Networked, autonomous field-deployable fire sensors

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*Abstract***.** An autonomous fire detector (AFD) is an electronic system consisting of fire detection sensors, a power source, a communication radio and a global positioning system receiver (GPS). AFDs will be stationed as sentries in and around a fire site to monitor the location and movement of the fire. The package could be dropped by spotter planes at a fire site or positioned by firefighters already on the ground. Using current radio technology, an AFD could be made to operate for a many days with a simple dry battery pack, and could be made to have a transmitting range of several kilometers. AFDs could communicate unit-to-unit as well as unit-to-base, which would provide extended range and flexibility. A transceiver/display unit carried by a fire team could be made equally light, inexpensive and portable. These devices could markedly increase safety and efficacy of the fire fighting team. AFDs can now be made with commercial-off-the-shelf components. The widespread availability of powerful microprocessors, sensitive detectors for particulate smoke, carbon monoxide and other fire-evolved gases and GPS receiver modules mean that small, inexpensive, field-deployable packages can be produced inexpensively to remotely sense fire phenomena. We have developed system models and built a prototype AFD using inexpensive, readily available components.

Keywords: Fire monitoring; field systems; fire detection; local fire detection; remote sensing

Introduction

One of the main problems in combating wildland fires is monitoring the time history of the fire (Chandler 1983). Understanding the size, location, and speed of advance of the fire front is critical to optimal allocation of fire fighting resources and maintaining safety of the fire crew. Investigation of major wildland fire accidents involving loss of life often indicates that the crews became imperiled because of insufficient or untimely information about the location and speed of advance of the fire (Rothermel 1993).

An autonomous fire detector (AFD) is a field deployed fire alarm that has the ability to report its location and whether a fire is in the vicinity. These devices might also be equipped to record local temperature, humidity and wind speed. The data is transmitted by radio to firefighters or to a central control receiver.

At present, once firefighters are on the ground near the fire site, they are effectively blind to the activity of the fire. Spotter planes and other aircraft may periodically over fly the area and report the movement and location of the fire to the incident commander, but often even this rudimentary data is lacking. In their simplest use model, AFDs could provide direct real time data to firefighters on the ground. The time history of the fire would be kept manually by recording the position and time of AFD fire alarms on paper maps.

Much effort has been expended in modeling the movement of fires in wildland settings (Andrews 1986, Finney 1994) but these models are only as good as the detailed weather, terrain and fuel load information. Lacking precise information of the fire site, these complex fire models can predict fire behavior for short time periods, but must then be 'tuned' with actual data to obtain long-term accuracy. These fire models are similar to modern weather simulations that are similarly adjusted periodically with weather data to provide long-term modeling.

Armed with handheld computers running these fire models, and provided with accurate real-time data for 'tuning', firefighters may be able to more accurately predict the behavior based on past fire movement even when only very imprecise weather, fuel and terrain information is available. The ability to predict the movement of the fire is a tremendous advantage to fire logistics and firefighter safety.

The use of satellites to obtain fire data for model tuning is possible, but there are complications imposed by limited satellite spatial resolution, complicated ground link equipment, and short satellite loiter time over the target area. Real time data can be obtained using unmanned or remotely controlled unmanned flying vehicles (UFVs) flying over the fire site, but this solution is both complex and difficult to support in the field, and would require additional worker training to operate and maintain the UFV. A small number of AFDs that are located in the forest could provide this data at low cost and with little additional effort in training or support. We present both an advanced and a simple AFD concept and show the initial design of a prototype.

Concept

In use, the AFDs would be dropped from a spotter plane or placed manually by fire crews over an area where a fire had previously been detected. The mechanical package of the AFD can be designed to be canopy penetrating (to descend to the forest floor) or canopy snagging (hangs in the upper branches of the canopy). The devices would periodically report their position and fire status to each other, a central receiver, or to radio receiving equipment provided to firefighters.

After they are deposited in the fire area, AFDs will locate themselves (via their internal GPS receiver) and report their position and fire alarm status. Communication will be provided by a low power radio transceiver, which allows AFD-to-AFD as well as AFD-to-base unit communication. One option for communication is a digital link with a network protocol. A diagram of the communication links between the various units is shown in Figure 1. The AFDs will periodically report their status to each other and a central control transceiver unit. On detection of a fire, the reporting AFD or AFDs will transmit an alarm to other AFDs in the area and to the central transceiver. Crews in the area can be alerted either directly from the reporting AFD, or through alarm messages that are relayed from the control transceiver. The control transceiver can have the capability of overlaying geographical information system (GIS) maps with the location and alarm state of the AFD, and presenting this data to the incident commander or other personnel at the fire site. This system represents a relatively complex configuration of the AFD system.

