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INSENS Sensor System

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Abstract

This paper describes an unattended ground sensor system that has been developed for the Immigration and Naturalization Service (INS). The system, known as INSENS, was developed at the Lawrence Livermore National Laboratory for use by the United States Border Patrol. This system assists in the detection of illegal entry of aliens and contraband (illegal drugs, etc.) into the United States along its land borders. Key to the system is its flexible modular design which allows future software and hardware enhancements to the system without altering the fundamental architecture of the system. Elements of the system include a sensor system capable of processing signals from multiple directional probes, a repeater system, and a handheld monitor system. Seismic, passive infrared (PIR), and magnetic probes are currently supported. The design of the INSENS system elements and their performance are described.

Introduction¹

The United States Border Patrol has been tasked to stop illegal entry of personnel and material into the United States along the border. Unattended ground sensors are key to this effort. Currently more than 4000 unattended sensors are deployed along the land borders of the US. In the summer of 1991 the Immigration and Naturalization Service and Lawrence Livermore National Laboratory began development of the next

generation of unattended ground sensors for use by the US Border Patrol. The project development team was made up of engineers and technicians from LLNL, Border Patrol sectors, and INS.

INSENS Overview

The INSENS system is compatible with existing INS sensor and support equipment including; probes, repeaters, and receiving stations. It is comprised of the following elements

- Seismic, magnetic, and infrared probes arranged to detect movement.
- A sensor system that evaluates the probe signal(s) and determines if a significant event has occurred. If so, the sensor transmits a coded alarm message.
- A repeater that receives coded alarm messages from a sensor(s) or other repeater and retransmits the alarm.
- A handheld portable monitor to decode and display the coded alarm message. The monitor can be used both by field personnel and, when located at sector headquarters, can be interfaced to the Border Patrol dispatch system.

The INSENS system employs a flexible modular design that allows future hardware and software enhancements to be made to the system without significantly changing the architecture. The system can be expanded to include new module types and probe capabilities as they become available. The design architecture for the system is based upon the Modular Intelligent Sensor System (MISS) architecture developed at LLNL.

Figure 1. shows the INSENS system components.

¹Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under Contract #W-7405-Eng-48



Figure 1: INSENS System Components
Portable Monitor, Sensor, Repeater, & External Power Source (back row left to right) Passive Infrared Probe, Magnetometer, & Seismic (front row left to right)

MISS

A MISS based system is comprised of multiple independent intelligent modules. Additional modules beyond those required for a basic system can easily be added to enhance its performance. For example, seismic probes can be added to a sensor that has only passive infrared probes to enhance operational performance.

All modules are completely self-contained and are capable of two-way communication with any other module. The key aspect of the MISS architecture is the inclusion of intelligence in all modules. This design philosophy allows the system's control module to perform a broader set of operational activities and relieves it from addressing the operational details of each probe in the sensor system. A by-product of this architecture is simpler, more generic system control software that allows easier inclusion of new probe types.

The MISS architecture uses a standard intermodule communication format so that modules can be added or removed as operational requirements change. The backbone of the architecture is based upon

the I²C bus developed by Philips/Signetics. This bus is designed as a low to medium speed multi-drop communication system for use among compatible chips or subsystems located within a single enclosure. Various components, including microprocessors, analog-to-digital and digital-to-analog converters, clock/calendars, and memories are currently supplied with I²C interfaces and are readily available from several manufacturers.

The I²C bus uses two signaling lines: a serial data line (SDA) and a serial clock line (SCL). These signaling lines are single ended, open collector and are both used during module to module communications. Devices connected to the I²C bus can act either as bus masters or slaves and communicate at the rate of the slowest module actively engaged in the communication up to a maximum rate of 100 kbits/second.

INSENS Modules

There are six major modules currently designed for the INSENS system:

- Control Processor Module
- Signal Processing Module
- Transmitter Module
- Receiver Module
- Sensor/Repeater Motherboard Module
- LCD/Motherboard Module

The entire INSENS system is assembled using subsets of these six modules.

