MD-08-SP

Martin O'Malley, *Governor*
Anthony G. Brown, *Lt. Governor*

John D. Porcari, *Secretary*
Neil J. Pedersen, *Administrator*

STATE HIGHWAY ADMINISTRATION

RESEARCH REPORT

Survey and Investigation of The State-of-the-Art

Remote Wireless Bridge Monitoring System

C. C. Fu, Ph.D., P.E. and Yaser Jaradat, Ph.D.
The Bridge Engineering Software and Technology (BEST) Center
Department of Civil Engineering
University of Maryland
College Park, Maryland 20742

Project number MD-08-SP608B4N
FINAL REPORT

May 20, 2008

Technical Report Documentation Page

1. Report No. MD-07-SP608B4N	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Survey and Investigation of the State-of-the-Art Remote Wireless Bridge Monitoring System		5. Report Date October 12, 2008 6. Performing Organization Code
7. Author/s C. C. Fu, Ph.D., P.E. and Yaser Jaradat, Ph.D.		8. Performing Organization Report No.
9. Performing Organization Name and Address Department of Civil And Environmental Engineering University of Maryland College Park, MD 20742		10. Work Unit No. (TRAIS) 11. Contract or Grant No. SP608B4N
12. Sponsoring Organization Name and Address Maryland State Highway Administration Office of Policy & Research 707 North Calvert Street Baltimore MD 21202		13. Type of Report and Period Covered Final Report 14. Sponsoring Agency Code (7120) STMD - MDOT/SHA
15. Supplementary Notes		

16. Abstract

In order to study bridges' long-term performance, the research team is interested in finding state-of-the-art technology by the industry and research institutes using an intelligent wireless monitoring system, instead of the conventional on-site bridge testing. The system could include (1) a practical plug-and-play battery-operated "wireless" data acquisition unit and (2) state-of-the-art "wireless" data transmission and communication technologies. The objective of this project is to further investigate and integrate the "off-the-shelf" wireless remote monitoring system with the latest technology for the project use.

17. Key Words Structural Health Monitoring, Wireless, Sensor, Civil Infrastructure, Data Acquisition System	18. Distribution Statement: No restrictions This document is available from the Research Division upon request.		
19. Security Classification (of this report) None	20. Security Classification (of this page) None	21. No. Of Pages 94	22. Price

Form DOT F 1700.7 (8-72) Reproduction of form and completed page is authorized.

Survey and Investigation of the State-of-the-Art Remote Wireless Bridge Monitoring System

Table of Contents

Survey and Investigation of the State-of-the-Art Remote Wireless Bridge Monitoring System

1. Introduction

Aging of civil infrastructures is a major issue in the construction industry. Civil infrastructures can include different types of systems such as buildings, communication systems, transportation systems, etc. The majority of these structures are made of conventional building materials, steel and concrete. The service life of such structures is usually estimated based on different factors, such as the type and use of the structure.

The prediction of a realistic lifetime of an existing structure in service is an important issue to reduce costs for the future. Therefore, it will be necessary to determine the real lifetime of structures which is often much longer than estimated by the usual theoretical models. Most structures can be used much longer than their calculated life cycle. This will reduce the overall costs of the structure.

The process of continuously monitoring the status of a structure to detect damage is known as *Structural Health Monitoring (SHM)*. The importance of health monitoring of civil structures has gained considerable attention over the last two decades. A variety of methods have been employed for SHM, which have improved over time with the evolution of technology.

Structural health monitoring can be defined as the diagnostic monitoring of the integrity or condition of a structure. The intent is to detect and locate damage or degradation in structural components and to provide this information quickly and in a form easily understood by the operators or occupants of the structure. The damage may result from fatigue, large earthquakes, strong winds, and explosion or vehicle impact. Early detection of damage or structural degradation prior to local failure can prevent "runaway" catastrophic failure of the system. The large physical sizes of bridges necessitate an extensive array of different sensors and appropriate technologies for data acquisition/reduction for rational health monitoring applications. Structural health monitoring systems should also be designed for a long life under severe environmental conditions. The system should be able to automatically detect, locate and assess structural damage anywhere within the bridge system (health monitoring), and to communicate the status (alerting) to responsible authorities. At its simplest application, the threshold exceedance anywhere in the bridge is monitored and an alarm is provided if pre-set threshold levels have been exceeded. This alarm may be used to automatically divert the traffic if it indicates damage due to earthquake, explosion or impact.

1.1 Research Problem Statement and Objectives

In order to study bridges' long-term performance, the research team is interested in finding state-of-the-art technology by the industry and research institutes using an intelligent wireless monitoring system, instead of the conventional on-site bridge testing. The system could include (1) a practical plug-and-play battery-operated "wireless" data acquisition unit and (2) state-of-the-art "wireless" data transmission and communication technologies. The objective of this project is to further investigate and integrate the "off-the-shelf" wireless remote monitoring system with the latest technology for the project use.

1.2 Implementation Summary

The project is divided into four tasks:

1. Studying the system's usefulness in field applications.
2. Identifying the wireless communication technology, including investigating the feasibility of using computational simulation and sensors for bridge health monitoring;
3. Detecting the capability of the available data acquisition unit;
4. Formulating the technology and architecture for a centralized monitoring system

Task1: Studying the system's usefulness in field applications

Field monitoring has proved its usefulness in detecting the condition of a bridge. One of the focuses of this project is studying the development of vibration-based damage detection techniques for monitoring the structural health of bridge structures. Researchers found that the fundamental premise is that changes to dynamic characteristics (notably natural frequencies and mode shapes) are indicators of the presence and location of damage. The dynamic characteristics of structural components and systems in both the laboratory and field are being measured as damage is incrementally induced. Measured changes are being used to evaluate and improve the reliability of techniques to detect and locate damage. Numerical models are being calibrated to measured responses and used to simulate additional damage scenarios and investigate the limitations of the vibration-based damage detection techniques.

Task 2: Identifying the wireless communication technology, including investigating the feasibility of using computational simulation and GPS sensors for bridge health monitoring

This work finds the latest technology directed toward achieving remote monitoring capability that allows a sensor system to detect significant events at a bridge, initiate communication via a telemetry link and deposit measured data associated with the event at a central and generally accessible site. The objective of this task is to investigate methods of achieving effective remote monitoring of innovative structures through the following subtasks: wireless transmission; various sensor interfaces and data compression; dial out remote monitoring; and remote connection to internet and satellite;

The remote monitoring system conceptually developed in this project will be able to communicate with various types of sensors, such as transducers, strain gauges, thermistors, corrosion sensors, vibration sensors, and fiber optic sensors. The project will investigate the various interfaces of these sensors with the acquired data acquisition system. The devices developed will provide wireless transmission between sensors to data logger or data logger to remote monitoring site. Dynamic dial-out capability, triggered by a special event, will be investigated. The design of appropriate PC software structures will facilitate the connection of a sensor system via Internet and modem. The feasibility of transmitting data via satellite will also be studied. Eventually, the project will test integrating the technology into a complete, cost effective integrated remote data acquisition system, which will be used in the HPS70W bridge monitoring project and may be used in future field monitoring projects in Maryland.

Task 3: Detecting the capability of the newly-acquired data acquisition unit

Wireless equipment for a new class of distributed sensors, was acquired through the funding provided by the National Science Foundation (NSF) and the College of Engineering, University of Maryland for this HPS70W bridge monitoring project. This new device is capable of measuring deflections and monitoring the health of bridges under static and highway traffic live loading conditions. The gauges are arranged in a special manner that allows continuous monitoring of the deflection curve of the structure. The output signals of the gauges are wirelessly transmitted to the control station via the equipment to be acquired and then processed to determine the linear, angular displacements and twist at critical discrete points in the structure. The experimental performance of the sensor is determined in both the time and frequency domains under static and dynamic loading conditions. The experiments are conducted on existing bridges in collaboration with the Maryland State Highway Administration. However, even with the latest technology, the range of the wireless is limited to 1,000 feet from the gauge locations to the control station.

The main purpose of this task aims at integrating a prototype of the proposed distributed sensors with the new wireless communication system and finding the potential capabilities and limitations of such a system. In this effort, the miniature circuit board of the system is programmed to convert the sensor output signals into a serial data stream, and transmit these signals via wireless radio link to a remote processing station for monitoring the bridge performance and health. This task is essential to improving the practicality of the sensor by eliminating the use of any wires connecting the sensor to the monitoring station, thereby enhancing the reliability of the entire monitoring system.

Task 4: Formulating the technology and architecture for a centralized web-based monitoring system

The scope of this task is to learn how to integrate and operate the new-generation, centralized web-based monitoring systems. Many specific settings and programs need to be in place in order for the correct operation of the system. The purpose of this research is to test and apply the new-generation device using the web interface. With full knowledge of the capabilities of the system, field tests can operate smoothly.

One of the tests to be conducted is to detect the ability to execute the modem configuration command. The command allows for the modem to turn on for a specified window of time each day. Without this command only one test could be run or the modem has to be constantly on. If only one test can be run, the objective of the system to run multiple tests is not realized. If the modem is constantly on, there is a waste of battery power and an extremely short time to test before the battery dies. Early evaluation of the web-based access revealed that one of the weaknesses of the interface lies with downloading the data. It is the goal to find whether the web is effective in executing all the commands for system parameters including changing sensor time, modem configuration, and gauge configuration, beginning with either the peaks or time history program, and erasing data files.

