buffer
      char rbuf[RBUFSIZE];       // receive buffer
      int circbuffer[50];
      int runningtotal;
      int index;
      char coordinate[RBUFSIZE+1];

      status = 0x0000;
      runningtotal = 0;
      index = 0;

      //allows serial port 0 to work.
      #if ROM==0
           reload_vec(14, Dz0_circ_int);
      #endif

      //initialize interrupt
      PRT0_init(ticks);
      //initialize serial ports
      Dinit_z1(rbuf,tbuf,RBUFSIZE,TBUFSIZE, MODE, IBAUD,
NO_MODEM, ECHO );
      Dinit_z0(rbuf,tbuf,RBUFSIZE,TBUFSIZE, MODE, IBAUD,
NO_MODEM, ECHO );

      input = 0;
      j = 0;

      while(1){
            runwatch();
            hitwd();


                  //hold value
                  outport(CS5+4 ,1);

                  //begin conversion to A/D
                  outport(CS4,0);

                  //read buffer for new coordinates
                  if( Dread_z0(buf,ENTER) != 0 ){
                        while(j<RBUFSIZE+1){
                              coordinate[j] = buf[j];
                              j = j+1;
                        }
                  }

                  //wait for interrupt
                  while(status != 0x0100);

                  //read A/D value
                  input = inport(CS4);

                  //return status register to normal and awaiting
                  // the next interrupt
                  status = 0x0000;

                  //release held value
                  outport(CS5+4 ,0 );

                  //place algorithm here
                  runningtotal = runningtotal + input -
circbuffer[index];
                  if((runningtotal<110 ) || (runningtotal>139) ){
                        crashtransmission();
                  }
                  circbuffer[index] = input;
```

```
                index++;
                if (index == 50){
                     index = 0;
                }
     }
}


//this is the initialization function for the programable
// interrupt
void PRT0_init(int load_value){
     DI();
     outport( TCR,    inport(TCR) & '\B11101110');
     // inhibit TIMER0 interrupt
     outport( TMDR0L, load_value   );
     outport( TMDR0H, load_value >> 8);
     outport( RLDR0L, load_value   );
     outport( RLDR0H, load_value >> 8 );
     outport( TCR,    inport(TCR) | '\B00010001');
     EI();
}



//this points the interrupt vector to the interrupt handler
#INT_VEC PRT0_VEC ISR_readAD

//this is the interrupt handler
interrupt ISR_readAD(){

     inport(TCR);
     inport(TMDR0L);

     status = 0x0100;
}

//this function calls the CDPD and transmits the gps coordinates
void crashtransmission(){

     //disable all interrupts
     DI();

     //wake up CDPD
     outport(CS5+1,1);

     //begin and continously transmit
     while(1){
          Dwrite_z1( buf, strlen(buf) );
     }

}
```