Control Processor Module (Sensor, Repeater, Monitor)

The INSENS control module is the central controller of each of the INSENS system components. By changing the operating software installed, the module can become the control module for a sensor, repeater, or portable monitor. In each case, the module coordinates all intermodule interactions. It interfaces with the operator either through its serial interface with the portable monitor or and external computer. It provides all system

control, console communication, and data fusion functions.

In normal sensor operation, the control module receives messages from the signal processing module, packages a message for transmission, and sends the message to the transmitter module for transmission. In repeater operation, the module receives messages from the receiver module, if appropriate packages a message for transmission, and sends the message to the transmitter module for transmission. It also monitors the on-board and external battery condition and controls the battery charger.

The monitor control processor module interfaces with the operator either through its front mounted keypad and LCD display or through its serial interface with an external computer. In normal operation, the module receives messages from the receiver module, and if appropriate displays the received and verified alarm message on its LCD display, and sends the message to the CADRE system or serial printer if attached. It also monitors the on-board battery condition.

Control Module Features	
Processor	80CL410, 12 MHz
Program Memory	64Kbyte
Data Memory	96Kbyte
Voltage	5±0.5 Volts
Current	< 25 mA Operating < 100 µA Sleep
Operating Temp.	-40°C to +60°C
Weight	3 oz
Size	3 x 6 x 0.5 in.

Signal Processing Module

The signal processing module is the interface between the attached probes and the sensor system. The INSENS sensor system contains two signal processing modules. Each module is a two channel, four input, general purpose data collection system with 13 programmable gains. Each module accepts input from up to two directional probes. Currently supported probes are: 10 Hz single-point seismic, two axis flux-gate magnetometer, and dual

element passive infrared. The amplifier's gain stages and filters are configured automatically based upon the attached probe type.

When the amplified signal from any attached probe exceeds a threshold, the module awakens from its sleep state and begins to process the probe signal. At the conclusion of the triggering event, the signal is classified and, if the event is determined to be significant based upon the installed classification algorithm, the module will awaken the Sensor Control Module and report the event.

Signal Processing Module Features	
Processor	80CL410, 12 MHz
Program Memory	64Kbyte
Data Memory	96Kbyte
Voltage	5±0.5 Volts
Current	< 25 mA Operating < 100 µA Sleep
Operating Temp.	-40°C to +60°C
Weight	3 oz
Size	3 x 6 x 0.5 in.
Channels	2 Directional
Gain	1 - 10,000 13 Discrete Steps
Freq. Response	0.05 to 70 Hz

RF Transmitter Module

This module contains a synthesized RF transmitter programmed to transmit FM frequency shift keyed (FSK) signals to the INSENS RF Receiver module or existing Border Patrol repeaters or monitoring sites. The data format is programmable and currently implements the INS Manchester encoding.

The transmitter is designed for broadband operation, requiring no tuning or adjustment over the entire 162 to 174 MHz frequency range. It contains a rugged output amplifier which will not be damaged when operated into a mismatched load. The transmitter frequency is temperature compensated for operation from -40° to +60°C.

Transmitter Module Features	
Processor	80CL410, 12 MHz
Program Memory	64Kbyte
Data Memory	96Kbyte
Voltage	5±0.5 Volts 8±1.0 Volts
Current	< 25 mA Operating < 100 µA Sleep 2A Transmit
Frequency Range	162 - 174 MHz 25 KHz steps
Modulation Type	FSK, INS Manchester
Carrier Power	2W / 5W selectable
Operating Temp.	-40°C to +60°C
Weight	3 oz
Size	3 x 6 x 0.5 in.

Sensor/Repeater Motherboard

The INSENS motherboard provides plug-in socket connections for all other systems module in the sensor. It provides system voltages and MISS system bussing for the various modules. It also contains the system's real-time clock, serial interface, battery charger and five volt power supply circuitry. A sensor system motherboard has five MISS connections normally containing two signal processing modules, one control module, and one transmitter module.

