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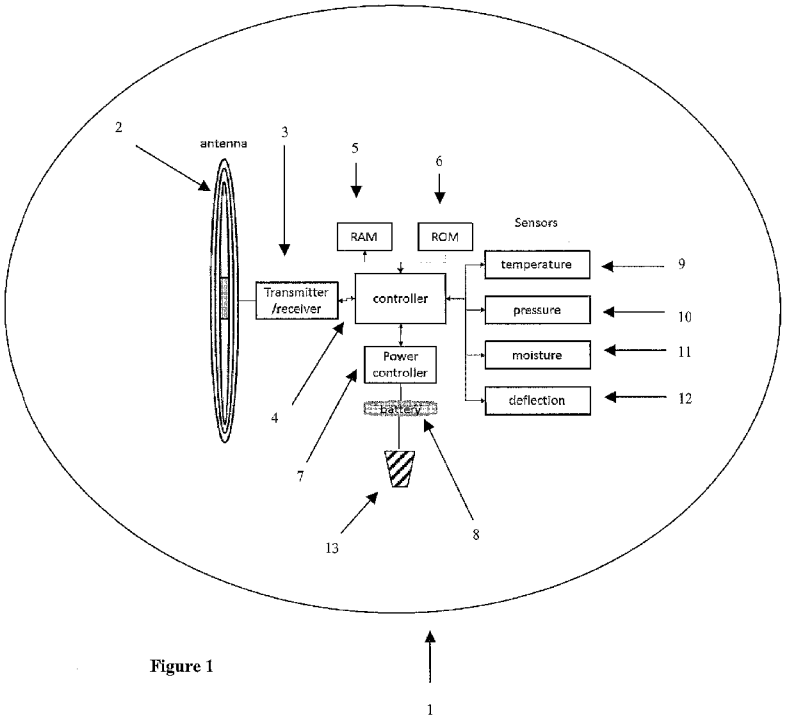


Figure 1

(57) Abstract: The present invention is related to sensors and wireless technology for infrastructure monitoring and maintenance. In particular, the invention is related to the monitoring and maintenance of vehicular infrastructure, such as back roads, city streets, state highways and interstate highways. For example, subsurface wireless sensors are configured for remote commanding and data transmission with external computer systems for real-time roadway condition information. Such a system allows constant evaluation and analysis to improve repair response time and facilitates accurate prediction of roadway breakdown.

WO 2016/130804 A1

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Wireless Road Sub-Surface Sensing System

Field Of The Invention

The present invention is related to sensors and wireless technology for infrastructure monitoring and maintenance. In particular, the invention is related to the monitoring and maintenance of transportation infrastructure, such as back roads, city streets, state highways and interstate highways. For example, subsurface wireless sensor systems are configured for remote commanding and data transmission with external computer systems for real-time roadway condition information. Such a system allows constant evaluation and analysis to improve repair response time and facilitates accurate prediction of roadway conditions and breakdown.

Background

Proper maintenance of vehicular infrastructure has positive impacts for many sectors of today's society. Ranging from traffic safety to improving business efficiencies and profitability, keeping vehicular roadways in good operating condition relies upon constant surveillance and monitoring.

To date, typical surveillance and monitoring systems employ wired sensors that must be placed into the ground individually with each sensor hard-wired to a data collector / logger on the roadway surface. This configuration requires extensive roadway digging and trenching at considerable cost to install and maintain the sensors and wires, in addition to adding a societal burden resulting from construction traffic delays. For example, routine maintenance may require redigging of trenches to replace wiring and to retrieve failed sensors.

What is needed in the art is a long-term wireless sensor network that is configured for remote command and data transmission.

Summary Of The Invention

The present invention is related to sensors and wireless technology for infrastructure monitoring and maintenance. In particular, the invention is related to the monitoring and maintenance of vehicular infrastructure, such as back roads, city streets, state highways and interstate highways. For example, subsurface wireless sensor systems are configured for remote commanding and data transmission with external computer systems for real-time roadway

condition information. Such a system allows constant evaluation and analysis to assess real-time status, improve repair response time and facilitates accurate prediction of roadway breakdown.

In one embodiment, the present invention contemplates a wireless sensor system within a casing, comprising: a) an embedded antenna, wherein said embedded antenna is configured to receive a plurality of operational commands and transmit a plurality of quantitative data sets with an external microprocessor data processing unit; b) a controller unit in electrical communication with said embedded antenna, wherein said controller unit processes said plurality of operational commands and said plurality of quantitative data sets; c) a read-only access memory unit comprising at least one software program configured to execute said plurality of operational commands by said controller unit; d) at least one environmental sensor in electrical configuration with said controller unit, wherein said at least one environmental sensor is configured to collect at least one set of said plurality of quantitative data sets on receipt of at least one of said plurality of operational commands by said controller unit; and e) a random access memory unit configured to store said quantitative data, wherein said quantitative data is transmitted to said external microprocessor device on receipt of at least one of said plurality of operational commands by said controller unit. In one embodiment, the at least one environmental sensor is selected from the group consisting of a temperature sensor, a pressure sensor, a moisture sensor and a deflection sensor. In one embodiment, the at least one of said plurality of operational commands comprises on/off times for said at least one environmental sensor. In one embodiment, at least one of said plurality of operational commands comprises a transmission disable time and a transmission read time for said quantitative data sets stored in said random-access memory unit. In one embodiment, the at least one of said plurality of operation commands comprises a shutdown command for at least a portion of said wireless sensor system. In one embodiment, the at least one of said plurality of operational commands comprises a reactivation command for at least a portion of said wireless sensor system. In one embodiment, the at least one of said plurality of operational commands comprises a power-off command to said wireless sensor system. In one embodiment, the at least one of said plurality of operation commands comprises a power-on command to said wireless sensor system. In one embodiment, the at least one set of said plurality of quantitative data sets comprises an identification code distinctive of said at least one environmental sensor. In one embodiment, the format of said at least one set of said plurality of quantitative data sets is reconfigured by said at least one operational command. In

one embodiment, the system further comprises a transmitter/receiver unit in electrical communication with said controller unit and said antenna. In one embodiment, the transmitter/receiver unit is reconfigured by said at least one operational command to optimize performance in response to changed environmental parameters. In one embodiment, the system further comprises a rechargeable battery in electrical communication with said controller unit. In one embodiment, the system further comprises at least one energy harvesting element in electrical communication with said rechargeable battery. In one embodiment, the at least one energy harvesting element is selected from the group consisting of a radio frequency, microwave, solar energy element, a thermal energy element, a wind energy element, a salinity gradient energy element and a kinetic energy element. In one embodiment, the system further comprises an external reader node in wireless communication with said antenna. In one embodiment, the external reader node is in wireless communication with at least one external radio transmission base station. In one embodiment, the at least one external radio transmission base station is in wireless communication with at least one external internet connected hub. In one embodiment, the at least one external internet connected hub is in electrical communication with said external microprocessor device. In one embodiment, the casing is inserted into a borehole. In one embodiment, the borehole is through a roadway surface. In one embodiment, the borehole is set to a depth ranging between approximately one to six feet below said roadway surface. In one embodiment, the controller unit, read-only access memory unit and said random-access memory unit are integrated on a printed circuit board. In one embodiment, the transmitter/receiver is further integrated on said printed circuit board. In one embodiment, the rechargeable battery is further integrated on said printed circuit board. In one embodiment, the at least one energy harvesting element is integrated on said printed circuit board.

In one embodiment, the present invention contemplates methods and devices to develop roadway frost-thaw prediction models. In one embodiment, the device comprises a plurality of sensors that are inserted into a roadway substrate. In one embodiment, the roadway substrate comprises asphalt. In one embodiment, the roadway substrate comprises concrete. In one embodiment, the roadway substrate comprises gravel and/or dirt. In one embodiment, the device comprises a plurality of sensors that are placed underneath a roadway substrate. In one embodiment, the plurality of sensors are placed at a depth between approximately one (1) foot to six (6) feet underneath the roadway surface. In one embodiment, the plurality of sensors are

placed underneath the roadway surface in a borehole. In one embodiment, the plurality of sensors are within the same borehole. In one embodiment, the plurality of sensors are within different boreholes. In one embodiment, the plurality of sensors are placed underneath the roadway surface at the same depth. In one embodiment, the plurality of sensors are placed underneath the roadway surface at different depths. In one embodiment, the plurality of sensors transmit data measurements. In one embodiment, each of the plurality of sensors is identified by a different RFID tag and the resulting data measurements are accurately retrieved from a specific sensor or from all sensors. In one embodiment, a roadway depth profile of health is constructed from the transmitted data measurements.

In one embodiment, the present embodiment comprises a programmable remotely activated roadway sensor. In one embodiment, the programmable remotely activated roadway sensor comprises an antenna in an electronic configuration with a controller unit, wherein said controller unit is attached to a RAM storage device and a ROM storage device. In one embodiment, the controller unit is further attached to a plurality of sensors. In one embodiment, the plurality of sensors are selected from the group consisting of temperature sensor, a pressure sensor, a moisture sensor and a deflection sensor. In one embodiment, the sensor comprises a rechargeable battery in electronic configuration with the controller. In one embodiment, the rechargeable battery is in electronic configuration with an embedded energy harvesting element, wherein said energy harvesting element provides power to recharge the rechargeable battery. In one embodiment, the energy harvesting element generates power in response to ambient conditions including, but not limited to microwave or radio frequency energy, temperature and motion. In one embodiment, the antenna is in wireless communication with an external microprocessor device. In one embodiment, the plurality of sensors are electronically configured upon receipt of a remote service call from the external microprocessor device. In one embodiment, the plurality of sensors are electronically calibrated upon receipt of a remote service call from the external microprocessor device. In one embodiment, the controller is electronically configured upon receipt of a remote service call from the external microprocessor device. In one embodiment, the controller configuration comprises a schedule of data measurement collection times for each of the plurality of sensors. In one embodiment, the controller configuration comprises a schedule of data measurement durations for each of the plurality of sensors. In one embodiment, the controller configuration comprises a schedule of

data transmission periods for each of the plurality of sensors. In one embodiment, the schedule of data transmission periods comprises a disable transmission time and a read transmission time.

In one embodiment, the present invention contemplates a roadway subgrade sensor system comprising: a) at least one sensor device placed within a roadway subgrade, comprising: i) a controller in electronic communication with at least one sensor, wherein each sensor is remotely programmed to collect data, and identified by a unique radio-frequency identification tag; ii) a battery connected to a power controller, said power controller in electronic communication with said controller; iii) at least one read only memory component in electronic communication with said controller and a random access memory component; iv) a transmitter and receiver in electronic communication with an antenna and said controller; and v) an enclosure containing at least said controller, battery, power controller, read only memory, random access memory component, and said transmitter and receiver; and b) a network integrated reader node comprising a data logger in radio signal communication that remotely activates said at least one sensor device. In one embodiment, the sensor device components are integrated into a printed circuit board and encased in said enclosure. In one embodiment, the sensor device further comprises an embedded energy-harvesting element in electronic communication with said battery. In one embodiment, the embedded energy harvesting element uses radio frequency or microwaves to generate energy. In one embodiment, the embedded energy harvesting element uses temperature to generate energy. In one embodiment, the embedded energy harvesting element uses vibration to generate energy. In one embodiment, the embedded energy harvesting element recharges said battery.