There are many simpler modes of operation of the AFD system, one of which is depicted in Figure 2. In this mode, the AFDs operate independently of each other, without a central control transceiver, instead reporting synthesized voice messages to firefighters on the ground. This message would contain the ID number of the AFD, its GPS position, and the alarm state of the device. Since the AFDs have highly accurate synchronized clocks via their GPS receivers, each can be programmed to transmit at a slightly different time in order to avoid AFD message collisions and interference, even when operating on a single radio frequency. The firefighter, equipped with nothing more than the present VHF/UHF FM radio transceiver ('handi-talki'), and with no additional infrastructure, would be able to receive voice AFD status on one of the normal radio communication channels. This mode of operation is most suitable when a few (~10) AFDs are used on geographically small fires.

A block diagram of the AFD is shown in Figure 3. A microprocessor coordinates inputs from the global positioning system receiver and the fire sensors, and generates the communication and modulation stream for the radio transceiver system. This communication stream can be digital, and can employ packet or radio-teletype encoding technology, or can be a synthesized voice, as discussed above. Several fire sensors may be used in an AFD. These sensors could be smoke detectors (photoelectric or ionization), gas detectors (combustion precursor gases, carbon monoxide, etc.), thermal (temperature), passive microwave or optical radiation detectors. The AFD internally measures the strength of signals from the sensors, and makes decisions as to the whether or not to issue an alarm. The use of more than one inexpensive detector can greatly reduce the probability of false alarms while not significantly increasing the cost. We are currently planning a test program to evaluate and optimize several fire sensor configurations during controlled wildland fires. The AFD will be programmed to observe and report sensor input periodically, and to 'sleep' in the interim to conserve battery energy.

Prototype Design

We have constructed a prototype AFD that follows the basic design discussed above. Any design must be sensitive to the multiple design constraints of low cost, ruggedness, low power consumption, and long transmitting range. The prototype is a transmit-only device and uses a simple messaging system to report the unit ID number, position and time (as determined by the GPS) and alarm status or sensor level for two sensors on a timed schedule. The units use UHF (433.9 MHz) frequency modulated (FM) radio transmitters operating audio frequency shift keying modulation (AFSK) to transmit digital information at 9600 bits per second. The entire transmission lasts under a second, conserving battery power. A radio receiver-demodulator attached via a serial link to a laptop computer receives the data stream and displays the messages. All of the components, including the radio transmitter, were obtained commercially. A photograph of the circuit boards of the prototype is shown in Figure 4, and a detailed block diagram is shown in Figure 5.

In order to speed development, a Parallax, Inc. Basic Stamp 2 (BS2) was used for the central processing unit. The BS2 has 16 digital input/output lines that can be programmed individually to perform a number of functions. The BS2 has several programmable 'sleep' modes that reduce power consumption to a very low level during idle periods (e.g. when no alarm or status information is being transmitted). The BS2 has a programming port and comes with development software using the powerful PBASIC programming language. Programs are developed on a PC-compatible computer and downloaded to the BS2, where they reside on an electrically erasable programmable memory (EEPROM). The combination of powerful input/output based programming language and self-contained development system makes the BS2 very easy to use for rapid development of simple applications. Detailed information about this processor can be found at the company's web site (Parallax 2001).

The prototype AFD has two 12-bit analog input channels to accept input from fire sensors. A Linear Technology, Inc. LTC1298 ADC communicates with the microprocessor via a 3 wire synchronous serial link. We are currently evaluating several sensor types for suitability in this application. We have successfully detected test fires using commercial ionization chamber smoke and carbon monoxide detector modules. In addition to the analog inputs, several switch inputs provide access to test routines, enable the device after deployment, and halt the device for storage. Four status LEDs provide visual indication of unit ID number, self test results, and AFD state information (alarm, transmitting, idle, etc.). An audio alert is also included to provide local indication of an alarm condition.