Motherboard Module Features	
MISS Buss Slots	5
Battery	8 Volt 2.5 Amp-Hr Sealed Lead-Acid
Battery Charger	
Input Voltage	6 to 30 Volts DC
Output Current	250 mA (nom.)
Efficiency	> 80%
+5 Power Supply	
Voltage	+5±0.25V
Output Current	170 mA (max.)
Efficiency	> 80% @ 1mA
Operating Temp.	-40°C to +60°C
Weight	2 lb. with batteries
Size	6 x 6 x 0.5 in.

RF Receiver Module

This module contains a synthesized receiver programmed to receive and decode signals from the INSENS RF Transmitter Module or existing Border Patrol sensors and repeaters. The receiver module contains a frequency synthesized, FM FSK data receiver. The data format is programmable and currently uses INS Manchester encoding.

The receiver uses high selectivity crystal and ceramic filters to reduce interference from adjacent frequencies. The design has been optimized for low power consumption. The receiver frequency is temperature compensated for operation from -40° to +60°C.

Receiver Module Features	
Processor	80CL410, 12 MHz
Program Memory	64Kbyte
Data Memory	96Kbyte
Voltage	5±0.5 Volts
Current	< 25 mA Operating < 100 µA Sleep
Frequency Range	162 - 174 MHz 25 KHz steps
Modulation Type	FSK, INS Manchester
Sensitivity	0.30 µVolt
Operating Temp.	-40°C to +60°C
Weight	3 oz
Size	3 x 6 x 0.5 in.

LCD/Motherboard Module

The portable monitor LCD/Motherboard provides plug-in socket connections for the control and receiver modules in the monitor. It provides system voltages and MISS system bussing for modules. It also contains the system's real-time clock, serial interface, battery charger, five volt power supply circuitry, LCD display, and keypad.

LCD/Motherboard Module Features	
MISS Buss Slots	2
Battery	9.6 Volt 0.8 Amp-Hr NiCad
Battery Charger Input Voltage Output Current	12 to 30 Volts DC 400 mA (max.)
+5 Power Supply Voltage Output Current Efficiency	$+5 \pm 0.2$ V 225 mA (max.) $> 80\% @ 1$ mA
Display	128x128 Pixel LCD with EL Backlight
Operating Temp.	-20°C to +60°C
Weight	1 lb. with batteries
Size	7.5 x 4 x 1.25 in.

Sensor

There are four major modules that make up the INSENS sensor system:

- Signal Processing modules
- Control Processor module
- Transmitter module
- Motherboard module

In addition, to detect activity or movement the INSENS sensor system uses four types of probes:

- Seismic probe
- Directional magnetometer
- Directional passive infrared probe
- Switch closure

In the INSENS system, signals from the various probes are received and digitized by the signal-processing modules. The signal processing module identifies the source of the signal (e.g., personnel, motorized vehicle, wind, etc.) and sends a message to the control module via the MISS bus.

The control module processes signals from a probe or probes (sensor fusion) as appropriate to determine if an event of interest has occurred. If so, the control module formats a message in the current INS communication format and sends the message to the transmitter module. The transmitter module then broadcasts the message on the

desired frequency to a receiving station, such as a portable monitor or repeater.

The motherboard module provides the interconnections required to support the MISS bus as well as the system power supply and interconnections to the outside world. Normal operating lifetime is thirty days when powered solely from the internal battery. The sensor lifetime can be extended if a source of external power (i.e. solar panels, local power, or the INSENS external power source) is available.

The sensor system is programmed to transmit a daily alarm message including battery status at a user set time to verify that the sensor is still operational. Changes in sensor tilt, configuration, probes and cabling, including cutting, are detected and appropriate alarm message is transmitted.

Sensor System Features	
Number of Probes	1 to 4 Directional
Lifetime	
Internal Battery	30 days
External Battery	180 days
Tamper Detection	Tilt Cable Cutting Probe Change
Miscellaneous	Self Configuring Daily Status Alarm
Operating Temp.	-40°C to +60°C
Weight	7 lb. with batteries
Size	7.2 x 7.2 x 5.6 in.

Probes

Four probe types are currently including with the INSENS sensor system:

- Seismic probes which detect small ground movement.
- Magnetometers which detect small changes in the local magnetic field caused by the movement of ferrous material.
- Passive infrared probes which detect small changes in thermal radiation within their field of view.
- Contact closures from other types of sensors such as switches and other commercial sensors.