In one embodiment, the present invention contemplates a method of collecting roadway subsurface environmental data, comprising: I) providing a sensor system comprising; a) at least one sensor device placed within a roadway subgrade, comprising: i) a controller in electronic communication with at least one sensor, wherein each sensor is remotely programmed to collect data, and identified by a unique radio-frequency identification tag; ii) a battery connected to a power controller, said power controller in electronic communication with said controller; iii) at least one read only memory component in electronic communication with said controller and a random access memory component; iv) a transmitter and receiver in electronic communication with an antenna and said controller; and v) an enclosure containing at least said controller, battery, power controller, read only memory, random access memory component, and said

transmitter and receiver; and b) a network integrated reader node comprising a data logger in radio signal communication that remotely activates said at least one sensor device; II) collecting data from at least one sensor of said sensor system that is uniquely identified by radio-frequency identification; III) transferring said data to a network reader node of said sensor system; and IV) accessing said data from said network reader node such that an assessment of roadway conditions is created. In one embodiment, the device is up to six feet below the roadway surface. In one embodiment, the collected sensor data may be analyzed to determine the environmental conditions of the roadway subsurface.

Definitions

To facilitate the understanding of this invention, a number of terms are defined below. Terms defined herein have meanings as commonly understood by a person of ordinary skill in the areas relevant to the present invention. Terms such as "a", "an" and "the" are not intended to refer to only a singular entity but also plural entities and also includes the general class of which a specific example may be used for illustration. The terminology herein is used to describe specific embodiments of the invention, but their usage does not delimit the invention, except as outlined in the claims.

The term "about" as used herein, in the context of any of any assay measurements refers to +/- 5% of a given measurement.

The term "casing" or "body" as used herein, refers to a sealable hollow structure that is capable of encasing and protecting components of a wireless sensor system. For example, such components may include, but are not limited to, an embedded antenna, an integrated printed circuit board and/or environmental sensors.

The term "embedded" as used herein, refers to the result of a process wherein a first component is impressed within the material of a second component such that the first component is essentially part of the first component.

The term "antenna" as used herein, refers to any conductor material by which electromagnetic waves can be sent out or received. Commonly used conductor material includes, but is not limited to, a wire/set of wires, a flexible metal rod (e.g., an aerial), or a smooth surface concave metal dish.

The term "operational commands" as used herein, refers to a set of instructions compatible with the execution of a software program. Such instructions are capable of wireless electromagnetic transmission from an external microprocessor device and received/processed by a wireless sensor system. The content of these instructions may configure/reconfigure any component of a wireless sensor system including, but not limited to, environmental sensors, controller units, random-access memory units and/or read-only access memory units.

The term "quantitative data sets" as used herein, refers to any formatted set of data collected from an environmental sensor as contemplated herein. Such data sets may be temporarily stored in a random-access memory unit until an operational command is received/processed by a controller unit, where software stored on the read-only access memory unit executes a wireless transmission of the data sets to an external microprocessor device.

The term "external microprocessor unit" as used herein, refers to any electronic device capable of data storage and analysis that is not part of, but in wireless communication with, a wireless sensor system. For example, an external microprocessor unit may be a computer.

The term "controller unit" as used herein, refers to any device, or set of devices, that manages, commands, directs or regulates the behavior of other device(s), component(s) and/or system(s). Electronic control units may be used in electronic systems for differentially controlling the operation of each unit within the system. Such controller units may be manufactured as a series of integrated printed circuit boards that interface with a motherboard, or they may be a plurality of circuits integrated onto a single printed circuit board.

The term "read-only memory (ROM) unit" as used herein, refers to a class of storage medium used in computers and other electronic devices. Data stored in ROM can only be modified slowly, with difficulty, or not at all, so it is mainly used to distribute firmware and/or operating software (e.g., software that implements operation commands for specific hardware components and is unlikely to need frequent updates).

The term "environmental sensor" as used herein, refers to any device capable of detecting, quantifying and/or transmitting data relevant to a specific environmental parameter. Such environmental parameters include, but are not limited to, temperature, pressure, moisture (e.g., humidity) and/or deflection (e.g., a quantifiable change in spatial orientation of a solid substrate such as soil, concrete and/or asphalt).

The term "temperature sensor" as used herein, refers to any device capable of detecting, quantifying and/or transmitting data relevant to the surrounding temperature.

The term "pressure sensor" as used herein, refers to any device capable of detecting, quantifying and/or transmitting data relevant to forces that may result in deflection or compression of the surrounding solid substrate such as soil, concrete and/or asphalt.

The term "moisture sensor" as used herein, refers to any device capable of detecting, quantifying and/or transmitting data relevant to the water content in the surrounding environment.

The term "deflection sensor" as used herein, refers to any device capable of detecting, quantifying and/or transmitting data relevant to the spatial orientation of the surrounding solid substrate such as soil, concrete and/or asphalt.

The term "random-access memory unit" as used herein, refers to any device that allows data items to be read and written in roughly the same amount of time regardless of the order in which data items are accessed. Random-access memory (RAM) can take the form of integrated circuits. RAM is normally associated with volatile types of memory, where stored information can be lost if the power is removed.

The term "shutdown command" as used herein, refers to an operational command to terminate operation of a specific component of a wireless sensor system.

The term "a portion" as used herein, refers to a single component, or series of components in electrical communication, within a wireless sensor system.

The term "reactivation command" as used herein, refers to an operational command to (re)initiate operation of a specific component of a wireless sensor system.

The term "power-off command" as used herein, refers to an operational command to terminate operation of an entire wireless sensor system.

The term "power-on command" as used herein, refers to an operational command to (re)initiate operation of an entire wireless sensor system.

The term "identification code" as used herein, refers to any string of electronic information within a set of quantitative data that distinguishes the specific environmental sensor that generated the set of quantitative data from other environmental sensors. Such identification codes are usually radiofrequency identification codes (RFID), where each code assigned to each

environmental sensor is different and unique from other codes assigned to other environmental sensors.

The term "transmitter/receiver unit" as used herein, refers to any electronic device that is configured to wirelessly transmit and receive electronic information via an antenna.

The term "rechargeable battery" as used herein, refers to any electrical battery that comprises one or more electrochemical cells, wherein at least one cell is a secondary cell. Secondary cells utilize electrochemical reactions that are electrically reversible. Rechargeable batteries may be any shape and/or size. Several different combinations of chemicals are commonly used, including: lead–acid, nickel cadmium (Ni-Cd), nickel metal hydride (NiMH), lithium ion (Li-ion), and lithium ion polymer (Li-ion polymer).

The term "energy harvesting element" as used herein, refers to any device capable of collecting and transmitting energy from the ambient environment. Energy harvesting elements are more commonly known as devices that take advantage of renewable energy sources including, but not limited to, solar, geothermal, wind, tidal, electromagnetic and/or electrochemical.

The term "external reader node" as used herein, refers to any device that is configured to wirelessly transmit/receive electromagnetic signals between a plurality of wireless sensor systems and an external microprocessor device. Such communication usually is routed through at least one radio transmission base station and the internet.

The term "radio transmission base station" as used herein, refers to any device that is configured to receive and re-transmit electromagnetic signals, without changing the format and/or content of the signals. Such stations may take the form of cellular (re)transmission towers, satellite (re)transmission towers, microwave (re)transmission towers, television (re)transmission towers and/or radio (re)transmission towers.

The term "internet connected hub" as used herein, refers to any device that is configured to receive/transmit wireless electromagnetic signals that is interfaced with the internet, without changing the format and/or content of the signals.

The term "borehole" as used herein, refers to any underground access pathway, regardless of shape, size or depth, into which at least one wireless sensor system may be inserted. Such boreholes are usually cylindrical in shape and may be configured with a sealable cap.

The term "roadway surface" as used herein, refers to the top of a roadway that is exposed to the atmosphere. A roadway surface may comprise materials including, but not limited to, dirt, sand, gravel, pavement, concrete and/or asphalt.

The term "printed circuit board (PCB)" as used herein, refers to any solid substrate that mechanically supports and electrically connects electronic components using conductive tracks, pads and other features etched from copper sheets laminated onto a non-conductive substrate. PCBs can be single sided (one copper layer), double sided (two copper layers) or multi-layer. Conductors on different layers are connected with plated-through holes called vias. Advanced PCBs may contain components - capacitors, resistors or active devices - embedded in the substrate.

The term "integrated circuit (IC)" as used herein, refers to a set of electronic circuits on one small plate ("chip") of semiconductor material, normally silicon. This can be made much smaller than a discrete circuit made from independent components. ICs can be made very compact, having up to several billion transistors and other electronic components in an area the size of a fingernail. The width of each conducting line in a circuit can be between approximately 10 - 100 nanometers.

Brief Description Of The Figures

Figure 1 illustrates one embodiment of a wireless sensor system configured for remote scheduling of operational commands and/or quantitative data set transmission.

Figure 2 illustrates one embodiment of a wireless sensor system as a cut-away view of a sensor system body/casing.

Figure 3 illustrates one embodiment of a two-way cellular, satellite and/or radio network capable of transmitting quantitative data sets and/or operational commands.

Detailed Description Of The Invention

The present invention is related to sensors and wireless technology for infrastructure monitoring and maintenance. In particular, the invention is related to the monitoring and maintenance of vehicular infrastructure, such as back roads, city streets, state highways and interstate highways. For example, subsurface wireless sensors are configured for remote commanding and data transmission with external computer systems for real-time roadway

condition information. Such a system allows constant evaluation and analysis to improve repair response time and facilitates accurate prediction of roadway breakdown.

I. Conventional Network Sensing Systems

A. Roadway Monitoring Applications

Radiofrequency identification (RFID) tagged sensors have been reported for monitoring temperature and water content in road structures up to depths of 2 meters, in particular to monitor freeze thaw cycles. These devices collected continuous data about significant parameters throughout the lifecycle of the road. Specifically, there is no suggestion of non-continuous operations that are remotely scheduled via operational commands received by an external microprocessor device. Further improvements of the technology were admitted to be necessary including: i) the use of sensor tags in soil; ii) integration with energy harvesting devices; iii) integration with data storage technology; iv) monitoring winter salt effects on roadways; and v) improving underground sensor data collection methods because of conventional limitations in sensor battery lifetimes. Kõrbe, K. et al. (2012) "Measuring Temperature and Water Content in Road Structures with Sensor Equipped RFID Tags" *In: 8th International DAAAM Baltic Conference*, April 19-21 2012, Tallinn, Estonia. These RFID tagged road sensors are capable of providing real-time data. In particular, these RFID sensors were placed in various positions in roadway structures but were not configured with embedded energy harvesting elements for battery recharging nor a remote scheduling capability for sensor operations. Kaare et al. (2012) "Wireless Sensing in Road Structures Using Passive RFID Tags" *Estonian Journal of Engineering* 18(4):314–323. The present invention has solved many of the problems identified in these studies.

