WIRELESS INFRA-RED SENSOR

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ABSTRACT

For several decades, the military has used the Multiple Integrated Laser Engagement System (MILES) with a series of IR sensors along a belt fastened to a vehicle for training and simulation. Now, an alternative to this legacy system, a solar rechargeable battery powered wireless IR sensor is replacing wired sensors. The use of short-range RF communications network, allows the MILES sensors strategic placement about a combat vehicle without the umbilical cabling normally required for power and signal coupling from the players processing unit. The RF network operates in the 340 to 380 MHz band, has channeling capability of over 1600 channels, and coexists with the vehicles on board high-powered radios without interference. The wireless sensor implements a custom designed IR sensing amplifier, designed for maximum sensitivity and minimal power dissipation, along with advanced semiconductor IC's for signal processing and power conversion. Solar recharging enables the sensor to operate for extended time, on a single battery that should last for years without replacement. A proprietary software protocol, developed for communication integrity, is a critical part of the overall system and supports other sensor types and control elements with low data rates for a wireless Vehicle Area Network. The system, successfully installed on several military training platforms, proves to be a viable product for military training and simulation systems for the 21st century.

KEY WORDS

Wireless, IR Sensor, MILES, Vehicle Area Network

INTRODUCTION

The MILES system is a sophisticated opto-electronic technology that allows the military to train with various weapons in a simulated combat environment. The MILES system uses IR sensors attached to the target combat vehicle that are designed to receive encoded 904 nanometer IR energy pulses from a shooting laser which is attached and aligned to a firing combat weapon. The sensor receives signal pulses from the laser, and transmits them to a processing unit that decodes the type of weapon fired, the ammo type, the player ID and assesses a hit, miss or kill. The signal transmission of the received laser pulses, from the sensors to the processing unit, has been successful through conductive wiring for nearly thirty years.

With the advent of wireless technology becoming an economic reality, the proposal was prepared to develop a wireless sensor system for MILES. The advantages of a wireless sensor system are obvious. They are quicker and easier to install on a vehicle than wired sensors and limitations by the cabling umbilical for sensor placement, a critical factor for proper target area coverage, no longer exist nor does the opportunity for failure from broken cables and damaged connectors.

This paper highlights technical aspects of a wireless IR sensor developed to replace wired sensors used in a MILES system. Emphasis will be on descriptions of the electronic system architecture and technical properties of the functional circuits within it. A brief description of MILES and the wireless network is included to facilitate understanding of the system. The discussion concludes with a brief commentary on additional applications and future directions for this technology.

DESIGN OBJECTIVES

- Battery operated
- Solar rechargeable
- Omni-directional IR reception
- MILES-21 compatibility
- RF frequency approved for use by military training facilities
- Small size and weight
- Immune from interference of existing electronic systems
- Non-interfering with existing electronic systems
- MIL-461 compliance
- Wide operating temperature range
- Low cost
- Ease of use

SYSTEM DESCRIPTION

<u>Conventional MILES System</u>

In a conventional MILES system (Figure 1) a 904 nanometer laser transmits MILES codes as a sequence of short (approximately 100 nanosecond) pulses at specific time slots based on intervals of a 48 kilohertz sampling rate. Encoding is accomplished by the presence of pulses in specific time slot positions within a 3.67 millisecond sequence. Each 3.67 millisecond sequence constructs a MILES word. A complete message can be a few milliseconds to several seconds in duration. Within this pattern of laser pulses, the type of weapon fired, ammo type, player ID and a sequence of hit and miss codes are encoded. These pulses of IR laser energy are received by the optical pickup device, typically a silicon photodiode, which converts the optical light energy into electrical signal pulses. The pulses are then coupled to an amplifier and then to a level sensing comparator. The comparator generally drives an open drain MOSFET transistor with its pull-up resistor in the processing unit allowing multiple sensors to share a common signal wire. The processing unit then decodes the received pulses into a miss, hit or kill. The cable connects the sensor unit to the processing unit between the open drain transistor and the processing units input connection. Power to the sensor is included on the cabling system.