2. Wireless Technology

Wireless communication, together with its applications and underlying technologies, is among today's most active areas of technology development. The very rapid pace of improvements in both custom and programmable integrated circuits for signal processing applications has led to the justifiable view of advanced signal processing as a key enabling the aggressively escalating capacity demands of emerging wireless systems. The term wireless networking refers to technology that enables two or more computers to communicate using standard network protocols, but without network cabling. Strictly speaking, any technology that does this could be called wireless networking. The current buzzword however generally refers to wireless LANs. This technology, fuelled by the emergence of cross-vendor industry standards such as IEEE 802.11, has produced a number of affordable wireless solutions that are growing in popularity with business and schools as well as sophisticated applications where network wiring is impossible, such as in warehousing or point-of-sale handheld equipment.

Wireless is certainly less expensive to install and support in most cases, especially in locations where it is cost prohibitive to install physical media or right-of-way issues persist.

Wireless telephony has been successful because it enables people to connect with each other regardless of location. New technologies targeted at computer networks promise to do the same for Internet connectivity.

Wireless systems promise lower capital and installation costs simultaneously ensuring reliable communication between sensing units. Due to reduced prices and rapid advancement of key technologies such as sensors, microprocessors, wireless networks and integrated circuits, it is now possible to provide a low cost alternative to the traditional wire-based monitoring systems by using a wireless monitoring system. A wireless infrastructure provides a free infrastructure by eradicating the need for the installation of wire. Also, its flexible infrastructure accommodates different network configurations such as direct communication between sensing devices. Wireless integrated network sensors (WINS) combine sensing, signal processing, decision capability, and wireless networking capability in a compact, low power system. The WINS architecture relies on a low power spectrum analyzer to process all ADC (analog-to-digital) output data to identify an event in the physical input signal time series.

2.1 Data Acquisition

The data acquisition portion of the WINS Process involves selecting the number, types and locations of sensors to be used along with the data acquisition hardware. Other considerations that must be addressed include how often the data should be collected and how to normalize the data. There are several key components of this system:

(1) Micro-sensors with built-in a-to-d conversion capability,
(2) Wireless data transmission,
(3) Power source, and
(4) A local excitation source.

Wireless data transmission makes use of very compact, low-power, R-F telecommunications hardware. Local excitation devices can overcome the problems of using ambient excitation sources that are not optimal for damage detection, and can aid in reducing the need for further data normalization.

Wireless networks offer several advantages over fixed (or "wired") networks:

Mobility:

Users move, but data is usually stored centrally. Enabling users to access data while they are in motion can lead to large productivity gains.

Ease and speed of deployment:

Many areas are difficult to wire for traditional wired LANs. Older buildings are often a problem; running cable through the walls of an older stone building to which the blueprints have been lost can be a challenge. In many places, historic preservation laws make it difficult to carry out new LAN installations in older buildings. Even in modern facilities, contracting for cable installation can be expensive and time-consuming.

Flexibility:

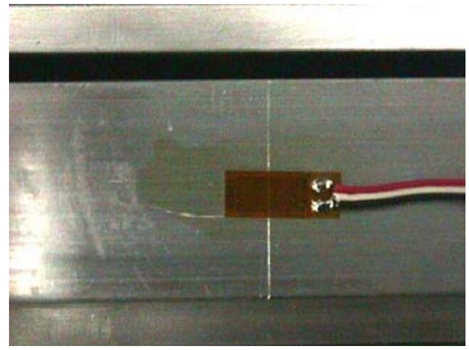
No cable means no re-cabling. Wireless networks allow users to quickly form amorphous, small group networks for a meeting, and wireless networking makes moving between cubicles and offices a snap. Expansion with wireless networks is easy because the network medium is already everywhere. There are no cables to pull, connect, or trip over. Flexibility is the big selling point for the "hot spot" market, composed mainly of hotels, airports, train stations, libraries, and cafes.

Cost:

In some cases, costs can be reduced by using wireless technology. As an example, 802.11-equipment can be used to create a wireless bridge between two buildings. Setting up a wireless bridge requires some initial capital costs in terms of outdoor equipment, access points, and wireless interfaces. After the initial capital expenditure, however, an 802.11-based, line-of-sight network will have only a negligible recurring monthly operating cost. Over time, point-to-point wireless links are far cheaper than leasing capacity from the telephone company.

2.2 Sensors

A device that produces a measurable response to a change in a physical condition is called a sensor or a transducer. Measurable response is many times electrical, but it could be optical or mechanical (but not limited to), such as a color or length change. Sensors are an important part to any measurement and automation application. In bridge application, possible sensors are described as follows:



Strain Gauges

Strain gauges measure the change in length of an object per unit length. In bridge applications, the most common strain gauges are designed to convert mechanical strain into an electrical signal. When a load is applied to an object, the electrically conductive material in the sensor is stretched, which causes an increase in the resistance of the conductor. The electrical resistance in the strain gauge varies linearly with applied strain. There are many types of electrical strain gauges, such as piezoresistive or semiconductor, bonded metallic wire, carbon-resistive, and foil gauges.

Displacement Transducers (LVDT)

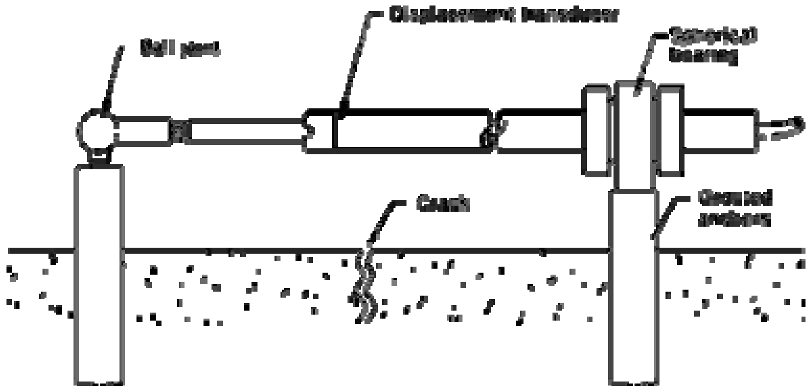
Linear variable differential transducer (LVDT) sensors measure movement in structural elements. These sensors consist of a series of inductors in a hollow cylindrical shaft with a solid core. This core or plunger stays in contact with an object and produces an electrical output proportional to its position. Force is needed to remain in contact with the object, which can come in the form of a pneumatic force, a spring, or an electric motor.

Inclinometers

Inclinometers are sensors that measure the horizontal angle or vertical deviation of a member. The sensors detect a change in position of a structural member, so they are used to measure displacement and monitor settlement in bridge applications. Common sensor technologies for inclinometers are accelerometer, capacitive, electrolytic, gas bubble in liquid, mercury, and pendulum.

Crack and Joint Sensors

Crack and joint meters monitor cracks and measure movement. Crack meters measure the change in width of a crack in a structural member, while joint meters measure the displacement and movement across joints in an assembly. The most common type of crack and joint sensors are electronic, such as the Carlson joint meter and the multiple position borehole extensometer. The displacement transducer converts mechanical displacement to an electronic output, similar to the strain gauge operating principle.



Accelerometers

Accelerometers are sensors that measure acceleration and vibration. They can have from one to three axes of measurement, where the axes are orthogonal to each other. Common types of accelerometers include piezoelectric, capacitance, null-balance, resonance, piezoresistive, and magnetic induction. When attached to a bridge member, vibration causes the accelerometer to send electric signals to a computer for conversion to units of acceleration.

Thermometers

Thermal sensors quantify temperature. Two basic methods for measuring temperature are contact and non-contact. Bridge applications call for contact devices, which need a sensor input or have an integrated sensor. Two common sensor types include vibrating wire temperature sensors and resistance temperature sensors.

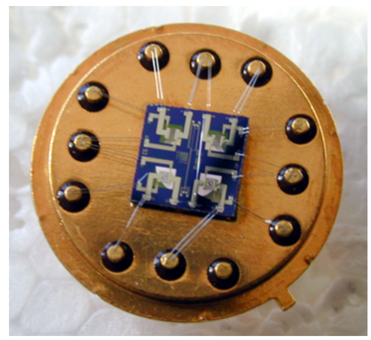
Fiber-optic Sensors

Fiber-optic sensors can perform the function of any conventional sensor, including those used in bridge applications. Optical fibers have very high bandwidths, and they are di-electric, so they are not subject to interference from electromagnetic waves. Fiber-optic sensors can function under adverse conditions from temperature, pressure, and toxicity.

Conditions that corrode metals have little effect on the optical fibers.

Fiber-optic sensors monitor structural health by sending light beams down optical fibers at regular intervals and measuring the change in time-of-flight. There are a few types of fiber-optic sensors currently being used in bridge applications. These types include Fabry-Perot sensors and Fiber Bragg Grading sensors, which measure interference fringes and frequency, respectively. A third type uses Brillouin Optical Time-Domain Reflectometry (BOTDR).

MEMS-based Sensors



Microelectromechanical (MEMS) technology combines mechanical elements with integrated electronic circuits. MEMS sensors gather information, and then the electronic circuitry can interpret and process that information. They are manufactured on an extremely small silicon chip (measured in micrometers) at relatively low cost. The small size of these devices heightens their versatility. In bridge health monitoring, MEMS technology can be applied to function as any sensor type.