The use of subsurface sensors contained in subsurface layers below the top structural roadway layers have been reported. MnROAD, "Minnesota's Cold Weather Road Research Facility. Subsurface sensors" *dot.state.mn.us/mnroad/instrumentation/sub-surface-sensors.html.* These sensors were described as being capable of monitoring changes in climate, material expansion/contraction, shrinkage, and creep. Specific sensors were disclosed to determine soil moisture (NP), water table level (OS), static pressure gauge (PL/PT & XL/XT), frost depth resistivity probe (RP), positive pore water pressure (SW/XS), drainage volume (TB), thermocouple (TC), soil moisture (TD), and soil moisture / frost depth (WM). WM sensors were

placed in proximity with TD sensors, while WM sensors were installed in a vertical stack of seven sensors to capture the moisture content at various layers below the pavement surface. Several of the VM sensors have been in use for 12 years with data collected automatically every 15 minutes over the life of each sensor. However, these sensors are not capable of receiving and executing remote (re)configuration operational commands for re-scheduling data collection times and/or data transmission periods.

Subsurface pressure sensors were used in measuring subsoil stabilization to evaluate the strength/bearing capacity for soil, which serves as a foundation for structures such as roadways and pavements. While capable of evaluating roadway soil subgrades by monitoring pressure changes, these sensors are not configured with a wireless network and moisture or temperature sensors. Barron et al., "Method and Device for Measuring Underground Pressure," *United States Patent 8,690,486* (herein incorporated by reference).

B. Wireless Network Configurations

Non-contact power/interrogation systems may be used with embedded sensing networks. For example, a multidrop network of multichannel, addressable sensing modules (ASM's), may be embedded within a composite structure, remotely powered, and interrogated by a personal computer through a non-contacting inductive link. Each ASM contains a microprocessor with non-volatile memory, multiplexer, programmable gain and filter instrumentation amplifier, and sigma delta analog to digital converter (all housed in two thin surface mount packages). An embedded mothernode includes circuitry for power and data reception (into the structure), and data transmission (back out of the structure). Embedded sensors could communicate information such as strain, stress, temperature, and pressure, to allow in service tracking of the materials behavior over time. Changes in behavior would indicate the need for service, repair, or replacement. Arms et al. "System for Remote Powering and Communication with a Network of Addressable Multichannel Sensing Modules" *United States Patent Application Publication Number US 2002-0050925* (herein incorporated by reference).

Soil moisture sensors for measuring moisture content in pavement subgrade are compatible with wireless operations. For example, operable sensors were tested at depths of less than three feet, but not at a six foot level as contemplated by the present invention. Further, these wireless networks did not use energy harvesting elements for battery recharging or were (re)configured with remote operational commands to (re)schedule data collection and/or data

transmission periods. Liu et al., (2004) "Development of Soil Moisture Sensor for Measuring Moisture Content in Pavement Subgrade" *In: Project 0-4415: Remote Monitoring Moisture Content in Test Pavement in Waco and Bryan Districts*, pp 1-4, Subsurface Sensing Lab, University of Houston.

Surface acoustic wave (SAW) devices have been used with wireless sensors or wireless identification tags. For example, SAW sensors can be designed to sense several physical or chemical quantities like temperature, pressure, stress, and/or gas concentration. During operation of a wireless sensor, energy delivered from an RF pulse sent by an interrogation unit may be received by an antenna, stored as a surface acoustic wave, modified by a sensor effect and then transmitted back to an interrogation unit. SAW devices have not been suggested to be configured into a network to evaluate a roadway subgrade environment. Stelzer, A. et al. (2001) "Wireless SAW Sensors for Surface and Subsurface Sensing Applications" *Proc. SPIE-Int. Soc. Opt. Eng.* 4491:358-366.

Other wireless sensor networks have been reported as useful for roadway surface monitoring but are not configured to evaluate a roadway subgrade environment. Collotta, M. et al. (2009), "Chapter 15: Wireless Sensor Networks to Improve Road Monitoring" *In: Wireless Sensor Networks – Technology and Applications*, pp 323-346. For example, a wireless sensor network system monitored various conditions for roadways, including traffic, weather conditions, and pollution. Bielsa, A. (2013) "Smart Roads - Wireless Sensor Networks for Smart Infrastructures: A Billion Dollar Business Opportunity" *M2M Telefonica,* m2m.telefonica.com/m2m-media/m2m-blog/item/426-smart-roads-wireless-sensor-networks-for-smart-infrastructures-a-billion-dollar-business-opportunity. Alternatively, a modified wireless sensor network system was installed on public transportation buses to evaluate road surface conditions. Zoysa, K. D. et al. (2007) "A Public Transport System Based Sensor Network for Road Surface Condition Monitoring" *In: ACM SIGCOMM Workshop on Networked Systems for Developing Regions (NSDR),* Kyoto, Japan. A wireless vehicle detector system (VDS) was imbedded in the roadway for traffic flow monitoring and signal control. The VDS sensors measured traffic volume, traffic speed, vehicle occupancy, presence, headway, gap between vehicles, direction of travel, and vehicle length. University of California at Berkley (2008) "Vehicle Detection with Wireless Sensors: *In: Tech Transfer Newsletter*, techtransfer.berkeley.edu/newsletter/08-3/vehicle-detection-with-wireless-sensors.php.

Near-field radio frequencies to transmit wireless data from a roadway embedded sensor was configured to detect traffic (vehicles) and determine what type of vehicle (e.g. truck) using magnetic sensing. *United States Patent Number 6,662,099* (herein incorporated by reference). This system does not have a capability to detect and/or monitor roadway conditions or evaluate sensor depth limitations, nor alternative sensor information. Other related patents disclose using wireless sensors for monitoring roadway surface conditions. *United States Patent Numbers 6,758,089, 7,090,392, 6,745,098 and 6,695,469* (all herein incorporated by reference).

C. Antenna, Transmitters And Receivers

An antenna is an electrical device which converts electric power into electromagnetic waves, or converts electromagnetic waves into electric power. Antennae are usually used with a transmitter and/or a receiver or a single component that integrates transmission and reception (e.g., transmitter/receiver or transceiver). In transmission mode, a transmitter supplies an electric current oscillating at radio frequency (i.e., a high frequency alternating current (AC)) to the antenna's terminals, and the antenna radiates the energy from the current as electromagnetic waves. In reception mode, an antenna intercepts some of the power of an electromagnetic wave in order to produce a tiny voltage at its terminals, that is applied to a receiver to be amplified to create a power signature. There can be pattern(s) embedded within a power signature can processed using appropriate algorithms to extract information (e.g., for example, software commands and/or formatted data).

Antennas are commonly used in systems such as radio broadcasting, broadcast television, two-way radio, communications receivers, radar, cell phones, and satellite communications, as well as other devices such as garage door openers, wireless microphones, Bluetooth-enabled devices, wireless computer networks, baby monitors, and/or RFID tags.

Typically, an antenna comprises an arrangement of electrically connected metallic conductors configured to communicate with a receiver and/or transmitter. An oscillating current of electrons forced through the antenna by a transmitter will create an oscillating magnetic field around the antenna elements, while the charge of the electrons also creates an oscillating electric field along the elements. These time-varying fields radiate away from the antenna into space as a moving transverse electromagnetic field wave. Conversely, during reception, the oscillating electric and magnetic fields of an incoming electromagnetic wave exerts force on the electrons in

the antenna elements, causing them to move back and forth, creating oscillating currents in the antenna.

Antennas can be designed to transmit and receive electromagnetic waves in all horizontal directions equally (omnidirectional antennas), or preferentially in a particular direction (directional or high gain antennas). In the latter case, an antenna may also include additional elements or surfaces with no electrical connection to the transmitter or receiver, such as parasitic elements, parabolic reflectors or horns, which serve to direct the radio waves into a beam or other desired radiation pattern.

D. Controller Units

A control unit may be a device, or set of devices, that manages, commands, directs or regulates the behavior of other device(s) or system(s). Electronic control units are used in electronic systems for differentially controlling the operation of each unit within the system.

There are two common classes of control systems, open loop control systems and closed loop control systems. In open loop control systems output is generated based on inputs. In closed loop control systems current output is taken into consideration and corrections are made based on feedback. A closed loop system is also called a feedback control system. Fuzzy logic is also used in control systems.

Logic control systems were historically implemented to manage electrical power flow using interconnected relays designed using a ladder logic, programmable logic controllers (PLCs) or microcontrollers. Logic controllers may also respond to switches, light sensors, pressure switches, etc., and can cause system components to start/stop operations at specific times and/or durations. Logic systems are used to sequence mechanical operations in many applications. Programmable logic controller software can be written in many different ways – ladder diagrams, sequential function charts (SFC) or in language terms known as statement lists and stored for execution in read-only memory.

Some controllers operate using linear control systems comprising linear negative feedback to produce a control signal that is mathematically based on other variables, with a view to maintain the controlled process within an acceptable operating range. The output from a linear control system into a controlled process may be in the form of a directly variable signal, such as a sensor may be on or off or timed to operate for any specific period of time.

Many controllers are operated using fuzzy logic. A modification of fuzzy logic has created fuzzy electronics that is an electronic technology that uses fuzzy logic instead of the two-value logic more commonly used in digital electronics. Basically, a measurement in a fuzzy logic system can be partly true, that is if yes is 1 and no is 0, a fuzzy measurement can be between 0 and 1. The rules of the system are written in natural language and translated into fuzzy logic. Measurements are generally converted to values between 0 and 1 by seeing where they fall on a triangle. Usually the tip of the triangle is the maximum possible value which translates to "1." Fuzzy logic, then, modifies Boolean logic to be arithmetical. Usually the "not" operation is "output = 1 - input," the "and" operation is "output = input.1 multiplied by input.2," and "or" is "output = 1 - ((1 - input.1) multiplied by (1 - input.2))". This reduces to Boolean arithmetic if values are restricted to 0 and 1, instead of allowed to range in the unit interval [0,1]. The last step is to "defuzzify" an output. Basically, the fuzzy calculations make a value between zero and one. That number is used to select a value on a line whose slope and height converts the fuzzy value to a real-world output number.

Since modern small microprocessors are inexpensive (e.g., < $1 US), it is very common to implement control systems, including feedback loops, with computers, often as an embedded system. Feedback loops may be simulated by having a computer make periodic measurements and then calculate from this stream of measurements. Computers (e.g., microprocessor devices) can emulate logic devices by making measurements of switch inputs, calculating a logic function from these measurements and then transmitting the results out to electronic controller units. Logic systems and feedback controllers are usually implemented with programmable logic controllers which are devices commercially available from electrical supply houses. They include printed circuit boards and a simplified system for program execution. Most often they are programmed with external microprocessor devices and/or read-only memory units.

E. Random-Access Memory

Random-access memory (RAM) is a form of computer data storage. A random-access memory device allows data items to be read and written in roughly the same amount of time regardless of the order in which data items are accessed. In contrast, with other direct-access data storage media such as hard disks, CD-RWs, DVD-RWs and the older drum memory, the time required to read and write data items varies significantly depending on their physical locations on the recording medium, due to mechanical limitations such as media rotation speeds

and arm movement delays. Random-access memory can also take the form of integrated circuits. RAM is normally associated with volatile types of memory, where stored information can be lost if the power is removed.

Popular forms of modern RAM devices include, but are not limited to, static RAM (SRAM) and dynamic RAM (DRAM). In SRAM, a bit of data is stored using the state of a six transistor memory cell. This form of RAM is more expensive to produce, but is generally faster and requires less power than DRAM and, in modern computers, is often used as cache memory for the CPU. DRAM stores a bit of data using a transistor and capacitor pair, which together comprise a DRAM memory cell. The capacitor holds a high or low charge (1 or 0, respectively), and the transistor acts as a switch that lets the control circuitry on the chip read the capacitor's state of charge or change it. As this form of memory is less expensive to produce than static RAM, it is the predominant form of computer memory used in modern computers. Both static and dynamic RAM are considered volatile, as their state is lost or reset when power is removed from the system. In general, the term RAM refers solely to solid-state memory devices (either DRAM or SRAM), and more specifically the main memory in most computers.