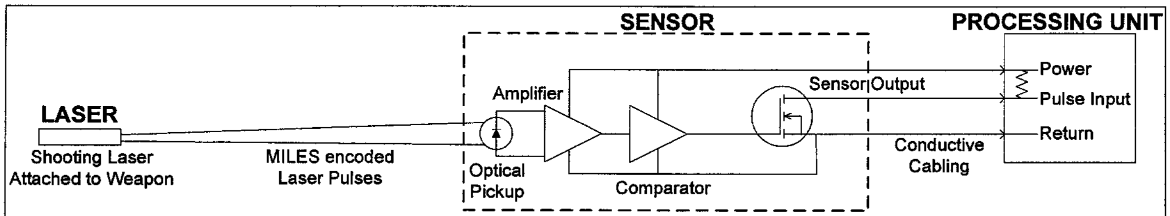

Figure 1. 904nm Laser transmits MILES pulse codes. Pulse codes are received by the sensor then transmitted to the processing unit through conductive wiring. The processing unit contains the logic and processor for decoding.

Wireless Sensor System

The wireless IR sensor eliminates the umbilical cable from the sensor to the processing unit. Instead of conductive cables between the sensor and the processing unit, an RF transceiver communicates MILES data and power comes from a battery located within the wireless sensor. Laser decoding, relocated to the wireless sensor, enables the wireless sensor to transmit compressed MILES data to the processing unit. The processing unit still does the assessment. By placing the decoding logic within the wireless sensor, a pulse stream of MILES data in the order of several seconds duration is compressed to a few milliseconds. This is very important since now the data transmission time over the RF link is short allowing multiple sensors as well as other wireless devices to share the bandwidth and co-exist on the same wireless network.

Wireless Network

The wireless sensors are required to send MILES data to the Processing unit through an RF communication process. There can be several wireless sensors as well as other devices required to communicate on the same RF medium. Since the wireless sensor is battery operated it is desirable to conserve energy and be able to power on the RF transceiver only when required. Power conservation was a major consideration in defining a network structure suitable for battery operated equipment that could have their RF transceiver powered down then quickly power up and communicate on the network. The wireless network architecture and methodology that could facilitate called for a star network topology (Figure 2) using RF carrier sensing with collision avoidance.

A star network topology has a central node with multiple slaves. This topology using RF carrier sensing with collision avoidance allows all the devices to communicate over the network without regard to time synchronization. A device on the network must first detect if any other device is currently transmitting before it can transmit. Detection, accomplished with circuitry in the RF transceiver module, detects the presence of RF signals in its operating frequency. If a device wishing to transmit does not detect any other device transmitting, then it may transmit. All slave devices in the network always transmit to the central node. The central node transmits acknowledgements back to the sending slave device. This method allows slave devices on the network to power down their RF transceivers when they do not have any data to transmit and can power on when they require to communicate on the network.

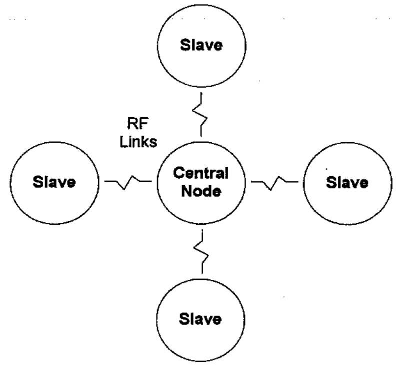

Figure 2. A star network topology has a central node with multiple slaves. In this case the central node is within the processing unit and the wireless sensors are slave devices. Communication between the slave devices and the central node is via RF transceivers.

WIRELESS SENSOR FUNCTIONAL DESCRIPTION

Given that the wireless sensor is battery operated, power conservation is very important. In fact, when the wireless sensor is in use, the majority of its circuitry is powered down. Figure 3 represents a functional block diagram of the wireless sensor. As illustrated in Figure 3, the wireless sensor contains an embedded solar panel, charge controller circuit, rechargeable battery, power regulators, IR sensing amplifier, digital logic, microcontroller and an RF transceiver. The majority of the time, the only circuit fully powered is the IR sensor amplifier, the microcontroller (in sleep mode) and their associated power regulators with a combined power consumption of less than 1.5 milliwatts. The digital logic and RF transceiver, normally powered down, are powered only when required. When pulses from the IR sensor amplifier signals the microcontroller, it wakes up from sleep mode and qualifies the pulse timing to ascertain it meets MILES codes timing parameters then signals to power on the digital logic. The digital logic can now decode the MILES laser pulses. The digital logic and the microcontroller work together and compress the MILES data stream. At the proper time, the microcontroller signals the RF transceiver to power up, and the compressed data is transmitted to the processing unit.

