2003-01-3010

Development of an Enhanced Emergency Locator Transmitter for General Aviation

Hampton C. Gabler, David Browning, and John Schmalzel
Rowan University

ABSTRACT

This paper describes the development of an Enhanced Emergency Locator Transmitter (E^2LT) for general aviation craft. The E^2LT will supplement existing Emergency Locator Transmitter systems which broadcast a simple radio beacon in the event of an aircraft crash. Unlike existing devices, however, the E^2LT device will transmit the crash site location and crash severity directly to Emergency Response Teams. The paper describes the design, development, and testing of an advanced emergency location system that combines inexpensive crash sensors, Web-enabled wireless communications and Global Positioning Systems to transmit crash site location to an Emergency Base Station. The purpose of the system is not only to shorten the time it takes for authorities to respond to the crash site, but to improve the quality of the response.

INTRODUCTION

The Federal Aviation Administration requires that all general aviation aircraft have an Emergency Location Transmitter (ELT) on board before they can be registered or authorized for flight. An ELT is designed to transmit a radio beacon when an aircraft is involved in a crash. First generation ELTs (TSO-91a compliant) transmit at 121.5 MHz while the newest ELTs (TSO-C126 compliant) transmit at 406 MHz. Once an ELT has been activated, Search and Rescue (SAR) aircraft and ground teams are dispatched to locate and aid the crash survivors.

Over 10,600 lives have been saved worldwide since the deployment of this successful system. However, Search and Rescue teams face serious challenges when searching for an ELT beacon. The first problem is false alarms. It has been estimated that only 1 in 1000 ELT beacons at 121.5 MHz are triggered by aircraft crashes. The remainder are false alarms triggered by events such as a hard landing, equipment malfunction, or inadvertent manual activation. The result is that Search and Rescue teams expend a great deal of time tracking down non-emergency activated ELTs.

Figure 1. The objective of the E^2LT System is to reduce Emergency Response Times

The second issue is that current ELT technology does not permit a pinpoint determination of the crash site or ELT beacon. The National Transportation Safety Board estimates that the position accuracy with newer units (TSO C126-compliant) is only 1 to 3 nautical miles compared to 12 to 16 nautical miles for older units [NTSB, 2000]. Newer models transmitting at 406 MHz may eventually encode GPS-location in the beacon, but this technology is not yet widespread. Currently, target accuracy yields search areas of about 12.5 square nautical miles for new units compared to 450 square nautical miles for older units.

Even for newer units, this is a large area to search in a timely fashion. In an actual crash, the speed with which the crash victims receive Emergency Medical Services is critical. Physicians speak of the "Golden Hour" during which emergency medical treatment is most effective. Clearly, any system which can improve the emergency medical team response time will reduce the risk of fatality from an aircraft crash such as shown in Figure 1.

The idea behind the system described in this paper is to take advantage of emerging new silicon accelerometers, embedded GPS chipsets, and inexpensive wireless modems to develop an Enhanced Electronic Location Transmitter (E^2LT) which dramatically improves upon the performance of existing ELT devices. The E^2LT will be designed to assist emergency response teams in three important ways.

- Improved Crash Location. The first objective is to provide a more refined fix on crash location. When combined with automated mapping tools showing the highway network, the E^2LT will allow Emergency Medical Services (EMS) personnel in some cases to dispatch Search and Rescue teams directly to the crash site by ground transportation.

- Improved Crash Detection. The second objective is to reduce the number of false alarms. Because the E^2LT transmits both crash site and crash severity, EMS dispatch personnel will know the severity of the crash before Search and Rescue personnel are dispatched. Although all ELT beacons – whether false or legitimate – must be investigated, emergency dispatch personnel can forewarn Search and Rescue Teams of what to expect.

- Scalability to Large Fleets. The third advantage is that emergency location transmissions take place over the Internet. The wireless communications protocol described below establishes a direct Internet connection between the onboard E^2LT unit and the EMS dispatch center. Because of the high bandwidth of the Internet, emergency message congestion is eliminated, and Search and Rescue Teams can readily handle multiple emergency requests.

OBJECTIVE

The goal of this paper is to describe the development of an Enhanced Emergency Locator Transmitter (E^2LT) for general aviation craft. The paper describes the design, development, and testing of an advanced emergency location system that combines inexpensive crash sensors, Web-enabled wireless communications and Global Positioning Systems to transmit crash site location to an Emergency Base Station.