One can read and over-write data in a RAM device. Many computer systems have a memory hierarchy consisting of CPU registers, on-die SRAM caches, external caches, DRAM, paging systems and virtual memory or swap space on a hard drive. This entire pool of memory may be referred to as "RAM" even though the various subsystems can have very different access times. Even within a hierarchy level such as DRAM, the specific row, column, bank, rank, channel, or interleave organization of the components make the access time variable, although not to the extent that rotating storage media or a tape is variable. The overall goal of using a memory hierarchy is to obtain the higher possible average access performance while minimizing the total cost of the entire memory system (generally, the memory hierarchy follows the access time with the fast CPU registers at the top and the slow hard drive at the bottom).

In many modern devices, RAM comes in an easily upgraded form of modules called memory modules or DRAM modules about the size of a few sticks of chewing gum. These can quickly be replaced should they become damaged or when changing needs demand more storage capacity. As suggested above, smaller amounts of RAM (mostly SRAM) are also integrated in the CPU and other ICs on a motherboard, as well as in hard-drives, CD-ROMs, and several other parts of a computer system. Most modern operating systems employ a method of extending

RAM capacity, known as "virtual memory". A portion of the computer's hard drive is set aside for a paging file or a scratch partition, and the combination of physical RAM and the paging file form the system's total memory. For example, if a computer has 2 GB of RAM and a 1 GB page file, the operating system has 3 GB total memory available to it. When the system runs low on physical memory, it can "swap" portions of RAM to the paging file to make room for new data, as well as to read previously swapped information back into RAM. Excessive use of this mechanism results in thrashing and generally hampers overall system performance, mainly because hard drives are far slower than RAM.

F. Read-Only Memory

Read-only memory (ROM) is a class of storage medium used in computers and other electronic devices. Data stored in ROM can only be modified slowly, with difficulty, or not at all, so it is mainly used to distribute firmware (software that is very closely tied to specific hardware, and unlikely to need frequent updates).

Read-only memory units generally refer to devices where memory is hard-wired, such as a diode matrix and/or mask ROM. Although discrete circuits can be altered (in principle), ICs cannot and are useless if the data is bad. More recently, however, ROM commonly refers to memory that is read-only in normal operation, while reserving the fact of some possible way to change it.

Other types of non-volatile memory such as erasable programmable read-only memory (EPROM) and electrically erasable programmable read-only memory (EEPROM or Flash ROM) are sometimes referred to, in an abbreviated way, as "read-only memory" (ROM); although these types of memory can be erased and re-programmed multiple times, writing to this memory takes longer and may require different procedures than reading the memory. When used in this less precise way, "ROM" indicates a non-volatile memory which serves functions typically provided by mask ROM, such as storage of program code and nonvolatile data.

Electronic devices that contain “stored programs” (e.g., executable software) may use a form of ROM storage to store executable software programs that run when an electronic device is powered on or otherwise begins execution. With the advent of integrated circuits, both ROM and its mutable counterpart static RAM were implemented as arrays of transistors in silicon chips; however, a ROM memory cell could be implemented using fewer transistors than an SRAM memory cell, since the latter needs a latch (comprising 5-20 transistors) to retain its

contents, while a ROM cell might consist of the absence (logical 0) or presence (logical 1) of one transistor connecting a bit line to a word line. Consequently, ROM could be implemented at a lower cost-per-bit than RAM for many years.

ROM is generally used to store the basic bootstrapping firmware for the main processor, as well as the various firmware needed to internally control self-contained components within an electronic system including, but not limited to, sensors, network controllers, power controllers, transmitter/receivers, graphic cards, hard disks, DVD drives, TFT screens, etc. Further, many of these ROM devices (e.g., BIOS) can be replaced with a Flash memory to permit in-place reprogramming should the need for a firmware upgrade arise. However, simple and mature sub-systems such as a communication controller integrated printed circuit board may employ mask ROM or OTP (one-time programmable).

ROM and successor technologies such as Flash are prevalent in embedded systems. These are in everything from industrial robots to home appliances and consumer electronics (MP3 players, set-top boxes, etc.) all of which are designed for specific functions, but are based on general-purpose microprocessors. With software usually tightly coupled to hardware, program changes are rarely needed in such devices (which typically lack hard disks for reasons of cost, size, or power consumption). Most products use Flash rather than mask ROM, and many provide some means for connecting to an external microprocessor device for firmware updates.

Classic mask-programmed ROM chips are integrated circuits that physically encode the data to be stored, and thus it is impossible to change their contents after fabrication. Other types of non-volatile solid-state memory permit some degree of modification:

i) Programmable read-only memory (PROM), or one-time programmable ROM (OTP), can be written to, or programmed via, a special device called a PROM programmer. Typically, this device uses high voltages to permanently destroy or create internal links (fuses or antifuses) within the chip. Consequently, a PROM can only be programmed once.

ii) Erasable programmable read-only memory (EPROM) can be erased by exposure to strong ultraviolet light (typically for 10 minutes or longer), then rewritten with a process that again needs higher than usual voltage applied. Repeated exposure to UV light will eventually wear out an EPROM, but the endurance of most EPROM chips exceeds 1000 cycles of erasing and reprogramming. EPROM chip

packages can often be identified by the prominent quartz "window" which allows UV light to enter. After programming, the window is typically covered with a label to prevent accidental erasure. Some EPROM chips are factory-erased before they are packaged, and include no window; these are effectively PROM.

iii) Electrically erasable programmable read-only memory (EEPROM) is based on a similar semiconductor structure to EPROM, but allows its entire contents (or selected banks) to be electrically erased, then rewritten electrically, so that they need not be removed from the computer (or camera, MP3 player, etc.). Writing or flashing an EEPROM is much slower (milliseconds per bit) than reading from a ROM or writing to a RAM (nanoseconds in both cases).

a) Electrically alterable read-only memory (EAROM) is a type of EEPROM that can be modified one bit at a time. Writing is a very slow process and again needs higher voltage (usually around 12 V) than is used for read access. EAROMs are intended for applications that require infrequent and only partial rewriting. EAROM may be used as non-volatile storage for critical system setup information; in many applications, EAROM has been supplanted by CMOS RAM supplied by mains power and backed-up with a lithium battery: and

b) Flash memory (or simply Flash) is a modern type of EEPROM. Flash memory can be erased and rewritten faster than ordinary EEPROM, and newer designs feature very high endurance (exceeding 1,000,000 cycles). Modern NAND flash makes efficient use of silicon chip area, resulting in individual ICs with a capacity as high as 32 GB; this feature, along with its endurance and physical durability, has allowed NAND flash to replace magnetic in some applications (such as USB flash drives). Flash memory is sometimes called flash ROM or flash EEPROM when used as a replacement for older ROM types, but not in applications that take advantage of its ability to be modified quickly and frequently. By applying write protection, some types of reprogrammable ROMs may temporarily become read-only memory.

G. Energy Harvesting Elements

Energy harvesting (i.e., for example, power harvesting or energy scavenging) is believed to be a process by which energy is derived from naturally-occurring sources (e.g., renewable energy sources). For example, as contemplated herein energy harvesting includes, but is not limited to, electromagnetic, solar energy, thermal energy, wind energy, salinity gradient energy and/or kinetic energy. Various devices are known to capture and store such renewable energy sources to power small, wireless autonomous devices, like those used in wearable electronics and wireless sensor networks. Energy harvesting has significant advantages for powering low-energy electronic devices because the renewable energy sources are present as ambient background and is free.

Energy harvesting devices can thus convert ambient energy into electrical energy having applications in various commercial sectors. For example, some energy harvesting systems convert motion into electrical energy, such as capturing the momentum of ocean waves (e.g., tidal energy sources). Other applications of energy harvesting devices include powering and/or recharging cellphones, mobile computers, radio communication equipment, and/or sensor networks.

As contemplated herein, energy harvesting can power autonomous environmental sensors such as those developed using MEMS technology. These systems are often very small and require little power, but their applications are limited by the reliance on battery power. In one embodiment, the present invention contemplates recharging a rechargeable battery using an energy harvesting element. For example, harvesting energy from ambient vibrations, wind, heat, electromagnetic signals or light could enable environmental sensors to be functional indefinitely.

Typical power densities available from energy harvesting devices are highly dependent upon the size and design of a specific harvesting generator. In general, for motion powered devices, typical values are a few $\mu W/cm^3$ for human body powered applications and hundreds of $\mu W/cm^3$ for generators powered from machinery. Most energy scavenging devices for wearable electronics generate very little power. For example, some energy harvesting elements include, but are not limited to, kinetic energy storage (e.g., using a mainspring or magnet), photovoltaic semiconductors, thermoelectric generators, microwind turbines, piezoelectric crystals/fibers and/or stray radiowave antennas.

Ambient-radiation sources may collect energy from ubiquitous radio transmitters. Historically, either a large collection area or close proximity to the radiating wireless energy source is needed to get useful power levels from this source. The nantenna is one proposed development which would overcome this limitation by making use of the abundant natural radiation (such as solar radiation). Deliberate broadcasting of RF energy may power remote devices and is useful in passive Radio Frequency Identification (RFID) systems. This method is contemplated as useful to power individual sensor system nodes in a wireless roadway sensor network.

Photovoltaic (PV) energy harvesting (e.g., solar energy sources) wireless technology offers significant advantages over wired or solely battery-powered sensor solutions: virtually inexhaustible sources of power with little or no adverse environmental effects. PV harvesting solutions have to date been powered by specially tuned amorphous silicon (aSi) a technology most used in Solar Calculators. In recent years new PV technologies have come to the forefront in energy harvesting such as Dye Sensitized Solar Cells (DSSC). The dyes absorbs light much like chlorophyll does in plants. Electrons released on impact escape to the layer of TiO2 and from there diffuse, through the electrolyte, as the dye can be tuned to the visible spectrum much higher power can be produced. At 200 lux a DSSC can provide over 15 μW per cm^2.

Piezoelectric energy harvesting elements convert mechanical strain into electric current or voltage. This strain can come from many different sources including, but not limited to, soil movement, geological deflection, human motion, low-frequency seismic vibrations, and/or acoustic noise. Piezoelectric conversions generally operates in alternating current requiring time-varying inputs at mechanical resonance to be efficient. Most piezoelectric electricity sources produce power on the order of milliwatts (mWs). Although it is not necessary to understand the mechanism of an invention, it is believed that piezoelectric elements may be useful for micro-scale devices, such as in a device harvesting geological deflection energy. For example, piezoelectric materials have the ability to transform mechanical strain energy into electrical charge. Piezo elements are being embedded in walkways to recover vibrational energy from footsteps. Micro-scale piezoelectric energy harvesting may be collected using a thin film PZT. Jeon et al., "MEMS power generator with transverse mode thin film PZT" Sensors and Actuators A: Physical 122(1):16–22 (2005). An ultra wide-bandwidth micro-scale piezoelectric energy harvesting device has been made by exploiting the nonlinear stiffness of a doubly

clamped microelectromechanical systems (MEMSs) resonator. The stretching strain in a doubly clamped beam shows a nonlinear stiffness, which provides a passive feedback and results in amplitude-stiffened Duffing mode resonance. Hajati et al., "Ultra-wide bandwidth piezoelectric energy harvesting" *Applied Physics Letters* 99(8):83-105 (2011).