GPS

Monitoring the health of bridges, dams, buildings, and other structures has evolved into an interesting mix of "cutting edge" and "tried and true" technologies. The use of automated sensors, providing virtually real-time information, in conjunction with periodic inspections and maintenance, enables the response of a structure under almost all naturally occurring physical conditions to be studied over almost any time regime. Global Positioning System (GPS) technology holds great promise as a useful tool for high-precision, real-time deformation monitoring.

Real-time kinematic (RTK) GPS can offer accurate, reliable and efficient positioning solutions and is widely applied in civil engineering nowadays. The requirement for successful RTK operation is the ability to generate and disseminate timely and reliable corrections, from a reference station with known coordinates to one or more rovers, where instantaneous integer ambiguities can be resolved. The Transmission Control Protocol/Internet Protocol (TCP/IP) protocol suite is the foundation of today's Internet. The TCP/IP protocol suite enables computers within a network to communicate with each other. On the internet a data stream is segmented into datagrams to be received by a remote host via an IP router. TCP or User Datagram Protocol (UDP) protocols are two common protocols which are widely used to reassemble the data fragments into the original data stream. TCP is bi-directional and acknowledgement of successfully receiving transmitted messages is required from receivers. Otherwise retransmission will be conducted for any failed datagram. Compared with UDP, TCP is more robust but sacrifices transmission speed. UDP is purely one way transmission. It has much faster transmission speed but does not provide reception acknowledgements.

2.3 Communication

Data Logging

Use a direct link in which a datalogger communicates directly with a computer port.

Ethernet (RS232)

An ethernet network connects to the internet and requires a cable or DSL modem. In SHM applications, the sensors are wired by a common cable that is connected to the base station. GPS receivers are used to receive and send data to and from the internet, so that a host PC can access this data via a remote connection. In recent years, ethernet technology is being replaced by the emergence of USB. Also, the cabling necessary for ethernet connections can be expensive and challenging to install, especially for large structures.

Ethernet + Radio Frequency

Ethernet technology can be combined with radio communication. Radio devices send out an electrical signal that propagates as an electromagnetic wave. In bridge applications, the base station requests data from sensors and the sensors respond. Radio frequencies are used for data transmission, which can be programmed remotely using software. One advantage of radio communication is that it is wireless.

Land Phone

Bridge health information can be transmitted via telephone lines. The data is sent over the lines in the form of analog waves; therefore, a modem is necessary to convert the data to digital, so a PC can access it. However, telephone modems have a limited bandwidth and can be a problem in isolated or older locations. The technology is becoming more outdated thanks to the development of wireless internet.

Land Phone + Radio Frequency

Another communication option involves combining telephone and radio frequency technologies. Both are described above.

Cell Phone

Cellular phone communication is a relatively new but promising option in bridge health monitoring applications. The base station near the structure is equipped with a remote cellular phone interface. This allows access to the sensing network from anywhere that has a cell phone network. Software can be used to control and program the sensors remotely. This technology requires little power and little maintenance, and it also offers fast data acquisition. In addition, this technology has reduced the costs and installation time in comparison to some other SHM communication options.

Satellite

SHM systems can communicate via satellites. Satellites orbit the earth in space as wireless receivers and transmitters. Sensor data is sent to satellites using an antenna, or the data is sent as radio signals via satellite uplinks. The satellite receives the information and sends it back to Earth to other antennas. This allows data to be shared over large distances and in areas that do not have traditional communication options, such as telephone lines or the internet. However, satellite technology is more expensive than the more traditional communication options.

UHF/VHF

Spread spectrum, UHF or VHF radio frequencies can be used to retrieve data from monitoring sites. 30MHz to 328.6 MHz are defined as Very High Frequency (VHF) and 328.6 MHz to 2.9 GHz are defined as Ultra High Frequency (UHF). FCC licenses are required for some RF ranges.

Wireless Internet

The use of wireless internet to communicate SHM information is becoming more popular in recent years. It eliminates the necessity to install and maintain cables and wiring in the sensor network. Wireless internet technology also allows remote data acquisition. Any computer can access the sensor network by using the internet.

Microwave

Microwaves are short-wavelength, high frequency signals. Like radio waves, microwaves are sent wirelessly from the base station near the structure to the host computer. The data transmission can be direct or via satellite. A disadvantage of microwave communication is that the signal can only travel in straight lines of sight; most microwave systems have a maximum range of about 30 miles. If the distance required is greater than this, a repeater station is necessary.

3. Survey of "Off-the-Shelf" Wireless Structural Health Monitoring Systems

3.1 Campbell Scientific

Campbell Scientific is active in the bridge health monitoring field. Campbell manufactures a variety of data acquisition systems with versatile capabilities that make them ideal for structural and seismic monitoring. Their data loggers have been used in applications ranging from simple beam fatigue analysis, to structural mechanics research, to continuous monitoring of large, complex structures (Campbelsci.com). Their systems can provide portable monitoring for buildings, retaining walls, highway overpasses, and bridges. Their data acquisition systems are reliable in all types of environments.

Campbell offers a range of dataloggers from the most basic system with just a few channels to expandable systems that measure hundreds of channels. The versatility of their systems allows them to be customized for each application. Scan rates can be programmed from a few hours to 100,000 times per second, depending on the datalogger model. Measurement types, recording intervals, and processing algorithms are also programmable. Dataloggers not only provide advanced measurement capabilities, but can also control external devices. The CR211 or the CR216 Datalogger combines an on-board 922 MHz or 2.4 GHz spread spectrum radio with the functionality of the CR200 Datalogger. It can measure the sensor(s) attached to it and then transmits its data wirelessly via its spread spectrum radio to a "master" datalogger, like the CR5000 and CR9000X.

Other than the CR5000 and CR9000X dataloggers, the power consumption is very low. Low enough that long-term usage can be obtained from a small 7 amp per hour battery and a 10 watt or 20 watt solar panel. The CR5000 pulls about ¼ amp of current @ 12 VDC, whereas the CR9000X will draw from 1 to 4 amps (at 12 VDC) depending on the configuration of measurement modules (the CR9000X input channels are user-configurable so the system can change based upon application needs).

The CR5000 and CR9000 dataloggers provide higher measurement speeds for dynamic measurements. Both loggers have been used to monitor bridges, buildings, light towers, interstate sign hangers, blast zones, etc. The CR5000 has a maximum measurement rate of 4500 Hz aggregate while the CR9000X can support simultaneous (~70 nanoseconds) 50 kHz measurements. The researchers at the ATLSS Research Center utilize the CR9000X and our CR9052DC anti-alias filter modules for their accelerometer and strain gauge applications. The CR9052DC is superior in noisy environments where strain gauge measurements are required.

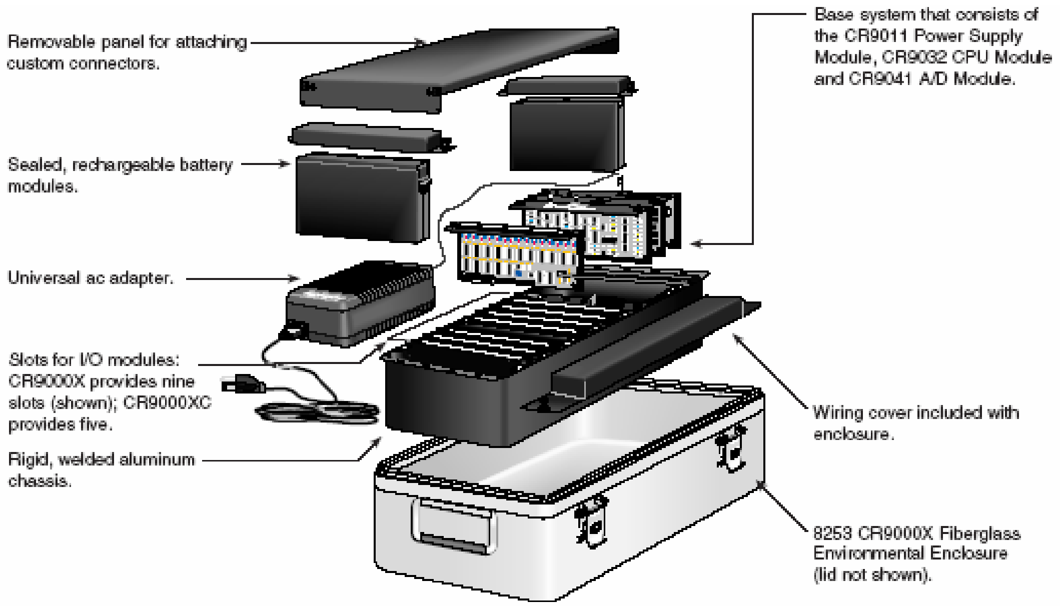


Figure 0-1:CR9000X

Communications:

Campbell Scientific offers a full range of telecommunication options that allow interrogation of a datalogger from a remote computer. Combinations of on-site and telecommunications can be used in the same application for maximum flexibility, convenience, and reliability.