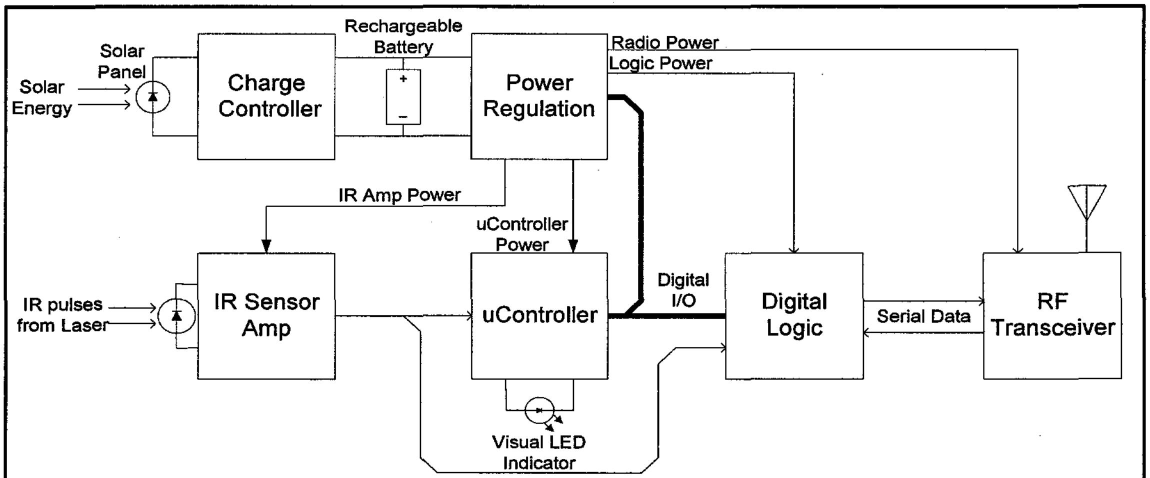

Figure 3. Wireless Sensor Functional Block Diagram

A great amount of attention was given to the design of each functional block shown in Figure 3. Particular consideration to power dissipation and performance specifications was paramount to the overall success of the wireless sensor. A brief discussion of each functional block shown in Figure 3 follows.

Solar Battery Charging

The charge control circuitry regulates the charge current from the solar panel and the state of charge on the battery. The solar cell and charge controller generally provide adequate recharge to the battery to restore the energy discharged during normal activity. Normal activity being defined as the typical frequency of being hit by MILES laser pulses and receiving solar energy of at least a 10 percent duty cycle over any 30 day period. Estimates, based on battery capacity and rate of power dissipation, suggest that the supplied battery should last for at least three years under these circumstances. More realistically, typical solar power should provide for even greater battery longevity.

A rechargeable alkaline battery was selected for the wireless sensor based on its ability to undergo numerous recharging cycles, as long as the depth of discharge is shallow. With the depth of discharge typically shallow on a daily basis, and with the expectation of solar energy available for recharging, the rechargeable alkaline battery is an ideal selection. In addition, alkaline batteries do not experience significant self-discharge and do not require exotic charge control.

Power Regulators

Multiple high-efficiency switching regulators provide power to different functions within the sensor and become operational only when required. With a sufficiently charged battery installed, the power to the microcontroller is always operational. Regulated voltage to the microcontroller and the charging circuit, supplied from this regulator, becomes the only power required when the sensor is in shutdown mode with less than 50 microwatts required from the battery. The life of the battery under this condition is estimated to be five years. The switching regulators that provide power to the IR amplifier, the digital logic and the RF transceiver circuit deliver energy to these circuits with greater than 85% efficiency. The microcontroller controls these regulators and powers them on when required. The switching regulators receive power directly from the battery and can operate down to a battery voltage of 1 volt.

IR Sensor Amp

Major emphasis was placed on the design of the IR sensor amplifier. It required omni-directional IR reception, high sensitivity, no false output pulses from noise, operation in full sunlight and low power consumption. Many different circuit topologies were investigated. None of the classical circuit solutions investigated could adequately meet all the parameters. The final design is composed of discrete components and optimized for high gain, low noise, and low power consumption. Omni-directional IR reception was achieved by a geometrically arranged array of photodiodes which mutually collect laser energy and has been designed to be hemispherical to within +/- 1dB variance. Sensor sensitivity is better than 2 picojoules per square centimeter @ 904 nanometers, with no false triggers in full sunlight. Power dissipation is less than 1.25 milliwatts in low ambient light levels, but do increase to greater than 20mW when the sensors are exposed to full sunlight. The additional power consumption when exposed to sunlight is not required from the battery since the solar panel provides this energy; hence, the battery is required to power the IR sensor amplifier only during times when solar power is absent.