SYSTEM REQUIREMENTS

The E^2LT system is composed of two major subsystems: (1) the Mobile Unit which is installed onboard the aircraft, and (2) the Base Station which is responsible for receiving distress calls from the Mobile Units and reporting their location to EMS 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 2 presents the system architecture of the mobile device. The system consists of a single chip embedded microprocessor which is connected to a crash sensor, a Global Positioning System (GPS) receiver, and an embedded wireless modem. In the event of a crash, the crash sensor(s) will detect the aircraft impact, and output a signal proportional to the deceleration of the aircraft. 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 crash, the microprocessor will poll the GPS receiver to determine the final resting position of the aircraft. The microprocessor will then use its embedded wireless modem to establish a communications link with the E^2LT Base Station. Once a link has been established, the onboard E^2LT Mobile Unit will transmit crash site location and the crash pulse to the E^2LT 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.

Crash Survivability

The Mobile Unit must be capable of surviving and properly functioning after a crash. The E^2LT was designed to meet the TSO requirements for crash survivability of ELTs. The following impact survivability requirements for ELTs are specified by TSO-C91A and TSO-C126 (FAA, 1992):

- Penetration Test – In this test, a hardened steel spike of mass 25kg is dropped onto the ELT.

- Impact of 100 G for 23 $\pm$ 2 milliseconds

- Impact of 500 G for 4 $\pm$ 1 milliseconds

After each of these tests, the TSO guidelines require that the system must successfully operate when activated.

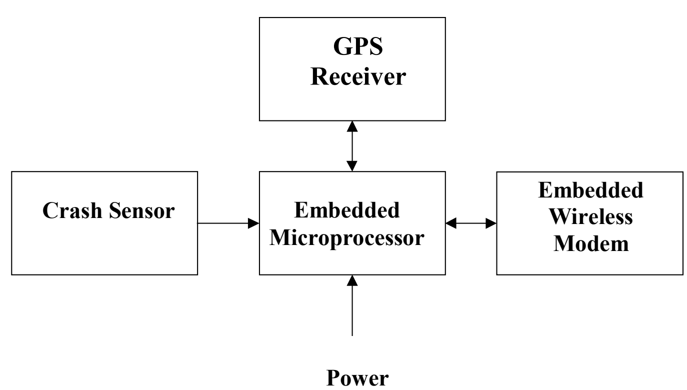

Figure 2. Mobile Unit Architecture

BASE STATION

The Base Station system will (1) receive the emergency call from 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 Mobile Units. Note that the prototype Base Station is intended only for laboratory use: it is not intended for use as a production system.

SYSTEM DESCRIPTION

This section describes the design of the E^2LT Mobile Unit and Base Station. Results of performance tests to date are presented.

MOBILE UNIT

The E^2LT Mobile Unit, shown in Figure 3, contains a two-axis silicon accelerometer, embedded 12-channel GPS system, embedded MicroChip PIC-17 microcontroller, and embedded wireless modem. All components are mounted on a custom printed circuit board which was designed at Rowan University, and constructed by a commercial fabrication facility.

Figure 3. Mobile Unit showing internal electronics

Crash Detection. Crash detection is performed with an array of accelerometers. Detection of longitudinal impacts requires an accelerometer aligned with the longitudinal axis of the aircraft (x-axis) while detection of vertical impacts requires an accelerometer aligned with the vertical axis of the aircraft (z-axis). In the case of angled impacts, the Mobile Unit would detect accelerations along both axes. The longitudinal and vertical components of deceleration are typically the most severe in an aircraft crash. In the interest of developing an inexpensive Mobile Unit, the project focused exclusively on detection of these dominant impact directions. Future systems may choose to add additional sensors for the detection of side (y-axis) impacts and the aircraft rotational orientation (yaw, pitch, and roll) – at an incremental cost to the Mobile Unit.

The system uses the Analog Devices ADXL-250, a low-cost crash sensor. 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 receiver. The system uses the Conexant Zodiac System, a low-cost embedded GPS receiver. This receiver can provide location resolution under 10 meters. The Zodiac system can receive up to 12 channels, and has onboard algorithms to improve location determination in difficult topographies such as urban canyons and under dense foliage.

Wireless Communications Transceiver. The system uses the Cellular Digital Packet Data (CDPD) protocol to transmit from the E^2LT Mobile Unit to the Base Station. CDPD is a cutting edge wireless communications protocol which allows direct connection of 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 microcontrollers 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 E^2LT system.