Asynchronous serial communication in RS-232 format is used to communicate with the transmitter and GPS unit. A commercial Garmin Model 12 GPS unit sends ASCII information indicating time, latitude and longitude over one serial link to the microprocessor. The messages transmitted by the GPS unit conform to the National Marine Electronics Association NMEA-0183 standard. The actual AFD will use one of the readily available unpackaged GPS 'decks' that do not have displays or keyboard input and are smaller and consume less power. Another RS-232 link is used to communicate ASCII information to the radio transmitter/modulator that is manufactured by RF Digital, Inc. The transmitter operates in the unlicensed portion of the UHF spectrum at 433 MHz with an output power of 1 mW. Because of the low output power of the transmitter, range is limited to around 100 m, but this may be increased readily by increasing transmitter power (which would require Federal Communication Commission licensing). The present range is sufficient for this proof-of-principle device.

A flow diagram of the software written for the prototype AFD is shown in figure 6. The powerful control-oriented PBASIC language simplified programming and reduced the initial effort to just a few days. There are other branch points in the software flow (not shown in Figure 6) that provide test functions (such as sensor and battery test) and readiness verification. Another Basic Stamp BS2 has been programmed as an input test set. This device produces simulated signals for the input switches and two analog voltages to represent sensor outputs, and allows us to test the AFD without directly stimulating the sensors.

Conclusion

We have demonstrated the concept and electronics for an autonomous fire detector that may be used as a fire sentry when fighting wildland fires. By keeping both the principles of operation and physical hardware simple, the device has been prototyped rapidly. We are currently evaluating 1 and 2-sensor fire detector packages using small test fires, and hope to further test a completed mechanical and electrical package with an extended range VHF radio transmitter during controlled burns in the spring of 2002.

Acknowledgements

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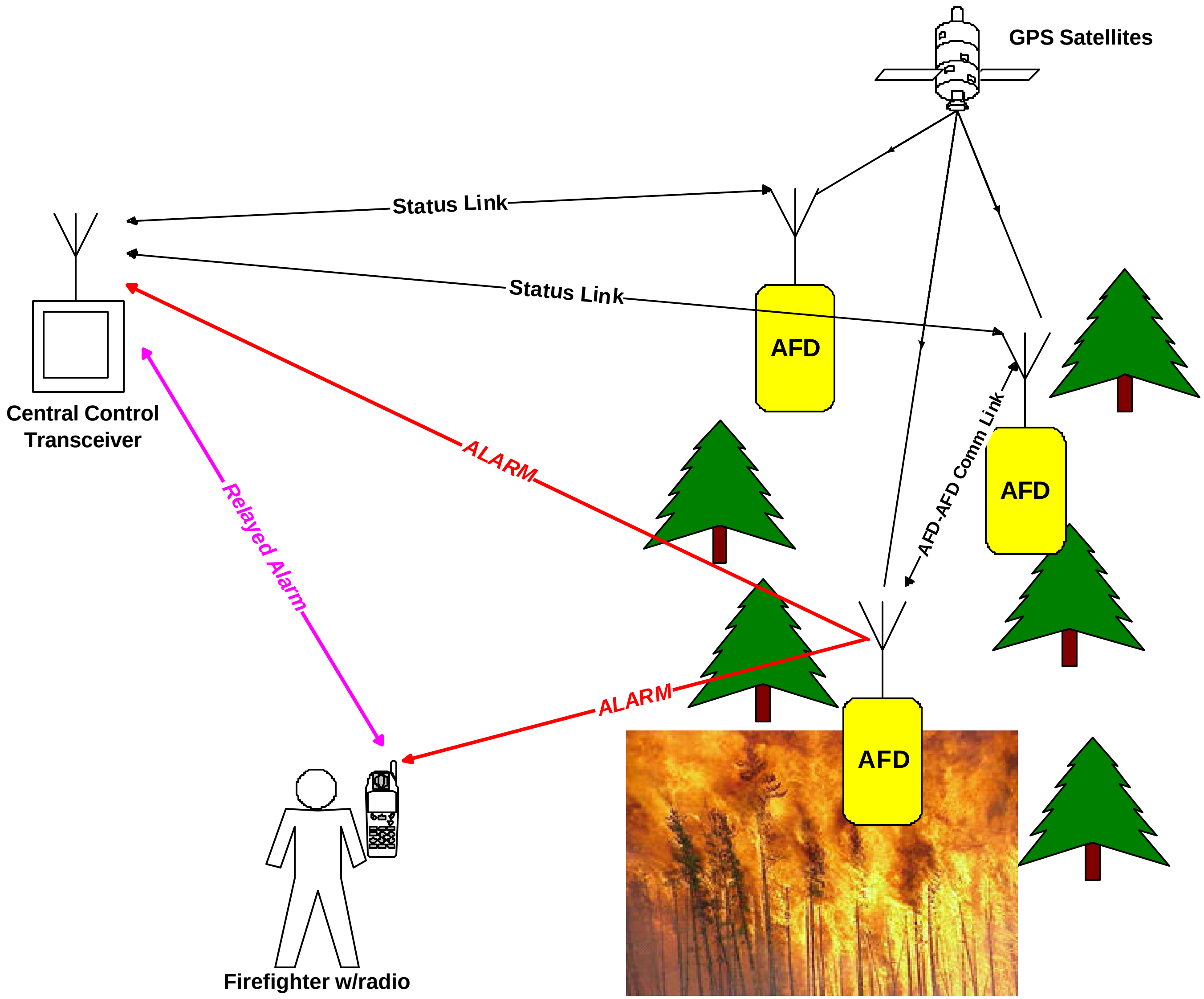