H. Environmental Sensors

An environmental sensor is a device that detects quantitative changes in environmental conditions and provides a corresponding output, generally as an electrical or optical signal. Technological progress allows more and more sensors to be manufactured on a microscopic scale as microsensors using MEMS technology. In most cases, a microsensor reaches a significantly higher speed and sensitivity compared with macroscopic approaches. A sensor's sensitivity indicates how much the sensor's output changes when the input quantity being measured changes. Environmental sensors contemplated herein include, but are not limited to, temperature sensors, actinometers, frequency domain sensor, humistors, hygrometers, pyranometer, pyrgeometer, rain sensor, seismometers, snow gauge, soil moisture sensor, stream gauge and/or tide gauges.

A temperature sensor comprises a thermocouple that converts temperature to an output voltage. A thermocouple is a temperature-measuring device consisting of two dissimilar conductors that contact each other at one or more spots. It produces a voltage when the temperature of one of the spots differs from the reference temperature at other parts of the circuit. Thermocouples are a widely used type of temperature sensor for measurement and control, and can also convert a temperature gradient into electricity. Commercial thermocouples are inexpensive, interchangeable, are supplied with standard connectors, and can measure a wide range of temperatures. In contrast to most other methods of temperature measurement, thermocouples are self powered and require no external form of excitation. The main limitation with thermocouples is accuracy; system errors of less than one degree Celsius (°C) can be difficult to achieve. Any junction of dissimilar metals will produce an electric potential related to temperature. Thermocouples for practical measurement of temperature are junctions of specific alloys which have a predictable and repeatable relationship between temperature and voltage. Different alloys are used for different temperature ranges. Properties such as resistance to corrosion may also be important when choosing a type of thermocouple. Where the measurement point is far from the measuring instrument, the intermediate connection can be

made by extension wires which are less costly than the materials used to make the sensor. Thermocouples are usually standardized against a reference temperature of 0 degrees Celsius; practical instruments use electronic methods of cold-junction compensation to adjust for varying temperature at the instrument terminals. Electronic instruments can also compensate for the varying characteristics of the thermocouple, and so improve the precision and accuracy of measurements. Thermocouples are widely used in science and industry; applications include temperature measurement for kilns, gas turbine exhaust, diesel engines, and other industrial processes. Thermocouples are also used in homes, offices and businesses as the temperature sensors in thermostats, and also as flame sensors in safety devices for gas-powered major appliances.

Resistance thermometers, also called resistance temperature detectors (RTDs), are sensors used to measure temperature by correlating the resistance of the RTD element with temperature. Most RTD elements consist of a length of fine coiled wire wrapped around a ceramic or glass core. The element is usually quite fragile, so it is often placed inside a sheathed probe to protect it. The RTD element is made from a pure material, typically platinum, nickel or copper. The material has a predictable change in resistance as the temperature changes and it is this predictable change that is used to determine temperature.

A silicon bandgap temperature sensor is a common form of temperature sensor used in electronic equipment. Its main advantage is that it can be included in a silicon integrated circuit at very low cost. The principle of the sensor is that the forward voltage of a silicon diode, which may be the base-emitter junction of a bipolar junction transistor (BJT), is temperature-dependent.

Actinometers are instruments used to measure the heating power of radiation (e.g., solar radiation as pyrheliometers). An actinometer is a chemical system or physical device which determines the number of photons in a beam integrally or per unit time. This name is commonly applied to devices used in the ultraviolet and visible wavelength ranges. For example, solutions of iron(III) oxalate can be used as a chemical actinometer, while bolometers, thermopiles, and photodiodes are physical devices giving a reading that can be correlated to the number of photons detected.

A frequency domain (FD) sensor is an instrument developed for measuring soil moisture content. The instrument has an oscillating circuit, the sensing part of the sensor is embedded in the soil, and the operating frequency will depend on the value of soil's dielectric constant.

Capacitance probe, or fringe capacitance sensors, use capacitance to measure the dielectric permittivity of the soil. The volume of water in the total volume of soil most heavily influences the dielectric permittivity of the soil because the dielectric of water (80) is much greater than the other constituents of the soil (mineral soil: 4, organic matter: 4, air: 1). Thus, when the amount of water changes in the soil, the probe will measure a change in capacitance (from the change in dielectric permittivity) that can be directly correlated with a change in water content. Circuitry inside some commercial probes change the capacitance measurement into a proportional millivolt output. Other configurations comprise a neutron probe where an access tube made of PVC is installed in the soil. The probe consists of sensing head at fixed depth. The sensing head consists of an oscillator circuit, the frequency is determined by an annular electrode, fringe-effect capacitor, and the dielectric constant of the soil. Electrical impedance sensors are soil probes and use electrical impedance measurements. The most common configuration is based on the standing wave principle where a device comprises a 100 MHz sinusoidal oscillator, a fixed impedance coaxial transmission line, and probe wires which is buried in the soil. The oscillator signal is propagated along the transmission line into the soil probe, and if the probe's impedance differs from that of the transmission line, a proportion of the incident signal is reflected back along the line towards the signal source.

A humistor is a type of variable resistor whose resistance varies based on humidity. A humistor has a ceramic composition comprising at least one component having a spinel type cubic symmetry selected from the group consisting of $MgCr_2O_4$, $FeCr_2O_4$, $NiCr_2O_4$, $CoCr_2O_4$, $MnCr_2O_4$, $CuCr_2O_4$, Mg_2TiO_4, Zn_2TiO_4, Mg_2SnO_4 and Zn_2SnO_4, and, if desired, at least one component selected from the group consisting of TiO_2, ZrO_2, HfO_2 and SnO_2. A humidity sensor has a sensing portion which usually comprises a humidity-sensitive resistor composed of an organic polymer, such as a polyamide resin, polyvinyl chloride or polyethylene, or a metal oxide. A capacitive humidity sensor detects humidity based on a change of capacitance between two detection electrodes provided on a semiconductor substrate. The capacitance type humidity sensor detects humidity by measuring the change in the electrostatic capacity of an element corresponding to the ambient humidity. A resistive humidity sensor detects relative humidity by measuring the change in the resistance of an element corresponding to the ambient humidity. Most of the resistance type humidity sensors include, but are not limited to, an electrolytic, polymeric, or metallic oxide sensor element. An impedance humidity sensor changes its

electrical impedance as the humidity of the surrounding environment changes, and the measured impedance is converted into humidity readings.

Capacitive humidity hygrometer sensors determine the effect of humidity on the dielectric constant of a polymer or metal oxide material. With calibration, these sensors have an accuracy of ±2% RH in the range 5–95% RH. Capacitive sensors are robust against effects such as condensation and temporary high temperatures. Capacitive sensors are subject to contamination, drift and aging effects, but are suitable for many applications.

Resistive humidity hygrometer sensors determine the change in electrical resistance of a material due to humidity is measured. Typical materials are salts and conductive polymers. Resistive sensors are less sensitive than capacitive sensors - the change in material properties is less, so they require more complex circuitry. The material properties also tend to depend both on humidity and temperature, which means in practice that the sensor must be combined with a temperature sensor. The accuracy and robustness against condensation vary depending on the chosen resistive material. Robust, condensation-resistant sensors exist with an accuracy of up to ±3% RH.

Thermal conductivity humidity hygrometer determine the change in thermal conductivity of air due to humidity is measured. These sensors measure absolute humidity rather than relative humidity.

Modern geological sensors (e.g., seismometers) may include, but are not limited to, electronic sensors, amplifiers, and/or recording devices covering a wide range of frequencies. Some seismometer sensors can measure motions with frequencies from 500 Hz to 0.00118 Hz (1/500 = 0.002 seconds per cycle, to 1/0.00118 = 850 seconds per cycle). Mechanical suspension orientations may be horizontal, vertical or triaxial. Sensitivities generally come in three broad ranges: geophones, 50 to 750 V/m; local geologic seismographs, about 1,500 V/m; and teleseismographs, used for world survey, about 20,000 V/m. Seismometers may come with two styles of output: analog and digital. Analog seismographs require analog recording equipment, possibly including an analog-to-digital converter. The output of a digital seismograph can be simply input to a computer. It presents the data in a standard digital format (often "SE2" over Ethernet). Accelerographs and geophones are often cylindrical magnets with a spring-mounted coil inside. As case moves, the coil tends to stay stationary, so the magnetic field cuts the wires, inducing current in the output wires. They receive frequencies from several

hundred hertz down to 1 Hz. Some have electronic damping, a low-budget way to get some of the performance of the closed-loop wide-band geologic seismographs. Strain-beam accelerometers constructed as integrated circuits are too insensitive for geologic seismographs, but are widely used in geophones. Some other sensitive designs measure the current generated by the flow of a non-corrosive ionic fluid through an electric sponge or a conductive fluid through a magnetic field.

Soil moisture sensors measure the water content in soil. A soil moisture probe is made up of multiple soil moisture sensors. Technologies commonly used in soil moisture sensors include, but are not limited to, frequency domain sensors such as a capacitance sensors, neutron moisture gauges that utilize the moderator properties of water for neutrons, soil electrical resistance, time domain transmission (TDT) and time domain reflectometry (TDR) sensors that take advantage of the fact that water has a high dielectric constant such that a higher water concentration causes a higher average dielectric constant for the soil and an average dielectric constant can be sensed by measuring the speed of propagation along a buried transmission line, heat dissipation sensors that rely on the effective thermal conductivity of soil whereas soil with additional water conducts heat more readily than dry soil.

An integrated circuit piezoelectric sensor (ICP sensor) is a device used to measure parameters including, but not limited to, dynamic pressure, force, strain, and/or acceleration. It contains a sensing element made of a piezoelectric material, which converts mechanical strain into an electrical signal, and an electronic circuit to amplify this signal and transmit it to an external device. In an ICP sensor, the built-in electronics convert the high-impedance charge signal that is generated by the piezoelectric sensing element into a usable low-impedance voltage signal that can be readily transmitted, over ordinary two-wire or coaxial cables, to any voltage readout or recording device. In addition to providing crucial impedance conversion, ICP sensor circuitry can also include other signal conditioning features, such as gain, filtering, and self-test features. The simplicity of use, high accuracy, broad frequency range, and low cost of ICP accelerometers make them suitable for use in most vibration or shock applications. The routine maximum temperature of ICP accelerometers is +250 °F (+121 °C); specialty units are available that operate to +350 °F (+177 °C). The electronics within ICP accelerometers require excitation power from a constant-current regulated, DC voltage source. This power source is sometimes built into vibration meters, FFT analyzers, and vibration data collectors. A separate signal

conditioner is required when none is built into the readout. In addition to providing the required excitation, power supplies may also incorporate additional signal conditioning, such as gain, filtering, buffering, and overload indication.