Telephone communication links require a CSI field modem at the datalogger site and a Hayes-compatible modem at the calling end. Remote RF or multidrop networks are accessible by telephone. Several types of telephones are available, including CDMA cellular digital modems as well as rugged landline modems for field use. Voice modems allow you to access your data via voice or to retrieve data to your computer. Many of the telecommunications links can be combined. Typical examples include Phone-to-RF and Phone-to-multidrop.

3.2 Crossbow

Crossbow Technology is a supplier of inertial sensor systems for aviation, land, and marine applications and other instrumentation sensors as well as a full solutions supplier in the wireless sensor networking arena and a manufacturer of smart dust wireless sensors. Crossbow has for years been creating and deploying smaller, smarter, wireless sensing devices and mesh networking platforms for large scale defense, environmental, agricultural, and industrial monitoring and control, building automation, security and asset tracking applications. Crossbow’s open architecture, TinyOS-based platform, enables highly intelligent multi-sensing devices to dynamically and reliably self-organize in order to efficiently capture and send detailed physical data anywhere, anytime.

By using wireless sensor technology available from Crossbow, seismic acceleration, strain, temperature, wind speed, and even GPS data can be monitored and measured. Alerts can be generated when parameters exceed certain thresholds; monitoring data can be used with existing analysis tools.

Sensor/Data Acquisition Modules

- Sensor Boards - Crossbow offers a variety of sensor boards for the MICA, MICA2, MICAz and MICA2DOT motes. These include MDA100, MTS300/MTS310, MDA500, MTS400/420, MDA300, and MTS510.
- Data Acquisition Board
  - Easy-to-use Screw Terminals
  - 8 Analog Inputs
  - 8 Digital Input/Output
  - 2 Relay Channels
  - Selectable Sensor Excitation of 2.5, 3, 5V
  - Qualified with numerous external environmental probes including humidity, soil moisture, PAR light, wind speed and direction
- Gateways & Network Interfaces Modules

MIB - Programming and Interface Boards

Crossbow offers the MIB family of basic Mote programming and interface boards for the MICA, MICA2, MICAz and MICA2DOT. The MIB510 offers RS-232 based serial programming and serial interface to the MICA family of Motes. The MIB520 provides USB connectivity to the MICA2/MICAz Motes for both communication and in-system programming. The MIB600 Ethernet Interface board delivers a LAN data interface and Mote programming.

Stargate - XScale Network Interface and Single Board Computer

Crossbow offers the Stargate family of products for interfacing its Sensor Networks to the Internet and WWW. The Stargate is a powerful Linux-based single board computer with Compact Flash, PCMCIA, Ethernet, USB Host, and additional interface. Crossbow is also planning the release of a series of packaging options for their Gateways. These options include indoor and outdoor packaging.

Processor/Radio Modules

Crossbow ships three Mote Processor/Radio module families – MICAz (MPR2400), MICA2 (MPR400), and MICA2DOT (MPR500). The MICAz radio works on the global 2.4GHz ISM band and supports IEEE802.15.4 and ZigBee. The MICA2 and MICA2DOT family is available in 315,433,868/900MHz configurations and support frequency agile operation.

These modules are designed for both end-user and OEM applications. All modules provide a processor that runs TinyOS-based code, two-way ISM band radio transceiver, and a logger memory capable of storing up to 100,000 measurements. In addition, these boards offer enhanced processor capabilities, including a boot-loader that allows for over-air reprogramming of Mote code.

Accelerometers

Crossbow accelerometers provide superior performance in small packages. Crossbow currently offers four different accelerometer series (LP, LF, HF, and TG), each optimized to meet the customer needs in a variety of typical applications.

3.3 Geokon

Instruments manufactured by Geokon are used primarily for monitoring the safety and stability of civil and mining structures such as dams, tunnels, mine openings, foundations, piles, embankments, retaining walls, slopes, subway systems, underground powerhouses, bridges, culverts, pipelines, shafts, slurry wall excavations, braced excavations, tiebacks, nuclear waste repositories, ground water remediation schemes and the like. Geokon manufactures a complete line of geotechnical instruments including extensometers, piezometers, strain gauges, crackmeters, jointmeters, load cells, settlement sensors, pressure cells, inclinometers, dataloggers and many other custom items made to order. The products section of this web site provides a brief description of Geokon’s standard product lines. Geokon’s dataloggers are designed around Campbell Scientific Inc.’s (CSI) similar models to eliminate the effects of electrical noise and interference on Geokon’s vibrating wire sensor signals.

Dataloggers

Model 8001 LC-1 Single-Channel Datalogger

The Model 8001 LC-1 Single-Channel Datalogger is an easy-to-use instrument for all types of vibrating wire sensors and their internal temperature sensors. It is housed in a rugged, weather-resistant Nema 4X aluminum enclosure designed for use in field environments. Power is supplied by two easily accessible ‘D’ cells or by solar panel for remote long-term applications. 8000 readings can be stored before the oldest data is over-written. Strings of LC-1 dataloggers can be daisy-chained using the RS-485 interface and versions are available with radios and modems to provide remote readout capabilities.

Model 8020 MICRO-10 Datalogger

The Model 8020 MICRO-10 Datalogger is a versatile low-cost instrument capable of reading practically all types of electrical sensors such as vibrating wire transducers, linear potentiometers, DCDTs, RTDs, thermistors, thermocouples, accelerometers, etc. The heart of the Micro-10 Datalogger is the Campbell Scientific CR10X MCU which serves as a microcomputer, clock, multimeter, calibrator, scanner, frequency counter and controller. The Micro-10 comes in a sealed weatherproof Nema 4 enclosure and includes the Model 8020-47 DSP filter for the elimination of spurious noise effects. User friendly Windows based MultiLogger software allows easy programming of scan intervals, selection of sensor types, setting of alarms, etc. Data is retrieved by telephone modems, solid state storage module, radios, or satellite transmission.

3.4 Daytronic

Daytronic offers a comprehensive hardware family from transducers and single-channel benchtop or machine-dedicated conditioner/indicators to high-speed PC/PLC front-ends and factory-wide distributed networks. Typical applications include production line automated testing, remote safety monitoring, prototype evaluation, "real time" process control via closed-loop servo systems, and statistical analysis of both "real time" and "historical" data. Daytronic products are used not only in automobile and turbine engine testing, but in durability, structural, and environmental tests.

System 10 Data Acquisition & Control System

System 10 is a flexible high-speed front-end systemwith stand-alone intelligence. Configurations range from simple multichannel dataloggers to factory-wide distributed tasking networks. While serving as a low-noise data-collection unit for virtually any computer under any operating system and programming language, System 10 provides multiple individually configurable data displays along with real-time signal processing and process control functions—all completely independent of the host computer.

A Self-Contained System

- fully modular, and indefinitely expandable through addition of mainframe racks and/or networking of individual "on-site" units.
- *completely stand-alone functionality* ensures maximum uptime; **no computer or programming required**
- high analog and logic I/O capacity
- multiple multichannel data displays, individually configurable by the user
- quick and easy setup or reconfiguration in the field (free Windows software available for setup of "A-Sized" systems)

3.5 Digitexx Data Systems

Digitexx provides System solutions for real-time data acquisition and processing for structural health monitoring, tall buildings, special structures (dams, bridges, and power generating facilities), and life lines. Also, Digitexx offers systems solutions for central monitoring for national arrays and regional sub-networks and distributed information data center.

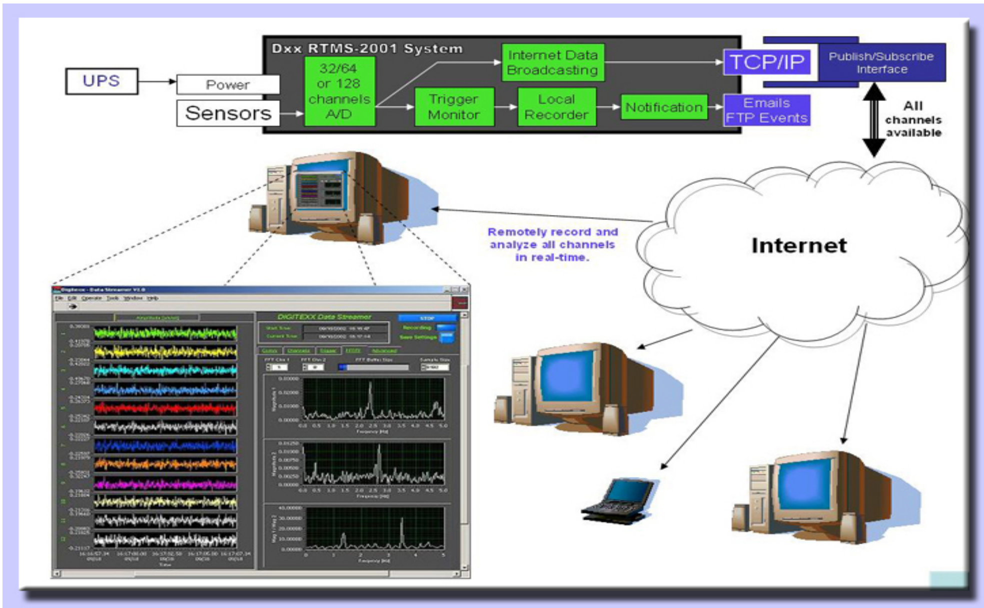
RTMS-2001RM Real-time Structural Monitoring System

This high performance COTS (Commercially Off The Shelf) system is a multi-channel (24, 32, 64) real-time data acquisition and analysis system, with manual and event driven (on any 10 channels) triggering. With 16 or 24 -bit resolution, the system has a sampling rate of up to 1,000 samples per second per channel.