Figure 1 - Deployment and communication between AFDs and base units, other AFDs and firefighters in a fully networked system.

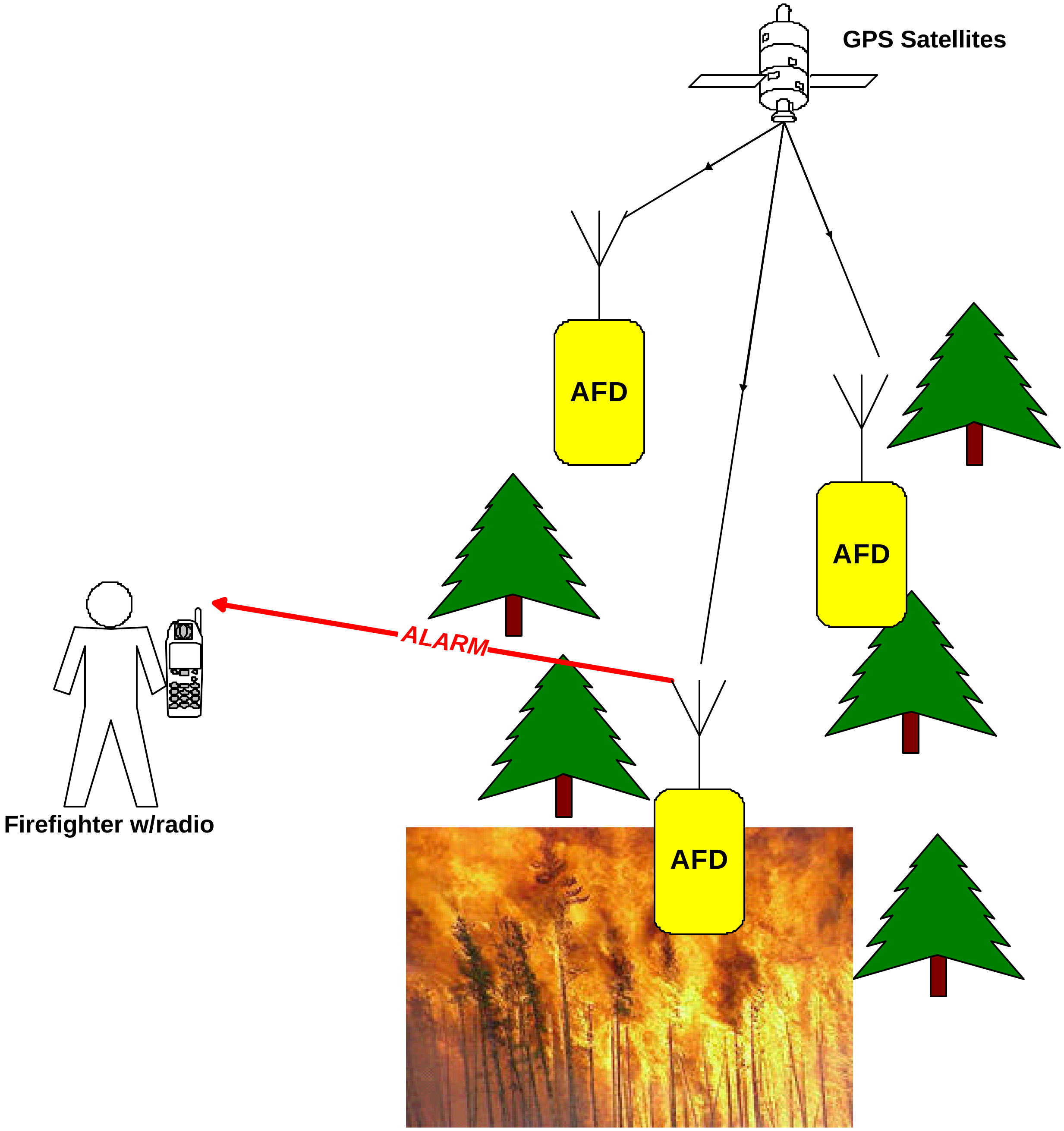

Figure 2 - Simple direct voice AFD operation. The AFDs report via synthesized voice messages directly to radio receivers at the fire site.