A pressure sensor measures pressure created by an expression of the force required to stop a material from expanding, and is usually stated in terms of force per unit area (e.g., newtons/cm^2). A pressure sensor usually acts as a transducer; it generates a signal as a function of the pressure imposed (e.g., for example, an electrical signal). Pressure sensors can alternatively be called pressure transducers, pressure transmitters, pressure senders, pressure indicators, piezometers and manometers, among other names. Pressure-sensing technology may include, but is not limited to the following categories:

i) Force collector sensors are electronic pressure sensors that generally use a force collector including, but not limited to, diaphragm, piston, bourdon tube, or bellows to measure strain or deflection due to an applied force or pressure over an area.

ii) Piezoresistive strain gauges that use a piezoresistive effect of bonded or formed strain gauges to detect strain due to applied pressure. Common technology types are Silicon (Monocrystalline), Polysilicon Thin Film, Bonded Metal Foil, Thick Film, and Sputtered Thin Film. Generally, the strain gauges are connected to form a Wheatstone bridge circuit to maximize the output of the sensor and to reduce sensitivity to errors. This is the most commonly employed sensing technology for general purpose pressure measurement. Generally, these technologies are suited to measure absolute, gauge, vacuum, and differential pressures.

iii) Capacitive pressure sensors that use a diaphragm and pressure cavity to create a variable capacitor to detect strain due to applied pressure. Common technologies use metal, ceramic, and silicon diaphragms. Generally, these technologies are most applied to low pressures (absolute, differential and gauge).

iv) Electromagnetic pressure sensors that measure the displacement of a diaphragm by means of changes in inductance (reluctance), LVDT, Hall Effect, or by eddy current principle.

v) Piezoelectric pressure sensors that uses the piezoelectric effect in certain materials such as quartz to measure the strain upon the sensing mechanism due to pressure.

This technology is commonly employed for the measurement of highly dynamic pressures.

vi) Optical pressure sensors that use of the physical change of an optical fiber to detect strain due to applied pressure. A common example of this type utilizes Fiber Bragg Gratings. This technology is employed in challenging applications where the measurement may be highly remote, under high temperature, or may benefit from technologies inherently immune to electromagnetic interference. Another analogous technique utilizes an elastic film constructed in layers that can change reflected wavelengths according to the applied pressure (strain).

vii) Potentiometric pressure sensor that uses the motion of a wire along a resistive mechanism to detect the strain caused by applied pressure.

II. Wireless/Remotely Activated Sensor Technology

The general field of sensors and wireless technology for transmitting and receiving information is generally used at various radio frequencies. For example, radio frequency identification tags and associated external reader nodes have been used for inventory control as well as for management of assets and tracking of items from a source to final users.

In some embodiments, the present invention contemplates placing a wireless sensor system at depths of up to 6 feet that is configured to support two-way wireless communication with an external microprocessor controlled device. Further, these wireless sensor systems are initially tuned for a specific need and can be remotely retuned for new uses by the wireless receipt of operational commands. Hardened PCBs comprising RFID tags to measure parameters of interest in aeronautics has also been widely developed. Wireless sensors as contemplated herein utilize a similar hardened technology to monitor subsurface parameters of interest (e.g., for example, temperature, moisture, pressure and deflection of soil, aggregate, and roadway asphalt/concrete). One practical application of an analysis of these subsurface parameters is development of advanced frost-thaw prediction models.

In some embodiments, the present invention contemplates devices and methods for retrieving data, remotely configuring a wireless sensor system that has been placed into a deep subsurface environment. For example, the contemplated wireless sensor system may be placed both within and under a roadway surface (e.g., for example, a 6 foot depth). Such a

configuration is capable of an accurate retrieval of quantitative data sets by remote operational commands, either from a specific environmental sensor or from all environmental sensors. The modular placement of multiple wireless sensor systems within a single bore hole provides simultaneous measurements at a variety of depths. Each environmental sensor has a specific RFID tag identification profile that provides for an ability to uniquely identify which environmental sensor is providing each quantitative data set, so a roadway depth health profile can be constructed.

In one embodiment, the present invention contemplates a wireless roadway sub-surface sensing system using conventional RFID tags for sensing of subsurface parameters including, but not limited to, temperature, moisture, pressure and deflection of soil, aggregate, roadway asphalt integrity and/or roadway concrete integrity. The use of environmental underground wireless sensors as contemplated herein is not limited to roadway infrastructure, but may also be used to monitor other transportation assets including, but not limited to, bridges, rail lines, airports and/or sea ports. Some embodiments contemplated herein can also be applied to agriculture, homeland security, construction and numerous other fields.

Some embodiments of the presently contemplated invention have specific advantages over roadway sensor networks currently known in the art by embedding sensor network components within a singular body/casing including, but not limited to: i) sensor-specific radio frequency identification tags that provides an identification code within each environmental sensor's quantitative data set that distinguishes one environmental sensor from another; ii) sensor controller units; iii) random access memory for data measurement storage; iv) read-only (metadata) memory for operational execution of controller functions; v) a power controller unit; and vi) a rechargeable battery, such that the singular body/casing comprises an enclosure capable of withstanding harsh conditions - for example, those under a roadway surface at a depth of up to six (6) feet.

Further advantages are found in an ability to provide a different RFID identification signature for each wireless sensor system that may be wirelessly communicated to an external microprocessor unit. Such wireless communication is facilitated by an embedded antenna and transmitter/receiver unit to enable a two-way information flow, even at depths of up to 6 feet under a roadway without loss of efficiency and/or accuracy.

Other advantages are found by the use of an embedded energy harvesting element capable of producing power under ambient conditions (e.g., temperature and/or motion) to recharge the sensor systems battery extending the life of the device.

Other advantages are found in that all sensors can be configured/reconfigured and/or calibrated by a controller unit. The configuration and/or calibration information is obtained via received operational commands (e.g., remote service calls) from external microprocessor devices over a transmission network. This information is received by an antenna and communicated into the transmitter/receiver units for ultimate storage in a random-access memory unit. The controller unit then accesses the random-access memory unit by executing an appropriate software program located within a read-only memory unit that executes functions including, but not limited to: i) set data collection times and data collection durations for each environmental sensor; ii) set collected data transmission times/durations of a wireless sensor system; iii) disable data transmission until a read signal is received from an external microprocessor device; iv) differentially control operations (e.g., on/off) of each individual environmental sensor within a wireless sensor system; v) configure power management services (e.g., a shut down command to power-off to any one of a wireless sensor system's components) to extend the wireless sensor system's lifetime; vi) turn off a wireless sensor system until a wakeup signal is received from an external microprocessor device; vii) configure/reconfigure quantitative data set formats to optimize data transmission through a transmission network; viii) configure/reconfigure a transmitter/receiver unit for optimal performance in response to changes in surrounding environmental parameters (e.g., depth, surrounding soil materials).

Wireless in situ environmental sensor systems, as contemplated herein, use low power, low cost, and ruggedized components capable of operating underground at depths of up to 6 feet. Radio frequency identification (RFID) technology may be used to identify the environmental sensor and/or wireless sensor system source of a quantitative data set and reception of operational commands. Antennae design for these sensor systems are integrated into (e.g., embedded) a device body and/or casing. Furthermore, transmitter/receiver components are also encased within the device body and/or casing. Transmission/reception may be supported by a variety of standardized protocols, for example, an IEE 1451 smart sensor protocols and metadata to support plug and play operations with any system that uses the sensor web enablement platform.

The environmental sensors as contemplated herein further provide a capability to measure in-situ parameters, including but not limited to, soil temperature, soil moisture, soil pressure and soil deflection. Although it is not necessary to understand the mechanism of an invention it is believed that optimal environmental sensor performance may be attained when a wireless sensor system body/casing is designed to withstand harsh environments. In general, roadway in-ground sensors as contemplated herein are specifically designed to provide for environmental and physical parameter sensing relevant to overall conditions of roadway surfaces and associated subsurface layers. For example, it is contemplated that such collected parameter data can be used to model present and future roadway conditions, determining frost-thaw depths, detecting roadway motion and use, and for assessing overall roadway health.

In particular reference to Figure 1, a wireless sensor system comprises a body/casing (1) that has embedded sensor system components. Each sensor system body/casing (1) comprises an embedded antenna (2) that is in electrical communication with an integrated transmitter/receiver unit (3). The integrated transmitter/receiver unit (3) is in electrical communication with a controller (4) that communicates with a random access memory (RAM) unit (5) and a read only memory (ROM) unit (6). The ROM unit (6) provides operating software for a controller (4) command execution to configure and/or reconfigure temperature sensors (9), pressure sensors (10), moisture sensors (11) and/or deflection sensors (12). The RAM unit (5) provides for storage of received sensor command instructions and/or sensor data information for wireless transmission. A power controller (7) regulates power to a controller (4) wherein a power controller (7) receives power from a rechargeable battery (8). A rechargeable battery (8) is re-powered by an energy harvesting element (13). A cut-away illustration of a sensor system body/casing (1) with an embedded antenna (2) and embedded environmental sensors (9, 10, 11) demonstrate how sensor system components could be designed onto a body/casing core comprising a hardened printed circuit board (PCB) (14). See, Figure 2. Sensor systems (1) contemplated herein can be configured into a network of sensors using numerous methods such as cellular, satellite and/or radio networks. For example, an exemplary radio network (15) may be a weightless radio network (weightless.org) that is integrated into an external reader node (16). Hop protocols may be used to transfer data (17) from one base station (18) to another and finally to an internet connected hub (19). See, Figure 3. Such a transmission network may either collect and transmit data from a wireless sensor system (1) to the internet connected hub (19), or

transmit sensor controller (4) commands from an internet connected hub (19) to a wireless sensor system (1). Wireless systems contemplated herein comprise micro-sensor nodes (e.g., external reader nodes) that can be configured to simultaneously transmit quantitative data sets from one or more wireless sensor systems using standard electronic interfaces and "plug and play" standardized drivers and/or sensing components.

Wireless sensor system deployment may be facilitated by drilling a bore hole (~ 4" diameter) where these wireless sensor systems can be placed in a flexible sleeve (~ 3" diameter) and inserted into the bore hole. A modular and accessible system is provided by capping the bore hole above a roadway surface for future retrieval of the inserted wireless sensor systems. This configuration not only saves initial costs but also maintenance costs. For example, to retrieve a failed sensor, the roadway cap is easily and quickly removed and the sleeve containing the wireless sensor systems can be removed with all encased sensors.

Unlike commercially available network systems, this wireless remotely commanded system, does not require a roadway surface data logger that is directly attached or connected (e.g., hard wired) to a sensor node. In some embodiments, the present invention contemplates external base computer stations capable of communicating with the wireless sensors from distances up to 16 kilometers.

Experimental

Example I

Sensor Implantation Testing

Initial testing of wireless nodes and sensors as contemplated herein has demonstrated an ability to be read using a variety of different antenna types and sensor node types (passive, battery assisted passive and active).

These tests indicate that sensor nodes can be read accurately to a tested depth of 6' using 400 - 900 MHz ultra high frequency (UHF) signals.

Example II

Roadway Testing

Roadway testing of sensors, readers and communications systems will be performed in accordance with Example I using a standardized roadway test bed facility. These tests will provide data for successful wireless communication with an external base computer at depths greater than six feet, and transmission in excess of 16 kilometer without loss of performance

.

Claims

I claim:

1. A wireless sensor system within a casing, comprising:
   a. an embedded antenna, wherein said embedded antenna is configured to receive a plurality of operational commands and transmit a plurality of quantitative data sets with an external microprocessor unit;
   b. a controller unit in electrical communication with said embedded antenna, wherein said controller unit processes said plurality of operational commands and said plurality of quantitative data sets;
   c. a read-only access memory unit comprising at least one software program configured to execute said plurality of operational commands by said controller unit;
   d. at least one environmental sensor in electrical configuration with said controller unit, wherein said at least one environmental sensor is configured to collect at least one set of said plurality of quantitative data sets on receipt of at least one of said plurality of operational commands by said controller unit; and
   e. a random access memory unit configured to store said quantitative data, wherein said quantitative data is transmitted to said external microprocessor device on receipt of at least one of said plurality of operational commands by said controller unit.