Standard features include:
- Data Broadcasting (all channels) over the Internet
- Pre-event
- Post-event
- Voting mechanism triggering
- Adjustable gain
- Signal filtering

The system also offers an extensive set of remote tools:

- Monitoring (E-mail, Web)
- Streaming (Internet/TCP)
- Data retrieval (TCP, FTP).



PDAQ-8 Portable Data Acquisition System

This fully portable system offers all the utilities and power needed for a field/remote operation. With 8 or 16 recording channels, 16-bit resolution, adjustable gain, manual and event driven triggering on all channels, the PDAQ-8 can record up to 20,000 samples per second per channel. The signal filtering package which accompanies the system also offers different topologies and type combinations, which are useful in the field. The PDAQ-8 is light (~14lbs) including the laptop and the battery. Its power is versatile (internal battery, external battery, or AC), and data can be visualized in real-time as it is acquired.

3.6 Computer Aided Solutions

Computer Aided Solutions has a range of expertise in designing and building systems for a variety of measurement, test, logging, control and vision applications. From cameras and sensors to acquisition hardware to operator interfaces, CAS can assemble turnkey systems to meet customers' exact needs. In addition to integration services, CAS also is able to provide other value-added services such as providing a single point of purchase for multiple items or loading and configuring software for embedded or industrial computers.

DataTaker

DataTaker is a supplier of data loggers and data recording equipment to customers in industry, public utilities, scientific and educational institutions.

- 4 to 12 Universal Analog Sensor Channels
- ±30 V Input Measurement Range
- 12 Digital Channels
- Serial Sensor Channel
- Built-in Display
- USB Memory Slot for Easy Data Transfer
- Ethernet, USB, RS-232, or RS-485 Communication with PC
- Modem Support
- Easy-to-use, Configurable, Windows-based Software
- Stand-alone and Real-time Data Acquisition
- Remote Monitoring and Control
- Removable Screw Terminals

DataTaker DT80

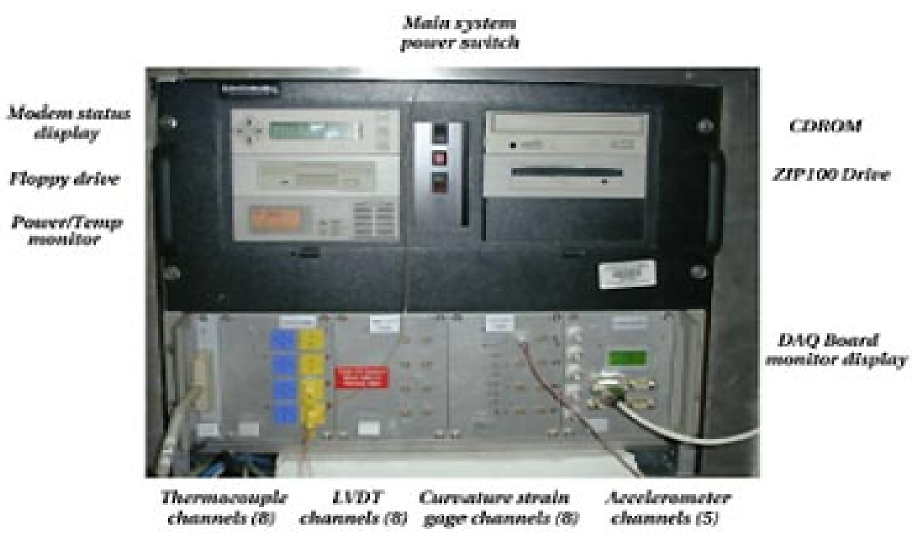
3.7 Smart Structures

Smart Structures LLC's systems aim to monitor various aspects of the structural health of the nation's bridge stock. These systems comprise integrated and unique devices with associated technology that analyze data obtained from 'smart' bridge management systems for the purpose of identifying potential structural deficiencies and trends that will reduce costs and inconveniences involved in maintenance, repair and rehabilitation, while improving safety and achievable in real time.

Data Acquisition System for Structural Monitoring

The system consists of a rack-mount UNIX-based PC (top rack) which controls a multifunction data acquisition card and modem. Signal conditioning modules and anti-aliasing filters are contained in a separate enclosure (lower rack). All the components are mounted in a rugged and vibration-isolated industrial rack mount chassis for easy transport and rapid setup should off-site repairs ever become necessary. The chassis contains an internal heater for cold weather operation. Although the system is supplied with a keyboard and mouse, power-up is automatic, and shutdown is via a simple pushbutton sequence. The system supports 32 channels and can be customized to support more channels as per client's requirements.

Fielded components of the monitoring system

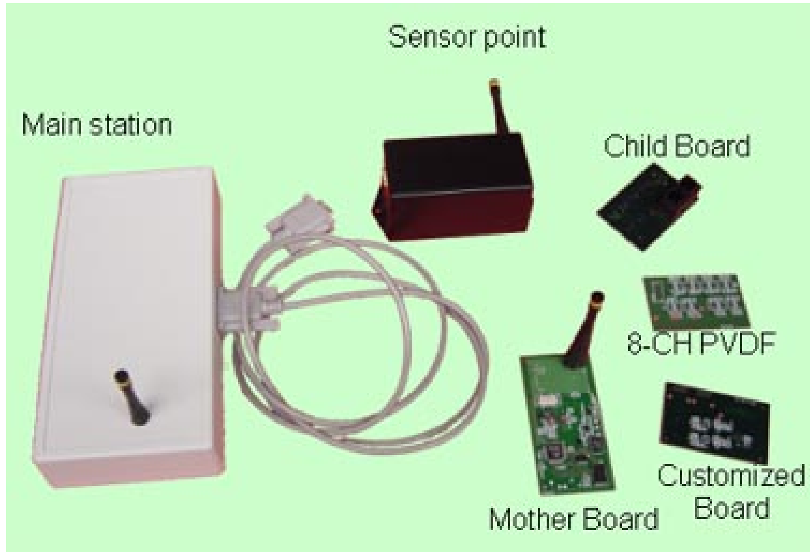


Close-up of instrumentation panels

Wireless Smart Sensor Network

Features:

- Remote controller is housed in an enclosure that collects and controls data using the serial port of a PC and customized software.
- Wireless PVDF is a Multi-channel (8) wireless smart sensor unit
- 12 bit resolution
- Sampling rate: 100 kHz
- Data Bus Architecture
- Two working modes: real-time mode and sleep mode.
- Operates in the 916 MHz frequency band.
- Coverage has a range of 300 feet with 33.6k baud – over large areas (several miles) are available.



3.8 Acellent Technologies

Acellent Technologies, Inc. is developing novel sensor networking techniques for monitoring the integrity of composite and metal structures.

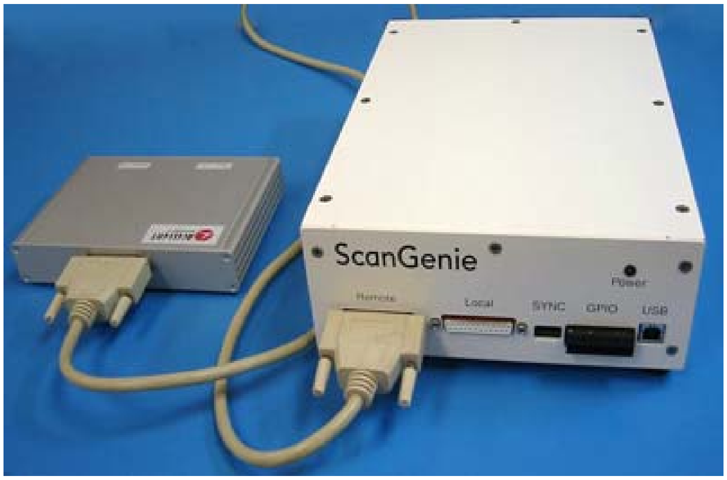
Acellent's patented SMART Layer is a thin dielectric film with an embedded network of distributed piezoelectric actuators/sensors. The layer can also incorporate other types of sensors to monitor properties such as strain and moisture. The monitoring layer either can be surface-mounted on existing structures or integrated into composite structures during fabrication thereby providing a built-in nondestructive assessment of the internal and external states of the structure.

The SMART Layer can network with various types of sensor enhancing its monitoring capabilities and eliminating the need to place each type of sensor individually on the structure.

Acellent Technologies manufactures SMART Layers in a variety of sizes, shapes, and complexities. The SMART Layers vary in complexity from 2 - sensor flat strips to multi-sensor 3-D shells. By integrating the SMART Layer with Acellent's software, the SMART Suitcase can monitor, in real time, the condition of the structures as well as automatically diagnose the "health" condition in terms of damage, hidden cracks, and material degradation of the structures with minimum human interference.