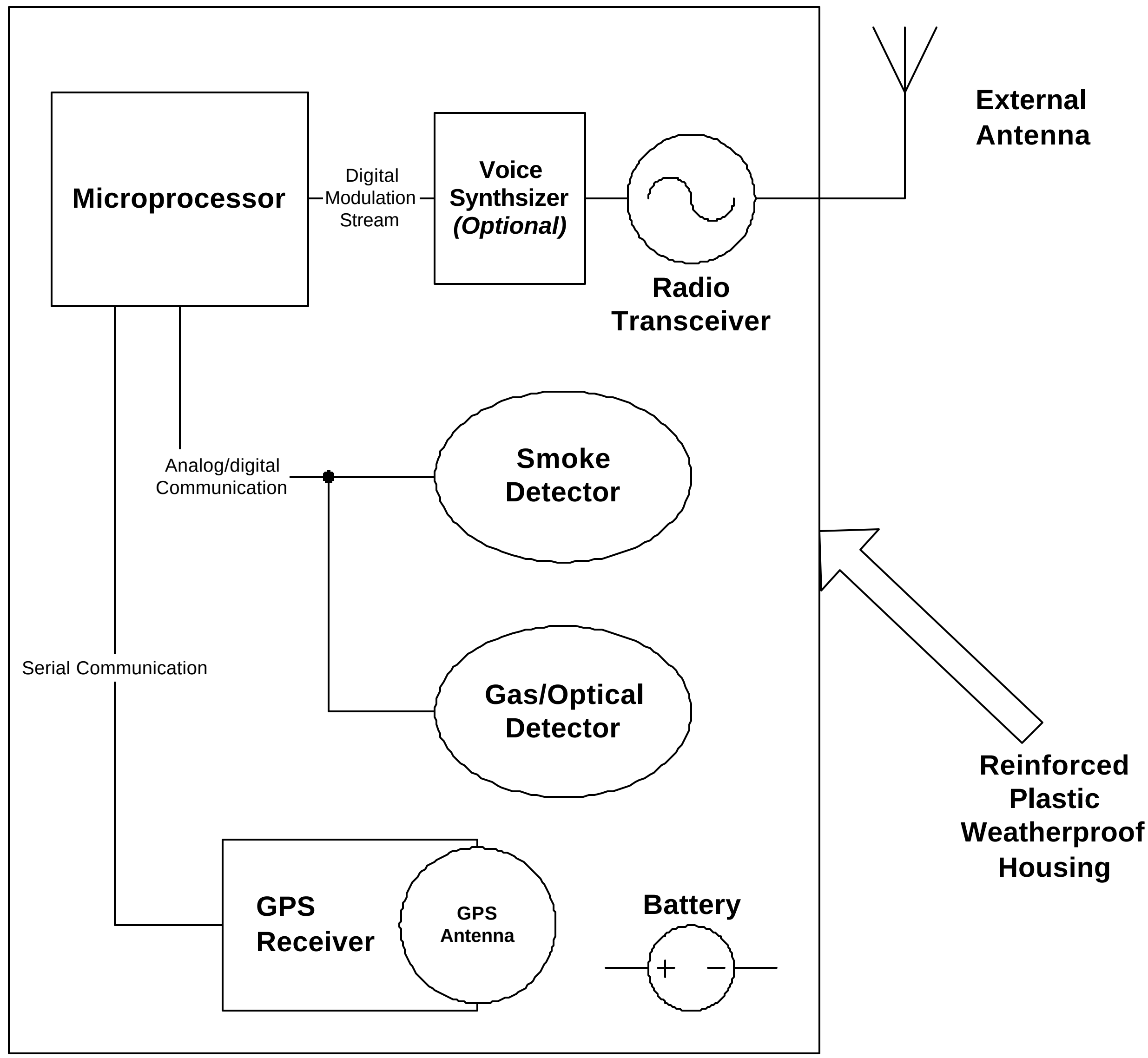

Figure 3 - Block diagram of the AFD, showing the logical and signal interconnections between the fire sensors, global positioning system receiver, radio transceiver and power system.

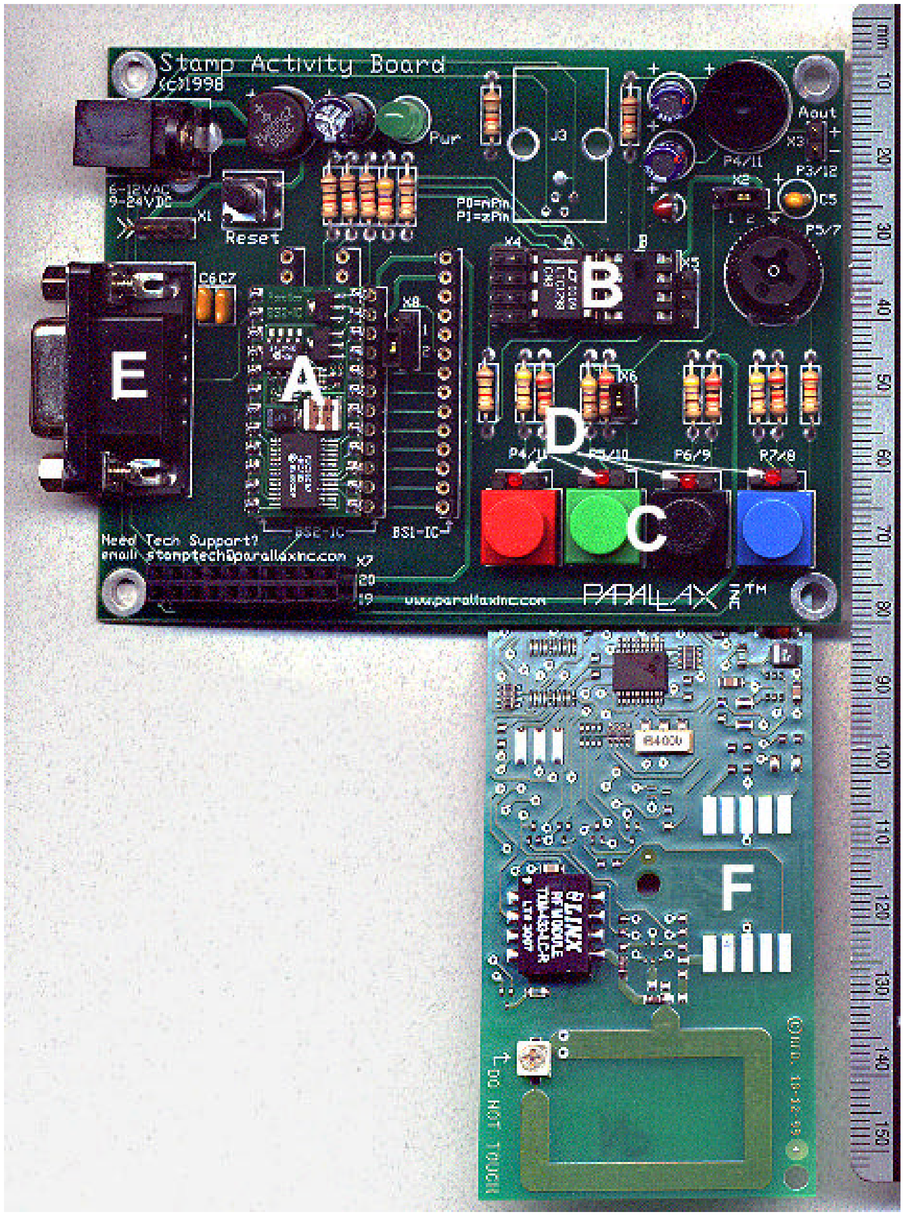

Figure 4 - Photograph of the prototype AFD. A - Parallax Basic Stamp microprocessor; B - Linear Technology LTC1298 2-channel analog-to-digital converter; C - Input switches for start-up, deactivation and test; D - Status LED indicators; E - Programming and GPS communication ports; F - RF communication deck.