Seismic

The INSENS seismic probe is a commercially manufactured 10 Hz geophone packaged in a weatherproof rugged housing. Seismic probes exhibit a maximum range of 100 feet and are commonly deployed along the southern land borders of the United States to detect entry of people or vehicles.

Magnetometer

The INSENS directional magnetometer probe is a very low power, ring-core fluxgate magnetometer which measures small changes in the local magnetic field caused by the movement of ferrous material. Significant power savings are realized by pulsing the primary coil at a frequency of 300 pulses-per-second. Magnetometers exhibit a maximum range of 70 feet and are used along all United States land borders to detect the movement of vehicles, bicycles, and weapons.

Passive Infrared

The INSENS directional passive infrared (PIR) probe is a commercially manufactured infrared telescope packaged in a weatherproof rugged housing. The detector generates a signal proportional to the temperature difference between the object and the local background environment. Time differences in the response from the two detectors are used to determine the direction of travel. PIR probes exhibit a maximum range of 120 feet and are commonly used along the northern land borders of the United States to detect entry of people or vehicles.

Repeater

There are four major modules that make up the INSENS repeater system:

- Receiver module
- Control Processor module
- Transmitter module
- Motherboard module

These modules are assembled into a common weatherproof rugged enclosure.

In the INSENS repeater system, signals from sensor systems and other repeaters are

received and validated by the receiver module. Once a valid message has been received the repeater control processor module is awakened and the received message is transferred over the MISS bus. The repeater control module determines if the received message should be repeated; if so, the transmitter module is instructed to transmit the received message on the desired frequency.

As is the case in the sensor system, the motherboard module provides the interconnections required to support the MISS bus as well as the system power supply, interconnections to the outside world.

The repeater system receives alarm messages on its programmed receive frequency. Using its synthesized transmitter, it can transmit the alarms on any of its output frequencies. The INSENS repeater determines what output frequency to use based upon the ID of the sensor transmitting the alarm message. A daily alarm message including battery status is transmitted at a user set time to verify that the repeater is still operational. It is designed to operate with either a single combination receive/transmit antenna or with individual antennas.

Repeater System Features	
Lifetime	30 days Continuous
External Battery Solar / AC	30 days Continuous
Tamper Detection	Tilt
Miscellaneous	Daily Status Alarm Dual/Single Antenna Intelligent Repeating
Operating Temp.	-40°C to +60°C
Weight	7 lb. with batteries
Size	7.2 x 7.2 x 5.6 in.

Portable Monitor

The INSENS portable monitor is a hand-held system used to receive and process alarm messages from one or more sensors. When connected to a sensor or a repeater, it may also be used to setup a number of functions

(receive & transmit frequencies, amplifier gains, etc.). Received messages are processed and verified, and, if valid, the sensor ID number and alarm message type are displayed for the operator on the portable monitor's fourteen line by eighteen character backlit LCD display. The portable monitor can also be connected to a serial printer or the existing CADRE system at the US Border Patrol Sector Headquarters to alert the dispatcher of activities at sensor sites.

There are three major modules that make up the INSENS portable monitor:

- Receiver module
- Control Processor module
- LCD/Motherboard module

These module are assembled into a single housing compatible with both fixed base and portable operation.

The portable monitor can be adjusted to only display messages from a specific sensor or repeater or from a range of sensors or repeaters. The portable monitor has also be designed for use as an in-field setup device. In this mode, the LCD display and keypad are used by the user to configure either a sensor or repeater.

Portable Monitor Features	
Lifetime	6 Hours
Internal Battery	Continuous
External 12-30V	
Alarm Display	Last 10 Messages
Operating Temp.	-20°C to +60°C
Weight	4 lb. with batteries
Size	8 x 4 x 4 in.

Conclusion

A complete sensor system including sensors, repeaters, and monitoring equipment has been developed for use by the United States Border Patrol in the detection and apprehension of illegal personnel and material entering the US. The system based upon the LLNL's Modular Intelligent Sensor System is flexible to allow for future enhancements as detection technology and target classification algorithms advance.

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