Acellent's SMART Layers have the following characteristic features:

- Ease of installation
- Actuating and Sensing Capabilities
- Built-in sensor network for area sensing
- Signal Consistency and Sensor Reliability
- Multiple wires from every transducer to improve reliability of the circuit
- Shielded SMART Layer to reduce EM noise
- Robust hardwire connections, 30 sensors wired directly to the SMART Suitcase
- Consistently repeatable signals



Acellent recently released the next generation SMART Suitcase system – ScanGenie. The ScanGenie is a USB-interfaced high-performance, portable device for the ultimate SHM application. For local mode, the layer is connected directly to the local port; the channels are limited up to 8 PZT actuators and 8 sensors. For remote mode, Acellent designed a Switch Amplifier Box to be used with the ScanGenie. Switch Amplifier (SA) Box is a remote high voltage switching and amplification hardware device that supports up to 64 PZT actuators/sensors and two temperature sensors.

3.9 Texas Measurements, Inc.

Texas Measurements markets strain gauges, measurement transducers, and associated instrumentation. Texas Measurements, Inc. represents the Japanese company Tokyo Sokki Kenkyujo Co., Ltd (TML). Their dataloggers/static strainmeters including TDS-602 with 1000 channels (built-in 30 channels max.), color LCD; TDS-303 with 1000 channels (built-in 30 channels max.), LCD; TDS-300 with 250 channels, operated by PC; TDS-102 with 100 channels (built-in 20 channels max.), battery operation, built-in telemetry MODEM and THS-1000 with 1000 channels, ultra-high speed scanning.

Dataloggers

TDS-102

Features

- 10 or 20 channels, expandable up to 100 channels
- Long term measuring using the built-in battery and sleep interval timer.
- Large capacity data memory provided
- Data transfer via RS-232C interface or memory card
- Wireless transmission of measurement data by the onboard telemeter.

3.10 Bridge Diagnostics, Inc.

Since 1989, Bridge Diagnostics, Inc. (BDI) has developed and refined their bridge testing equipment and procedures for field testing.

Structural Testing System (BDI-STSII)

The system was designed for performing live-load tests on highway and railroad bridges. Developed through field testing, the system is portable, lightweight, and implementable. The BDI-STSII allows a typical short-to medium-span bridge or similar structure to be instrumented and load tested with up to 64 sensors in less than a day by a two-person crew.

- The BDI Strain Transducers supplied with each BDI-STSII can be mounted to steel, concrete, or timber members with minimal surface preparation.
- The BDI Strain Transducers automatically identify themselves to the BDI-STSII, and are called “Intelliducers.” Intelliducers eliminate the need to track channel numbers or calibration factors.
- The Automatic Remote Load Position Indicator allows tracking of the loading vehicle as it crosses the structure. It also provides radio communication between the testing personnel.
- BDI WinSTS testing software is included.
- The BDI-STSII units are connected in series and mounted on the structure.
- Lead-wire length for each sensor is only about 15 feet (6 meters), rather than the typical 100-200 feet (30-60 meters). This reduces weight and saves time rolling up cables.

- Heavy-duty, quick-lock military-style connectors are used throughout for easy and fast assembly.
- The BDI-STSII can be powered either by a 110/220 AC generator or a 12VDC battery.

The NEW Wireless Structural Testing System (STS-WiFi) is the latest development by Bridge Diagnostics, Inc.. Based on the design of our very successful BDI-STSII data acquisition systems, the STS-WiFi operates on standard 802.11 b/g broadband wireless communications, eliminating the need to run cables to each 4-channel node and back to the computer.

3.11 ATI Telemetric

ATI products have been used extensively for powertrain testing, in automotive, aerospace and a variety of other R&D-related applications. ATI transmitters are crystal-based and do not require tuning. The operation also permits multiple channels to be used concurrently, with no cross-talk. The RF output signal from the transmitters is relatively powerful which makes the system immune to electrical interference. Since the transmitters are potted in high strength epoxy, they are capable of operating in environments with excessive vibration and heat

ATI offers a wide range of telemetry transmitter products. Whether it's a single channel or multi-channel system, a short range or long range requirement, ATI has a solution for various transducer / sensor inputs.

Wireless Bridge Monitoring System - Telemetry

The **2050B** series Transmitters can transmit most any type of sensor up to 500 feet; eliminating long cable runs. The Transmitter is housed in a weatherproof NEMA 4X enclosure for outdoor use and supplies excitation to the sensor. The 3024 Receiver monitors up to four Transmitters while the 3025 monitors up to eight. As many as 32 separate Transmitters may be used in the same vicinity. The 2025BP-400 Receiver and 3022 Receiver Module each provide a dedicated Digital Display which can be scaled to read out in engineering units. Continuous analog outputs per channel are provided. Possible applications include highway bridges, railroad bridges, lock gates, amusement park rides, and coupling signals from rotating machinery.

THE ACQUIRED EQUIPMENT

The equipment acquired through this NSF grant prior to this project includes:

1. **Two, 16 Channel *Digital* Strain Gauge Transmitter** (Model 3040D-16).
   - Provides 5 volts excitation and bridge completion. Can be configured for ¼, ½ or full bridge inputs.
   - Powered internal rechargeable battery.
   - Spare battery and intelligent charger provided
   - Minimum 1000 feet range, and capable of up to 2 miles.
   - Provides minimum 200 samples/second per channel update rate.
   - Independent coarse zero/balance control per channel. Permits compensation for large initial offsets.
   - Independent low/OK/high input balance indicator per channel.
   - Includes remote power activation from receiver.
2. **Eight, 4 Channel Receiver Module** (Model 3023M-2.4); includes digital display and analog outputs.
3. **Two Receiver Mainframe; (Model 3023);** accepts up to eight Receiver Modules. Can be powered 12 Volts DC.
4. **Status Module** (Model 3022-4S); includes following status for each channel: No data, good data and bad data. Also includes push-button tare per channel.
5. **Notebook PC-Based Data Acquisition System;** includes the following:
   - IBM ThinkPad G40 Notebook Computer. Includes 2.4GHz P4, 15"' XGA TFT, 256MB DDR, 40GB hard drive and CD-RW/DVD drive.
   - GW Instruments Model iNet-230**,** PCMCIA Controller for Windows based notebook computer. Includes Strip Chart/oscilloscope software and Visual Basic and C interface.
   - Model iNet-100B**,** instruNet External A/D Box with 3m cable. Includes BNC and screw terminal connections.

The Main Specifications of the telemetry system are listed in the following table.

Table 4.1. Specifications of the equipment needed

Transmitter System	Receiver Module	Receiver Mainframes
• **Bandwidth:** DC to 1100 Hz (-3dB)	• **Display:** 3½ Digit LCD	• **Power:** 12 Volts DC
• **Transmission range**: 1000ft ≤ 2 miles	• **Resolution:** Infinite	
• **Integral Non-Linearity:** ±0.10%	• **Output:** ± 2 Volts	
• **Repeatability:** ±0.05%		
• **Maximum Error:** < 0.25% F.S.		

FEATURES
• Transmits Sensor Signals via Radio Transmitter to a Stationary Receiver
• Transmitters available for Strain, Torque, Pressure, Voltage, Temperature... Most Any Type of Signal
• Eliminates LONG cable runs.
• Up to 32 Channels of Input Signals.
• Immune to electromagnetic interference, dust, oil, moisture, etc.
• Single channel systems available.
• Remote Shunt Calibration Option Available.

3.12 Geomation Inc.

To help make dams safer, Geomation developed the System 2300, the first networked system designed specifically to overcome the barriers inherent in collecting data automatically from multiple instruments deployed within and around dams. Beginning with the U.S. Army Corps of Engineers in 1987, Geomation customers now include many U.S. and foreign government agencies, water and power utility companies, energy producers and transporters, and natural resource ministries in various regions of the world.

The Geomation System 2300 field monitoring and control system supports universal instrumentation interfacing.

- Directly connect sensors to monitor temperature, pressure, flow, level, displacement and environmental parameters.
- Directly connect to valves and actuators to control remote processes. Flexible communications allow you to deploy reliable field networks economically.

- Bridge wireless field networks to long range WANs.
- Communication options include radio, wireline, fiber-optic, telephone, microwave and satellite.
- Battery operation allows economical installation in remote locations.

The GEONET Suite of software applications provides integrated system solutions: system configuration and programming, logging, data presentation, graphing, reporting and data management. GEONET Suite is built on an open-access SQL database, and supports customized development for your specific needs with Microsoft Visual Basic© and the GEONET Developer's Kit.

Recnetly, Geomation is expanding beyond its proven System 2300 products with the addition of a more versatile platform-the OutDAQ™ Generation-that uses industry standard communication protocols and is more cost effective and reliable for dispersed outdoor installations. The OutDAQ Generation is suited to a wide range of applications-wherever environmental factors pose challenges to the automated collection and monitoring of physical data.

OutDAQ RTUs offer you flexible solutions for remote automated data acquisition and control. You can purchase a complete SCADA system, including installation and commissioning by Geomation or one of our Authorized Distributors; or you can buy just the components you need to extend the functionality of an existing system. Integrated assemblies are also available to make installation in the field quick and simple. Whether acquired as a total system solution or as individual components or assemblies, OutDAQ RTUs are fully backed by Geomation service and technical support, so you'll always know where to go for answers and satisfaction.

3.13 MicroStrain Inc.

MicroStrain has developed and patented temperature compensated differential variable reluctance transducers (DVRT). Due to their extremely small size, high accuracy and ability to withstand high temperatures, temperature gradients, saline and pressurized oil environments, the MicroStrain DVRT stands out from other sensors in the market.