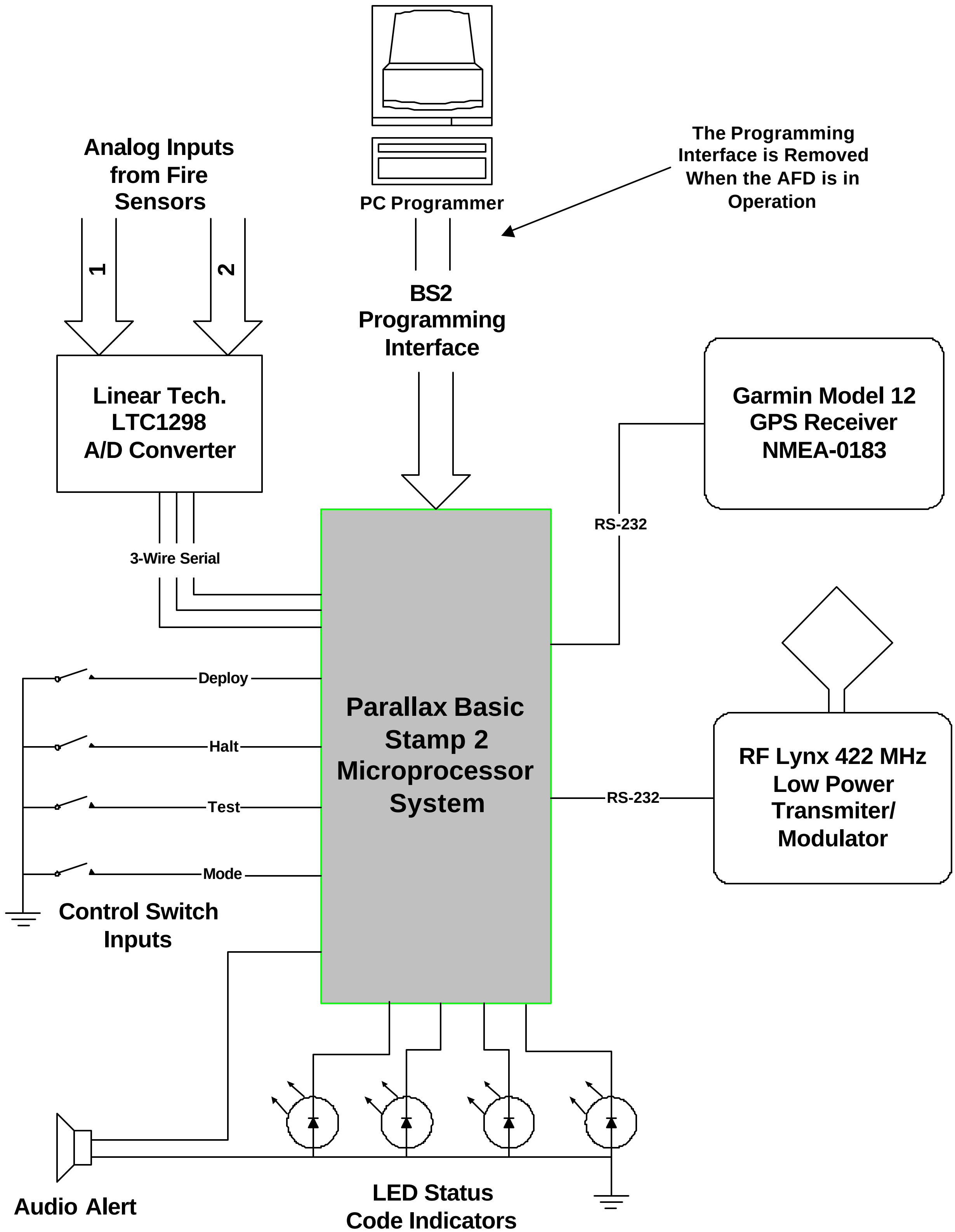

Figure 5 - Detailed block diagram of the prototype AFD. Fourteen of the sixteen available input/output pins of the BS2 are used in this application.