2. The wireless sensor system of Claim 1, wherein said at least one environmental sensor is selected from the group consisting of a temperature sensor, a pressure sensor, a moisture sensor and a deflection sensor.

3. The wireless sensor system of Claim 1, wherein said at least one of said plurality of operational commands comprises on/off times for said at least one environmental sensor.

4. The wireless sensor system of Claim 1, wherein said at least one of said plurality of operational commands comprises a transmission disable time and a transmission read time for said quantitative data sets stored in said random-access memory unit.

5. The wireless sensor system of Claim 1, wherein said at least one of said plurality of operation commands comprises a shutdown command for at least a portion of said wireless sensor system.

6. The wireless sensor system of Claim 1, wherein said at least one of said plurality of operational commands comprises a reactivation command for at least a portion of said wireless sensor system.

7. The wireless sensor system of Claim 1, wherein said at least one of said plurality of operational commands comprises a power-off command to said wireless sensor system.

8. The wireless sensor system of Claim 1, wherein said at least one of said plurality of operation commands comprises a power-on command to said wireless sensor system.

9. The wireless sensor system of Claim 1, wherein said at least one set of said plurality of quantitative data sets comprises an identification code distinctive of said at least one environmental sensor.

10. The wireless sensor system of Claim 1, wherein the format of said at least one set of said plurality of quantitative data sets is reconfigured by said at least one operational command.

11. The wireless sensor system of Claim 1, wherein said system further comprises a transmitter/receiver unit in electrical communication with said controller unit and said antenna.

12. The wireless sensor system of Claim 11, wherein said transmitter/receiver unit is reconfigured by said at least one operational command to optimize performance in response to changed environmental parameters.

13. The wireless sensor system of Claim 1, further comprising a rechargeable battery in electrical communication with said controller unit.

14. The wireless sensor system of Claim 1, further comprising at least one energy harvesting element in electrical communication with said rechargeable battery.

15. The wireless sensor system of Claim 14, wherein said at least one energy harvesting element is selected from the group consisting of a electromagnetic energy element, solar energy element, a thermal energy element, a wind energy element, a salinity gradient energy element and a kinetic energy element.

16. The wireless sensor system of Claim 1, further comprising an external reader node in wireless communication with said antenna.

17. The wireless sensor system of Claim 16, wherein said external reader node is in wireless communication with at least one external radio transmission base station.

18. The wireless sensor system of Claim 17, wherein said at least one external radio transmission base station is in wireless communication with at least one external internet connected hub.

19. The wireless sensor system of Claim 18, wherein said at least one external internet connected hub is in electrical communication with said external microprocessor device.

20. The wireless sensor system of Claim 1, wherein said casing is inserted into a borehole.

21. The wireless sensor system of Claim 20, wherein said borehole is through a roadway surface.

22. The wireless sensor system of Claim 21, wherein said borehole is set to a depth ranging between approximately one to six feet below said roadway surface.

23. The wireless sensor system of Claim 1, wherein said controller unit, read-only access memory unit and said random-access memory unit are integrated on a printed circuit board.

24. The wireless sensor system of Claim 11, wherein said transmitter/receiver is further integrated on said printed circuit board.

25. The wireless sensor system of Claim 13, wherein said rechargeable battery is further integrated on said printed circuit board.

26. The wireless sensor system of Claim 14, wherein said at least one energy harvesting element is integrated on said printed circuit board.

AMENDED CLAIMS
received by the International Bureau on 26 July 2016 (26.07.2016)

1. A wireless sensor system within a casing, comprising:

a. an embedded antenna, wherein said embedded antenna is configured to receive a plurality of operational commands and transmit a plurality of quantitative data sets with an external microprocessor unit;

b. a controller unit in electrical communication with said embedded antenna, wherein said controller unit processes said plurality of operational commands and said plurality of quantitative data sets;

c. a read-only access memory unit comprising at least one software program configured to execute said plurality of operational commands by said controller unit;

d at least one environmental sensor that detects at least one sub-surface parameter said at least one environmental sensor in electrical configuration with said controller unit, wherein said at least one environmental sensor is configured to collect at least one set of said plurality of quantitative data sets on receipt of at least one of said plurality of operational commands by said controller unit; and

e. a random access memory unit configured to store said quantitative data, wherein said quantitative data is transmitted to said external microprocessor device on receipt of at least one of said plurality of operational commands by said controller unit.

2. The wireless sensor system of Claim 1, wherein said at least one environmental sensor that detects at least one sub-surface parameter is selected from the group consisting of a temperature sensor that detects a sub-surface temperature, a pressure sensor that detects compression or deflection in a solid substrate, a moisture sensor that detects moisture in a subgrade and a deflection sensor that detects a spatial orientation of a solid substrate.

3. The wireless sensor system of Claim 1, wherein said at least one of said plurality of operational commands comprises on/off times for said at least one environmental sensor.

4. The wireless sensor system of Claim 1, wherein said at least one of said plurality of operational commands comprises a transmission disable time and a transmission read time for said quantitative data sets stored in said random-access memory unit.

5. The wireless sensor system of Claim 1, wherein said at least one of said plurality of operation commands comprises a shutdown command for at least a portion of said wireless sensor system.

6. The wireless sensor system of Claim 1, wherein said at least one of said plurality of operational commands comprises a reactivation command for at least a portion of said wireless sensor system.

7. The wireless sensor system of Claim 1, wherein said at least one of said plurality of operational commands comprises a power-off command to said wireless sensor system.

8. The wireless sensor system of Claim 1, wherein said at least one of said plurality of operation commands comprises a power-on command to said wireless sensor system.

9. The wireless sensor system of Claim 1, wherein said at least one set of said plurality of quantitative data sets comprises an identification code distinctive of said at least one environmental sensor.

10. The wireless sensor system of Claim 1, wherein the format of said at least one set of said plurality of quantitative data sets is reconfigured by said at least one operational command.

11. The wireless sensor system of Claim 1, wherein said system further comprises a

transmitter/receiver unit in electrical communication with said controller unit and said antenna.

12. The wireless sensor system of Claim 11, wherein said transmitter/receiver unit is reconfigured by said at least one operational command to optimize performance in response to changed environmental parameters.

13. The wireless sensor system of Claim 1, further comprising a rechargeable battery in electrical communication with said controller unit.

14. The wireless sensor system of Claim 13, further comprising at least one energy harvesting element in electrical communication with said rechargeable battery.

15. The wireless sensor system of Claim 14, wherein said at least one energy harvesting element is selected from the group consisting of a electromagnetic energy element, solar energy element, a thermal energy element, a wind energy element, a salinity gradient energy element and a kinetic energy element.

16. The wireless sensor system of Claim 1, further comprising an external reader node in wireless communication with said antenna.

17. The wireless sensor system of Claim 16, wherein said external reader node is in wireless communication with at least one external radio transmission base station.

18. The wireless sensor system of Claim 17, wherein said at least one external radio transmission base station is in wireless communication with at least one external internet connected hub.

19. The wireless sensor system of Claim 18, wherein said at least one external internet connected hub is in electrical communication with said external microprocessor device.

20. The wireless sensor system of Claim 1, wherein said casing is inserted into a borehole.

21. The wireless sensor system of Claim 20, wherein said borehole is through a roadway surface.

22. The wireless sensor system of Claim 21, wherein said borehole is set to a depth ranging between approximately one to six feet below said roadway surface.

23. The wireless sensor system of Claim 1, wherein said controller unit, read-only access memory unit and said random-access memory unit are integrated on a printed circuit board.

24. The wireless sensor system of Claim 23, wherein said transmitter/receiver is further integrated on said printed circuit board.

25. The wireless sensor system of Claim 23, wherein said rechargeable battery is further integrated on said printed circuit board.

26. The wireless sensor system of Claim 23, wherein said at least one energy harvesting element is integrated on said printed circuit board.

STATEMENT UNDER ARTICLE 19 (1)

The Examiner states that:

> Claim 1 differs from D1 in an embedded antenna, and a read-only access memory unit comprising at least one software program. However, the differences are merely matters of design option when the general knowledge in the relevant field of the art is used in view of the feature of D2 ...

PCT Written Opinion; Box No. V (Continuation). The Applicants disagree. Nonetheless, without acquiescing to the Examiner's argument but to further the prosecution, Applicants have amended Claim 1 to recite that the environment sensor "detects at least one sub-surface parameter" and Claim 2 is amended to clarify the sub-surface parameter that is detected by the representative environmental sensors:

> For example, the contemplated wireless sensor system may be placed both within and under a roadway surface (e.g., for example, a 6 foot depth). Such a configuration is capable of an accurate retrieval of quantitative data sets by remote operational commands, either from a specific environmental sensor or from all environmental sensors. The modular placement of multiple wireless sensor systems within a single bore hole provides simultaneous measurements at a variety of depths. Each environmental sensor has a specific RFID tag identification profile that provides for an ability to uniquely identify which environmental sensor is providing each quantitative data set, so a roadway depth health profile can be constructed.

Applicants' Specification pg 29 ln 30 - pg 30 ln 7, and

> In one embodiment, the present invention contemplates a wireless roadway sub-surface sensing system using conventional RFID tags for sensing of subsurface parameters including, but not limited to, temperature, moisture, pressure and deflection of soil, aggregate, roadway asphalt integrity and/or roadway concrete integrity.

Applicants' Specification pg 30 ln 8 - 11, and

> The term "temperature sensor" as used herein, refers to any device capable of detecting, quantifying and/or transmitting data relevant to the surrounding temperature.
>
> The term "pressure sensor" as used herein, refers to any device capable of detecting, quantifying and/or transmitting data relevant to forces that may result in deflection or compression of the surrounding solid substrate such as soil, concrete and/or asphalt.
>
> The term "moisture sensor" as used herein, refers to any device capable of detecting, quantifying and/or transmitting data relevant to the water content in the surrounding environment.

The term "deflection sensor" as used herein, refers to any device capable of detecting, quantifying and/or transmitting data relevant to the spatial orientation of the surrounding solid substrate such as soil, concrete and/or asphalt.

Applicants' Specification pg 8 ln 1 - 11. This amendment is made not to acquiesce to the Examiner's argument but only to further the Applicants' business interests, better define one embodiment and expedite the prosecution of this application.

As such, the Applicants respectfully submit that the pending claims (independent and dependent) are novel and have inventive step over D1 and D2.

CONCLUSION

The Applicants believe that the arguments and claim amendments set forth above traverse the Examiner's rejections and, therefore, request that all grounds for rejection be withdrawn for the reasons set above. Should the Examiner believe that a telephone interview would aid in the prosecution of this application, the Applicants encourage the Examiner to call the undersigned collect at 781-848-4020.