MicroStrain's sophisticated sensor technology has applications with medical instruments, health monitoring of civil structures (bridges, dams, buildings) and aerospace sensing.

Wireless

Linearly sensor development in wireless technology, MicroStrain launched the Micro Datalogging Transceiver in 2001. This is a high-speed system that enables wireless data collection from up to 8 channels of sensor input. It can be triggered to initiate data collection remotely or by any specified sensor exceeding a programmable threshold.

The scalable Wireless Web Sensor Network allows the transmission of data from 1,000 unique sensors to one web based receiver, enabling data to be shared globally in real time. This network can be used in structural, agricultural, environmental, military and industrial applications. The system can not only collect data from hundreds of nodes, but can then, utilizing the web based system, allow the information to be shared with an unlimited number of users with secure access. For example, in an earthquake situation, the sensors can report information to construction engineers as well as fire, police and safety workers to intelligently assist critical emergency response.

For structural health monitoring (SHA) application, wireless tri-axial accelerometer nodes, such as Microstrain G-Link, and wireless multi-channel strain gauge nodes, such as Microstrain SG-Link, are frequently deployed. A base station can be placed within certain distances of the sensing nodes as shown in the following picture. To make a remotely reprogrammable wireless sensors for structural health monitoring (Arms, et al, 2004), the base station can be housed in a heated NEMA 4X enclosure and can contain a digital ratio receiver with RS-232 output, Panasonic "Toughbook" personal computer, 802.11b WiFi card with PCMCIA interface to the notebook PC, and cellular telephone with modem interface. This system was deployed on a large civil structure in North America, i.e. the Ben Franklin Bridge, spanning the Delaware River from Camden NJ to Philadelphia, PA.

3.14 Physical Acoustics Corporation (PAC)

Physical Acoustics Corporation (PAC) designs and manufactures acoustic emission sensors and acoustic emission measurement instruments under a program which is certified to ISO-9001 standards. Acoustic emission research is offered at the advanced basic level, with the company currently active on several commercial industrial and government applied research contracts. PAC's REACT division is collaborating with universities and industry for advancing AE sensor technology.

PAC provides complete Acoustic Emission system solutions to satisfy industry, universities and research establishment needs worldwide for:

- Sensors, Systems and Software for Source Characterization
- DSP for polyMODAL Wave Studies research and applications
- Feature Extraction Knowledge-based Systems for Industrial use
- Technology Transfer and Strategic Alliances to expand AE
- Educational Training and AE Certification

AE instrumentation typically consists of:

- A sensor that converts a stress (sound) wave to an electrical signal
- A low noise amplifier that raises the signal to a usable level
- Signal processing electronics for feature extraction and waveform capture
- Microprocessor, and DSP based parallel distributing processing instrumentation
- Knowledge-based software for easy analysis, defect correlation and development of expert systems that comply with demanding AE Standards
- Decision and feedback electronics to utilize the information

3.15 Kipp & Zonen, Inc.

Kipp & Zonen specializes in the field of measurement and recording of meteorological and industrial parameters involving high-performance radiometers and data acquisition equipment. They also provide scientific solution systems to the climatology, agronomy, hydrology, public health and industrial markets, in particular those related to climate change and global warming.

Data Loggers

Kipp & Zonen loggers can read-out the majority of our sensors. They have a waterproof version, meant for unattended logging up to 6 months and offer a handheld logger with a LCD-display.

The **LOGBOX** series are waterproof dataloggers meant for unattended logging for longer periods up to 6 months on its internal batteries. The **LOGBOX** has a large storage memory and extended battery life to allow long term projects to be monitored at remote sites, or short term logging at frequent intervals. The majority of Kipp & Zonen sensors can be connected to the **LOGBOX**. Choose combinations of single ended or differential voltage, current inputs or digital count.

Channels can be individually programmed with logging interval and gain to suit each sensor type. Units for scaling are defined by the user for easy and straightforward operation. At user-set levels, the **LOGBOX** will give an electrical relay or alarm output from up to two different channels. There is also a timed start/stop function. It is supplied with a 'ready-to-go' package of batteries, datalead & Windows communication software.

The Logbox datalogger has the following features:

- Weatherproof housing and connectors as standard
- Unattended battery operation up to 6 months
- 4 or 8 channel versions with optional relay outputs
- Internal clock and selectable logging intervals
- Software, cables, battery and connectors included

3.16 Geospace Technolgies

Geospace Technologies specializes in Geophones, Hydrophones, Seismology Equipment, Connectors, Vibration Detectors, Velocity Detectors, Sensors, Seismic Exploration, Pressure Transducers, Seismic Instrumentation, Pressure Detectors, Vibration Monitoring, Intrusion Detection, Cable, Firing Line, Leader Wire, Motion Sensors, Transducers, Telemetry Cable, 3-Component, 4-Component, Ocean Bottom. For industrial applications, Geo Space produces Geophones which are sensors that convert motion into electric signals and are known as geophones or seismometers. They are also called detectors, transducers or probes.

Geophones are used today in a variety of applications that are far removed from their original purpose as earthquake detectors. Geo Space began producing geophones over three decades ago and is one of the world's leading manufacturers of inertial sensors. Geo Space geophones have been taken to sea, dropped from the air, buried on the battlefield, attached to machinery and deployed on the moon.

Vibration Monitoring

Measurement of vibration levels to locate and position critical machinery and equipment in factories and offices. Low-cost geophones are ideal solutions to this problem.

Structural Evaluation

Geophones detect seismic and microseismic events to predict and analyze deformation of buildings, dams, mines and bridges.

3.17 National Instruments

National Instruments is a technology pioneer and leader in virtual instrumentation – a revolutionary concept that has changed the way engineers and scientists in industry, government, and academia approach measurement and automation. National Instruments, a market leader in PC-based data acquisition, offers the most complete family of data acquisition devices for desktop, portable, and networked applications on several buses, including PCI, PCI Express, PXI, PCMCIA, USB, CompactFlash, Ethernet, and FireWire, and many operating systems, including Windows, Linux, Mac OS X, Pocket PC/Windows CE, and RTX

The M Series family of data acquisition devices sets a new standard for performance, value, I/O capability, and safety. It features the newly designed NI-STC 2 device controller, NI-PGIA 2 amplifier technology, NI-MCal calibration technology, and high-speed digital isolators.

NI CompactDAQ hardware provides the plug-and-play simplicity of USB to sensor and electrical measurements on the benchtop, in the field, and on the production line. By combining the ease of use and low cost of a data logger with the performance and flexibility of modular instrumentation, NI CompactDAQ delivers data measurements in a small and affordable system.

NI supplies a wireless modem which provides:

- Wireless FieldPoint-to-PC link
- Cables directly to the FP-1000 module or any RS-232 serial port
- Transmits up to 20 miles with line-of-sight antennas
- Superior noise immunity
- Certified for use in the U.S., Canada, and Latin America

The SRM6000 is a spread-spectrum modem that converts a FieldPoint I/O system to a wireless I/O system. The radio modem is designed specifically for wireless communications in industrial environments with noise immunity and range using frequency-hopping spread-spectrum technology. The SRM6000 radio modem is preconfigured to work with FieldPoint I/O systems and software, which simplifies the implementation of a wireless FieldPoint system.

NI also supplies PDS Data Acquisition device which provides:

- Handheld measurement hardware for PocketPC
- Up to 16-bit accuracy, up to 500 kS/s sampling rate
- Multifunction devices for PCMCIA
- Handheld measurement application development with LabVIEW PDA

NI data acquisition (DAQ) devices for PDAs give the freedom to take measurements anywhere. They are small and light enough to fit in the pocket and work with a number of industrial handheld devices and touch-panel displays that run Windows CE or PocketPC OSs. NI PDA DAQ products can solve your challenges, whether you wish to combine the functionality of multiple handheld instruments onto a single PDA, or you want to develop a completely customized handheld measurement device that takes advantage of PDA memory and wireless communication capabilities.

4. Survey of Wireless Structural Health Monitoring Systems by Researchers

4.1 Northwestern University's Basic Industrial Research Laboratory (BIRL)

Northwestern University's Basic Industrial Research Laboratory (BIRL) installed what is believed to be the first global remote monitoring system on a highway bridge. The system-installed on a rolling bascule bridge over Sturgeon Bay in Door County, WI, allows engineers located at the laboratory in Evanston, Ill., to closely monitor crack propagation and other conditions on the bridge, which is near the end of its design life. The basic approach to global monitoring pioneered by BIRL requires the use of one or more remotely mounted data acquisition systems linked by RF transceivers to a host computer connected to a phone line. The SoMat Model 2100 field computer system from SoMat Corp. of Champaign, Ill., is used in this application. SoMat's Test Control Software (TCS) includes a networking feature that allows multiple Model 2100 field computers to communicate with a single host. The field computers communicate with the host computer via a pair of SoMat Wireless Data Links (WDL), a rugged spread-spectrum RF transceiver. With the proper antennae, a WDL pair is capable of communication and control of a Model 2100 at distances up to one mile from the host computer.