RF Transceiver

The RF network was required to operate within 340 to 380 megahertz with channel spacing intervals of 25 kilohertz. This provides the wireless network 1601 channels in which it may operate allowing the frequency coordinator, at each training facility, flexibility to regulate RF traffic and ensure all RF systems operate without interference from one another. Power, cost, and performance are all critical parameters of the RF transceiver unit. It is required to power up and become stable rapidly, without a heavy power surge, and provide adequate RF transmission power and receive signal sensitivity for reliable communication between the wireless sensor and the processing unit. The over the air data rate is also important since the objective is to spend as little time as necessary for transmission allowing multiple devices access over the wireless network. Interference from the existing vehicles on board high-powered (50 Watt) radios is also a major concern. The transmitted RF power from a wireless sensor is less than 1 milliwatt. This requires greater than 100dB of blocking from the existing vehicles radios and the wireless network radios. This was achievable by careful design of the RF filters, shielding and antenna system. Reliable communication distances of up to 50 feet are attainable, even with the vehicles 50 watt radio transmitting at full power, regardless of proximity of the wireless sensors to the vehicles radio antenna.

Digital Logic

The wireless sensor contains enough digital logic to implement a full MILES decoder as well as the digital serial transceivers to interface to the RF transceiver. Some innovative digital design allowed a reduction of the amount of logic from previous designs. This allowed the decoder to fit into a smaller logic device. In addition, it had to be low cost and non-volatile with instant power on so as not to miss the beginning of a MILES message. The wireless sensor uses a CPLD device that met these requirements adequately. The component consumes less than 40 milliwatts, is non-volatile, and powers up in less than 200 microseconds without any significant surge current on the power supply.

Microcontroller

The microcontroller brings in the intelligence required for the wireless sensor to operate within the wireless network. It is responsible for preparing the data into packets that properly communicate within the wireless network protocol as well as providing all the control signals for proper power sequencing of the sensor functions. It detects that communication between the sensor and the processing units RF transceivers occur without errors and provides the retry logic necessary to attain error free data transfers. It also monitors the charge status of the battery, performs diagnostics on the digital logic, RF transceiver and power regulators, and can display this to the user by visual cues through an LED indicator lamp.

The microcontroller also required non-volatile storage and low power consumption. It consumes less than 10 microwatts in sleep mode and less than 20 milliwatts when operating at full speed and has the processing capacity and ample resources to control all the functions necessary within the wireless sensor and the wireless network protocol.

FUTURE DIRECTIONS

Currently redesign is in process of the wireless sensor packaging to fit into a smaller and lower profile. This improved form will make the sensor less vulnerable to obstacles, such as tree branches, disturbing the mounting of the sensor on a vehicle. There are also plans to extend the network to include additional instrumentation on a wireless Vehicle Area Network for combat training vehicles. The networks software protocol already supports this and minor modifications could be implemented without much difficulty.

A non-rechargeable lithium battery is under consideration for the wireless sensor. With the actual power consumption of the wireless sensor as low as it is, and with the aid of supplemental solar power, a single AA lithium battery has the capacity to operate the sensor for over 2000 hours. At the rate of use the sensor actually experiences, solar recharging is in question about its benefits. A lithium battery will extend the operational temperature of the sensor, is inexpensive and is available through consumer retail stores. A non-rechargeable battery would also eliminate the charge control circuit, thus further reducing cost and complexity.

CONCLUSIONS

The wireless IR sensor, designed, produced and fielded on several combat vehicles, has met or exceeded all the design objectives and has performed exceptionally well in all installations. The wireless IR sensor has been through all the necessary qualification testing for radiation and susceptibility dictated under MIL-461 as well as environmental, operational and MILES-21 decoding requirements. The wireless IR sensor rivals the performance of wired sensors and provides the additional benefit of mounting location flexibility, as regards to placement on a target vehicle. In short, they provide a reliable alternative to wired sensors with all the advantages expected of a wireless system.

The wireless network, developed for this system, has successfully incorporated the wireless sensor along with other devices onto the network, providing wireless control and instrumentation free of cables and connectors. The wireless network has the capacity to include additional devices for control and instrumentation in a wireless Vehicle Area Network.