Power. Power for this system is provided by a long life battery pack. Future systems will recharge the battery pack through a connection with the aircraft's onboard electrical system. To isolate the E^2LT from the aircraft, this will be the only interconnection between the E^2LT and the plane. Power from the aircraft will be conditioned as necessary before input to the E^2LT electronics.

Manual Activation / Shutoff. An external switch is provided to allow the Mobile Unit to be powered down. An internal switch is provided to allow direct transmission of GPS coordinates over the CDPD modem for tracking purposes. Future systems will include an external switch to allow manually activation of the Mobile Unit.

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 non-crash events such as hard landings. To detect a crash, the microprocessor samples the accelerometer output at 1000 Hz (1 sample per millisecond). The current crash algorithm triggers the E^2LT when two consecutive acceleration measurements which exceed 2G's are read on a single channel.

Future projects will investigate the development of an improved algorithm which uses the crash signature (crash pulses) measured by the accelerometers to differentiate between crash and non-crash events. To support this effort, crash pulses can be obtained from full fuselage vertical drop tests such as those conducted by the Federal Aviation Administration [Abramowitz et al., 1999]. However, this effort also requires access to deceleration pulses from normal and hard landings. To the knowledge of the research team, no such data is available and would needed to be developed through measurement of aircraft deceleration during actual landings.

BASE STATION

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 aircraft accidents 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.

WIRELESS WEB COMMUNICATION

One key feature of this system is Mobile Unit-to-Base Station communication over the wireless Web. Traditional wireless technology is based upon circuit-switched communication in which the wireless network assigns a dedicated frequency to the call between the aircraft 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 University system, on the other hand, each aircraft has a unique IP address and wireless communication is conducted using packet switching. 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.

Wireless Data Protocol. The system uses Cellular Digital Packet Data (CDPD), sometimes referred to as a Wireless IP connection, to transmit data between the Mobile Unit and the Base Station. 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).

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 aircraft. Crash location can be as straightforward as the GPS location longitude and latitude. Crash severity will be provided for each crash sensor, and can 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 at what angle the impact took place and may provide an early indication of what type of impact surface to expect.

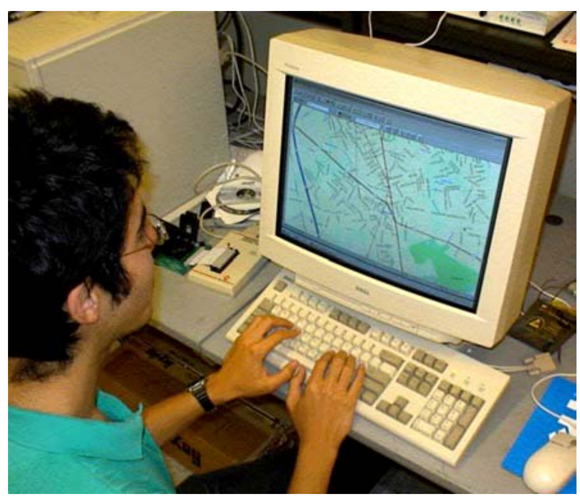

Figure 4. Base Station: Research Prototype

PERFORMANCE TESTING

The performance of EELT Mobile Unit is being evaluated through a number of laboratory tests. This section describes the results of performance testing to date.

NON-IMPACT TRACKING TESTS

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, a car with an 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 target car as it was driven from street to street, and even identify which lot it was parked in upon its return.

IMPACT PENETRATION TESTS

TSO-C126 specifies several shock and impact tests designed to ensure that an ELT performs properly in a crash. Our research program has adopted these tests to evaluate the performance of the E^2LT Mobile Unit. In the first test, TSO-C126 requires that an ELT successfully survive an impact penetration test designed to simulate the loads to which an ELT might be subjected in a crash. As shown in Figure 5, the Rowan impact penetration test consists of a mass of 25 kg attached to a T-shaped penetrating device and then dropped from a height of 15 centimeters. The 25 kg mass is mounted above the penetrating device and attached to a 1-meter tall drop tower. The penetrating device is made of steel of sufficient hardness that the ELT, rather than the test device, absorbs the impact energy. When dropped from the TSO-C126 specified height of 15 centimeters, the impact velocity of the penetrating device is approximately 1.7m/s. TSO-C126 requires that the ELT still operate after the penetration test.