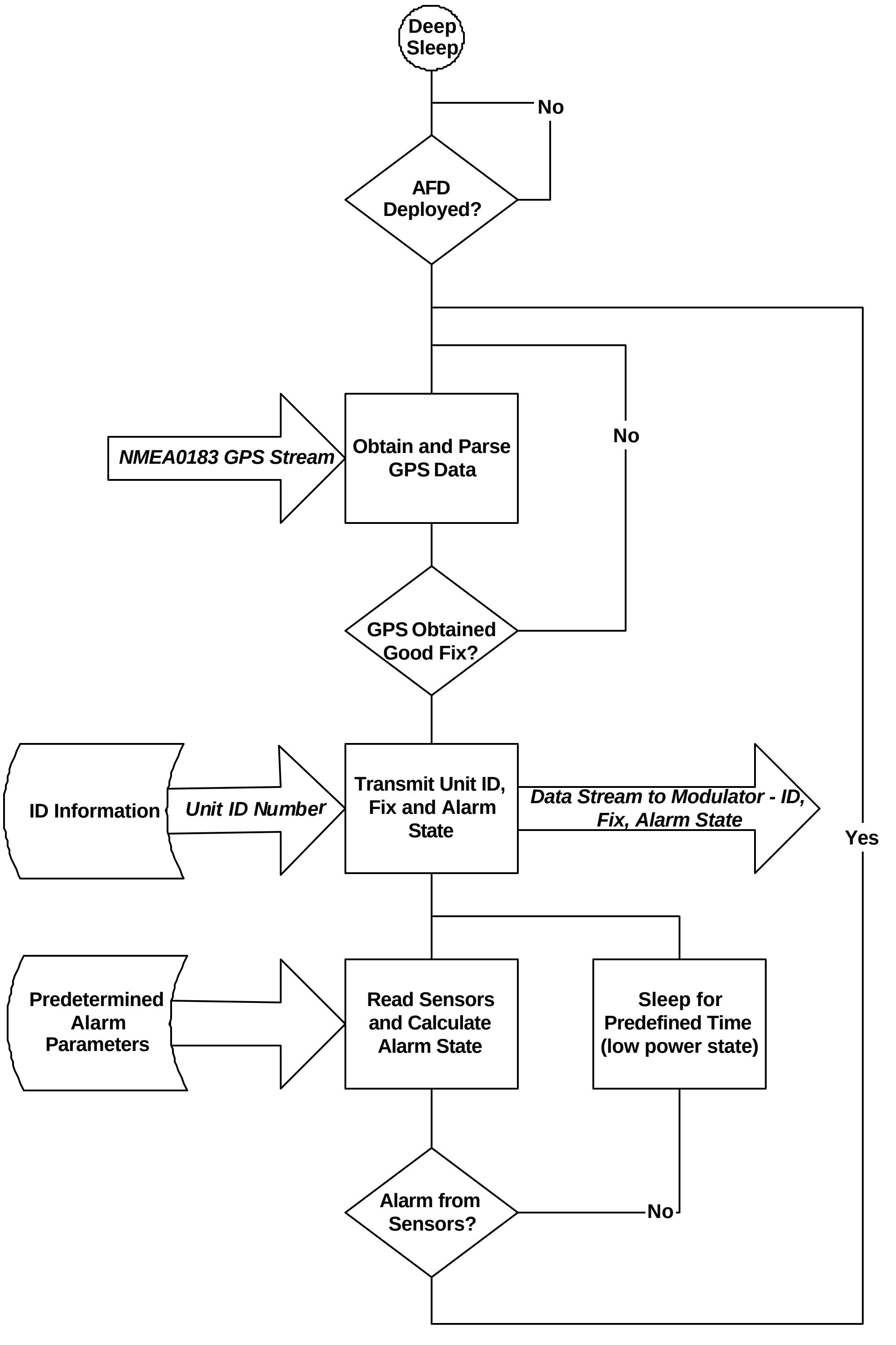

Figure 6 - Software flow diagram for the AFD prototype. The software makes use of the powerful instructions in the Parallax, Inc. PBASIC programming language.