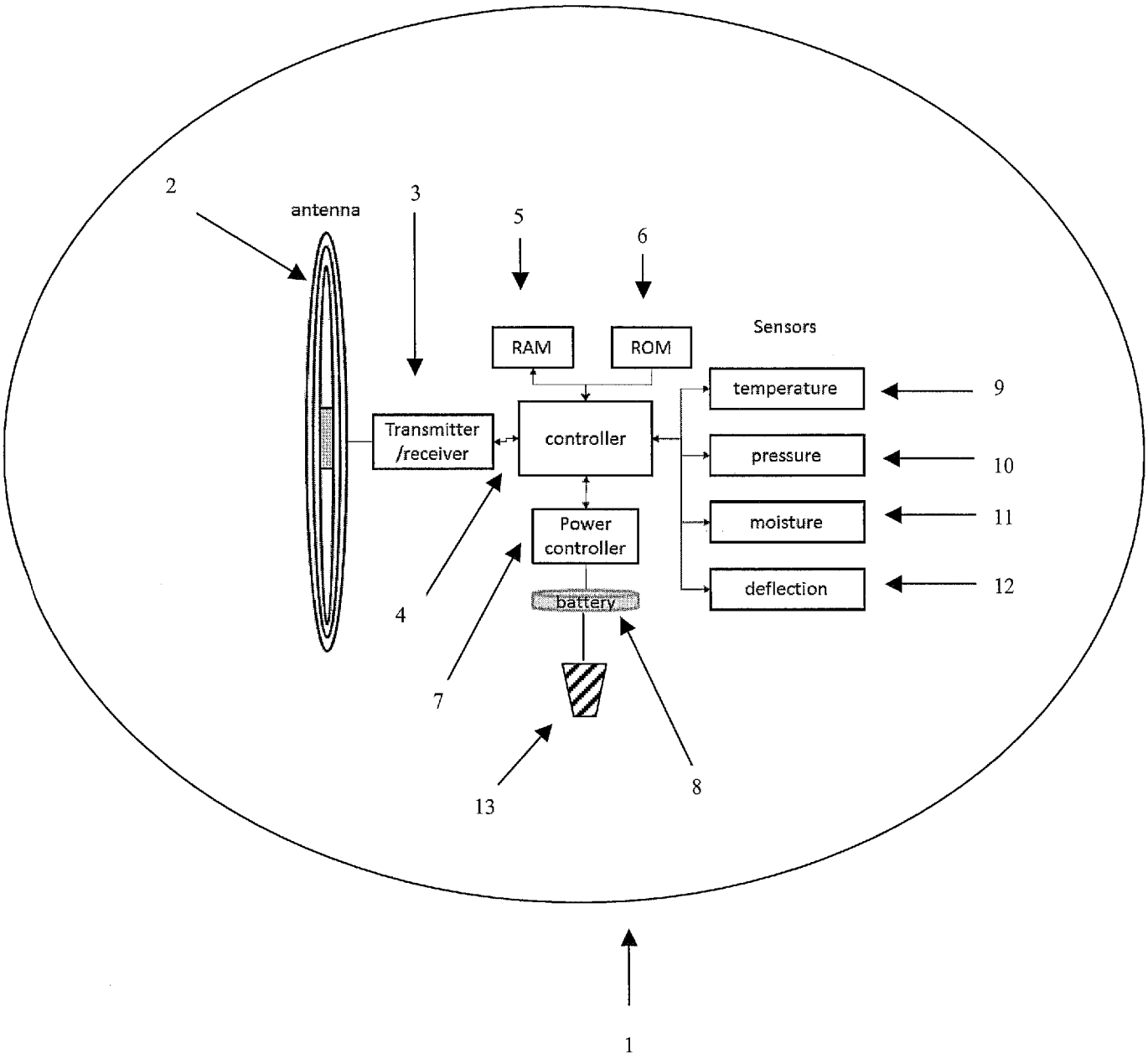

2
antenna
3
5
6
RAM
ROM
Sensors
temperature
9
Transmitter
/receiver
controller
pressure
10
moisture
11
Power
controller
deflection
12
battery
4
7
13
8
1

Figure 1

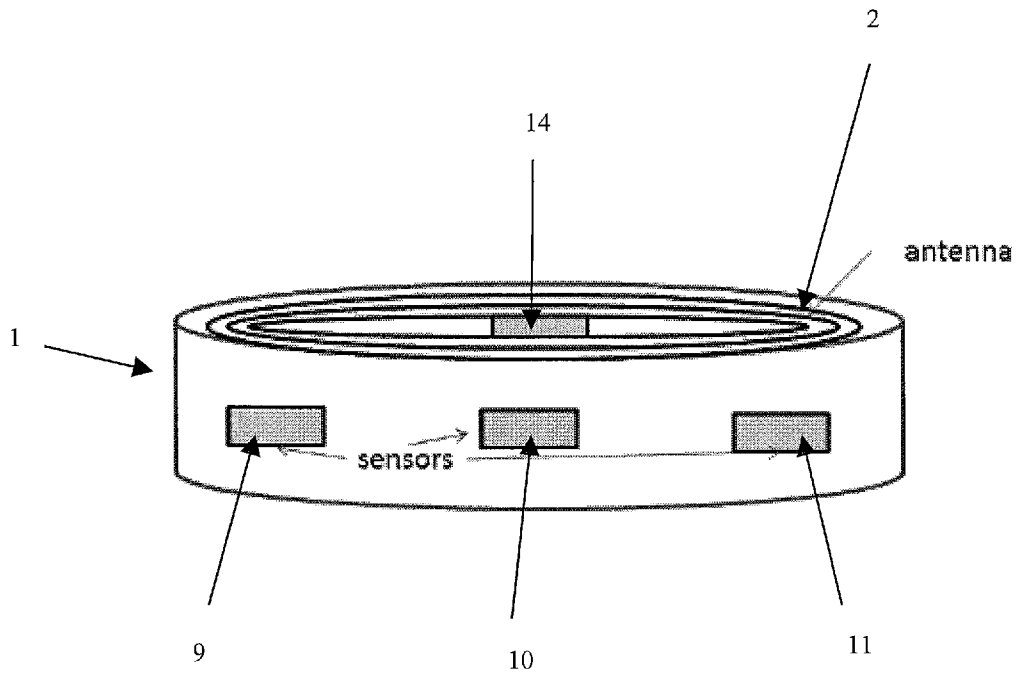


Figure 2

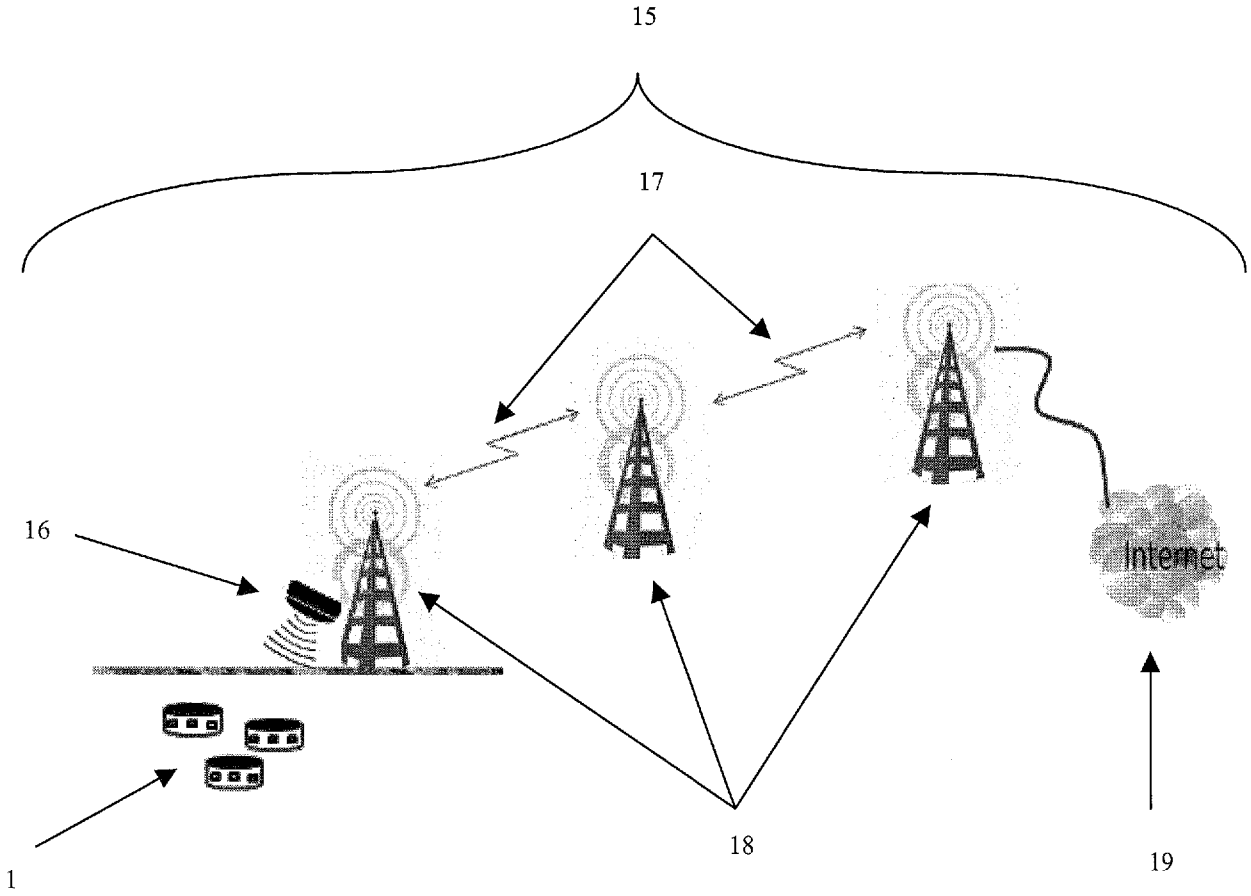


Figure 3

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2016/017548

A. CLASSIFICATION OF SUBJECT MATTER

G08C 17/02(2006.01)i, H04Q 9/00(2006.01)i, G08G 1/00(2006.01)i, G08B 21/18(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G08C 17/02; G08C 19/16; G01N 25/04; G08G 1/01; G08G 1/00; G08G 1/042; G01K 7/00; H04Q 9/00; G08B 21/18

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & Keywords: wireless sensor system, environmental sensor, borehole, external radio transmission base station, road condition

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 6441748 B1 (MASAHITO TAKAGI et al.) 27 August 2002 See column 1, lines 30-47, column 2, lines 43-48, column 3, lines 30-52, column 4, lines 15-26, column 5, lines 1-6; and figure 6.	1-26
Y	US 2004-0004554 A1 (REGASWAMY SRINIVASAN et al.) 08 January 2004 See paragraphs [0054]-[0058]; and figure 4a.	1-26
Y	KR 10-2010-0062810 A (ELECTRONICS AND TELECOMMUNICATIONS RESEARCH INSTITUTE) 10 June 2010 See paragraphs [0011], [0024]; and claim 10.	13-15,20-22,25-26
Y	US 2003-0103547 A1 (PATRICK A. LEONHARDT) 05 June 2003 See paragraph [0011]; and claim 23.	16-19
A	US 6075466 A (SIMON S. COHEN et al.) 13 June 2000 See column 8, line 14 - column 9, line 34; and figures 1A, 5.	1-26

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents,such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
30 May 2016 (30.05.2016)	**30 May 2016 (30.05.2016)**

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.
PCT/US2016/017548

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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		EP 0912969 B1	19/04/2000
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		WO 98-003950 A1	29/01/1998