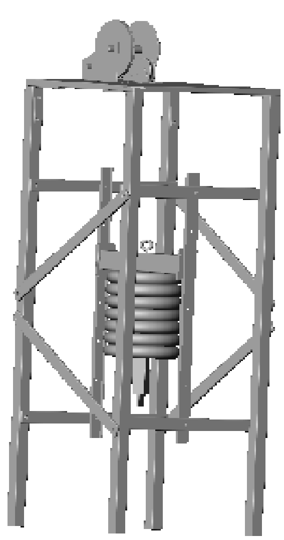

Figure 5. Impact Penetration Test Apparatus

VERTICAL DROP TESTS

TSO-C126 requires the following two shock tests.

- Impact of 100 G for 23 ± 2 milliseconds
- Impact of 500 G for 4 ± 1 milliseconds

The first test simulates the shock loadings that might be observed in a crash. In this test, the ELT must correctly detect the impact and activate the ELT. The second test simulates a non-impact shock such as might be observed in a hard landing. In the second test, the ELT must not activate. The ELT must survive both tests.

The research team is currently conducting these tests using a five-meter drop tower constructed for this task. We are currently performing vertical drop tests in which the Mobile Unit is dropped onto foam-covered barrier impacts at speeds up to 30 km/hr. These tests are designed to evaluate the impact survivability of the electronics as well as testing the ability of the system to detect and report collisions of this magnitude.

LIMITATIONS OF THE E^2LT

The features that make the E^2LT a promising accident location technology also limit the universality of its use. Wireless transmission using CDPD or similar wireless communication protocols, can only be used in areas where such technology is available. As a result, the E^2LT cannot be relied upon for emergencies taking place in remote places, such as over bodies of water. Additionally, GPS receivers are only useful if the antenna can lock on to a sufficient number of GPS satellites. The functionality of GPS in areas of dense foliage is hence uncertain, and will need to be investigated.

Due to these limitations, the E^2LT is intended as an accessory to existing ELTs, not as an independent system. Once installed, however, the E^2LT will greatly enhance the existing system. It will automatically detect when a crash occurs. The system also possesses the ability to pinpoint the location of the crash using GPS. Additionally, the E^2LT can directly contact Emergency Dispatch Personnel using CDPD or similar cellular technology. Emergency personnel can thus directly receive the coordinates of the crash, and a rescue team can then be launched within a matter of minutes.

CONCLUSIONS

This paper has presented the results of a research project to design, develop, and test an Enhanced Emergency Locator Transmitter system that combines wireless communications and Global Positioning

Systems with a network of inexpensive sensors for crash detection. Efforts to date have successfully designed and constructed a working prototype system. Successful operation of the prototype has been demonstrated in establishing a wireless web connection between the Mobile Unit and the Base Station. This paper has discussed the system requirements, summarized the design of the Mobile Unit and Base Station, and presented the results of performance tests to date.

ACKNOWLEDGMENTS

The authors wish to acknowledge Gregory McDonough, Ed Kondrath, and Nick Vitillo of the New Jersey Department of Transportation for their support of this research effort. The authors also wish to gratefully acknowledge the invaluable efforts of the following undergraduate engineering research assistants who made the success of this project possible: Jack Gamble, Mark Ghose, Pat Kane, Chris Molnar, Joseph Plitz, Amip Shah, Daniel Smith and Manning Smith.

REFERENCES

1. Federal Aviation Administration, Regulation Part 91, Section 91.207 Emergency Locator Transmitters (ELTs)

2. Abramowitz, A., Ingraham, P. A., and McGuire, R., “Vertical Drop Test of a Shorts 3-30 Airplane”, U.S. Department of Transportation, FAA, DOT/FAA/AR-99/87 (November 1999)

3. Radio Technical Commission for Aeronautics (RTCA), “Minimum Operational Performance Standards 406 MHz Emergency Locator Transmitters (ELT)”, RTCA/DO-204 (September 1989)

4. Radio Technical Commission for Aeronautics (RTCA), “Minimum Operational Performance Standards for Emergency Locator Transmitters”, RTCA/DO-183 (May 1983)

5. Federal Aviation Administration (FAA), “TSO-C126, 406 MHz Emergency Locator Transmitter (ELT)”, Technical Standard Order C126 (December 1992)

6. National Transportation Safety Board (NTSB), Safety Recommendation A-99-69 to A-99-73 (February 8, 2000)