4.2 Stanford University/University of Michigan

The prototype wireless SHM system by Professor Kincho H. Law of Stanford University, Professor Jerome P. Lynch and other researchers of these two universities is developed with a wireless sensor network server and several sensing units. Each wireless sensing unit can accommodate four analog sensors. The data server is used to organize and collect data from multiple wireless sensing units in the sensor network. The data server also provides Internet connectivity so the sensor data or desired engineering analysis results can be viewed remotely from other computers over the Internet. The design of the prototype system is oriented for a large-scale and low-power wireless SHM application in civil structures. Its hardware performance is summarized below:

- Power consumption: 70-80 mA when active; 0.1 mA standby
- Communication range: 90 m indoor, 300 m outdoor
- 16 bit Analog-to-Digital conversion, 4 A2D channels
- Local data processing
- Point-to-multipoint, and peer-to-peer communication
- Low hardware cost

4.3 Iowa State University

The HPS Bridge SHM system developed by Iowa State University consists of off-the-shelf components from several manufacturers. The primary components of the SHM system are as follows:

- Strain sensing equipment of a Si425-500 interrogator developed by Micro Optics, Inc. and 30 Fiber Bragg Grating (FBG) sensors
- Video equipment of network video camera
- Networking components of DSL modem with Internet service, 2.4 GHz Wireless-802.11g router and access points
- Data management equipment of data collection server, web server amd data storage server.

The SHM system can then be divided into three major sub-systems as data storage/processing sub-system, gateway sub-system and data acquisition sub-system to effectively monitor and evaluate structures continuously from a remote site.

4.4 Clarkson University

The Wireless Intelligent Sensor and Actuator Network (WISAN) is designed with the goal of continuous structural health monitoring in mind. The intelligent capabilities of limited signal processing, compression, waveform generation and embedded computation intelligence (fuzzy logic and neural networks) makes this sensor network almost universally applicable to a variety of SHM methods.

Data acquisition models of WISAN are built around an ultra-low-power microcontroller MSP430F1611 from Texas Instruments. The data acquisition models each provide up to six 12-bit analog-to-digital channels, two 12-bit digital-to-analog channels, 16 general-purpose digital input/output channels, and up to 16M-bit of non-volatile EEPROM memory. The modular design allows a scalable design with a flexible number of input/output channels and relieves the network protocol controller from executing the signal processing tasks. The data acquisition modules connect to the network interface via an internal bus. The network interface modul implements the network protocol based on IEFFF 802.15.4 standard. A 2.4G-Hz module CC2420 from Chipcon is used for the radio interface. All the components of a sensor node are low-priced, facilitating the target cost of $100 per channel. Currently the Clarkson University research team is working on the second generation design of this prototype.

4.5 University of California, Berkeley

A wireless Sensor Network (WSN) for structural health monitoring by the University of California, Berkeley team was designed, implemented, deployed and tested on the 4200-ft long main span and the south tower of the Golden Gate Bridge (GGB). The wireless network is composed of multiple nodes and a base station. A node consists of a note and a sensor board. The node measures vibration at two different orders of dynamic bandwidth with the data communicated back to the base station through wireless communication. The base station is a server providing more computational power and larger storage than a mote node and possibly a connection to the Internet. In the GGB deployment a laptop was used as a base station. The software architecture of the GGB nodes uses new components integrated into the TinyOS infrastructure.

The data acquisition system performs three primary functions: sensing, signal processing and communication. Crossbox MicaZ motes were for control and control and communications. The analog signals output by the low-noise accelerometers pass through low-pass antialiasing filters on the way to a 16-bit analog-to-digital converted before the data is first logged into the flash of the mote and then wirelessly transmitted.

The network deployed at the Golden Gate Bridge measured ambient structural accelerations from wind load at closely spaced locations, as well as strong shaking from a possible earthquake, all at low cost and without interfering with the operation of the bridge. For this deployment, 64 motes were deployed over the main span and southern tower and the deployment is considered the largest wireless sensor network ever installed for structural health monitoring purposes.

4.6 University of Southern California

A multi-hop wireless data acquisition system (Wisden) is developed for structural health monitoring on a large seismic test structure. Wisden is a system consisting of tens of wireless nodes, placed at various locations on a large structure, to collect and reliably transmit time-synchronized structural vibration data to a base station. Each Wisden node is a Mica2 or MicaZ mote that measures structural vibrations with the help of a vibration card developed for high quality low-power vibration sensing. Attached to this card is a highly sensitive tri-axial accelerometer. A base station provides the functionality equivalent to a data logger or data acquisition unit. Wisden implements a NACK-based hybrid hop-by-hop and end-to-end reliability scheme. Wisden also uses certain techniques in data synchronization and data compression in transmission.

4.7 University of Dayton

A virtual Wireless Infrastructure Evaluation (WISE) system was designed and developed with two primary features: (1) software-based virtual instrumentation program developed to control the system, acquire data, and monitor the results through a user-friendly graphical user interface, and (2) computer-controlled site network of multiple-channel wireless transmitters throughout the structure.

4.8 University of Illinois at Chicago

In this application, a simple Radio Frequency (RF) channel with Frequency Shift Keying (FSK) modification is employed to cut down the power consumption but still provide demanded data rate and transmit range. The wireless sensors are designed to be low-cost, non-onstructive, unattended and dynamically reprogrammable. Both a wireless accelerameter and a PVDF made of piezoelectric materials are used in this application to measure frequency, displacement and also strain. Features of the wireless PVDF sensor includes up to 8 PVDF sensors connected to single unit, with operating range of –20 to +85 °C, PVDF sensor bandwidth of 50 Hz, and wireless operating range of up to 500 feet outside and 200 feet inside. The MEMS-based accelerometer is 5 mm x 5mm x 2 mm in size with an 8 lead hermetic LCC package. The wireless accelerometers have specifications of ±200 mg acceleration input range, -30 to +85 °C operating temperature range, 100 mg/V sensitivity, 0.1-100 Hz accelerometer bandwidth and the same wireless operating range as that of the PVDF sensor. The inspection based on a wireless sensor approach was conducted on a deck beam bridge.

4.9 University of Illinois at Urbana

The Berkeley Mote smart sensor is recognized as an important new open hardware/software platform utilizing TinyOS for structural health monitoring and damage detection (SHM/DD). The mote platform has a microprocessor and radio communication. However, the available sensors are limited and are not necessarily optimized for civil infrastructure application. Low frequency responses (e.g., below 1 Hz) typically found in tall and/or long civil infrastructure need to be measured; sensors with DC capacity are preferable. The UI research team selected foil strain gauges, which have a wide frequency range, including DC, and polyvinylidene fluoride (PVDF) film sensors, for their low power requirements, ruggedness and low cost.

4.10 TransTech Systems, Inc.

The Bridge Health Monitoring System (BriHMS), which was developed in a program sponsored by U.S. Tank-Automotive and Armaments Command under contract DAAE07-99-C-L069, was designed to provide dynamic, real-time information to battle control centers regarding bridge capacity and health, including:

- Dynamic calculation of Military Load Classification (MLC)
- Real-time condition assessment
- Remaining life information estimation

The mechanical and electrical components were tested and calibrated in the laboratory before being mounted on the AVLB test bridge. The BriHMS was designed and constructed with off-the-shelf parts and software, which are readily available. This allows for the system to be produced easily and rapidly. It also allows for easy acquisition of spare and replacement parts and grades to be implemented without the need for a major redesign. The bridge mounted portion, referred to as the Local Processing Module, consists of an intelligent data acquisition system that includes necessary signal conditioning to obtain the data, digitize it, multiplex it and transmit it over a wireless Ethernet link. The Remote Processing Module is a ruggedized Panasonic notebook computer that performs all processing and analysis. Data acquisition is controlled by operator commands on the notebook computer.

4.11 The Western Transportation Institute (WTI) at Montana State University

Three types of strain gauges were used in evaluating MDT's highway bridge deck designs: Vishay foil strain gauges (35) bonded to reinforcing steel, Vishay embedment-type strain gauges (7) suspended in the concrete and Geokon vibrating wire strain gauges (16) suspended in the concrete. Additionally, 16 temperatures are recorded via thermistors internal to the vibrating wire strain gauges. The strain gauges were placed in each bridge deck prior to casting the concrete. The gauges were positioned to monitor both longitudinal and transverse strains at three different depths through the thickness of the deck.

All strain data is collected and stored using a single CR5000 Measurement and Control System mounted under each bridge. The bonded and embedded gauges require Wheatstone Bridge arrangements designed and fabricated by WTI. Corresponding voltages are routed through a single AM16/32 multiplexer. Vibrating wire strains and temperatures are read using a single AVW1 Vibrating Wire Interface coupled with an AM16/32 multiplexer. All gauges are read once every hour. For the wireless communication part, data from each bridge is periodically transmitted to WTI through the Internet via a network of RF400 Spread Spectrum radios based at the Saco School. Weather data is monitored using a CR10X Measurement and Control System and transmitted directly to WTI via the Internet.

5. Field Investigation Experience of Wireless Structural Health Monitoring Systems

5.1 Case study 1: Wireless Structural Monitoring using Ivoncon of a Newly Replaced Fiber Reinforced Plastics (FRP) Bridge Deck

The first experiment using the wireless technology by the research team is on the rehabilitation of a steel truss bridge (MD24 over Deer Creek) using lightweight FRP deck (Figure 5.1). Load tests and structural monitoring are commonly used to gain information regarding the health and performance of an existing structure. For structures using relatively new materials, such as FRP, the use of load tests can prove the structures' capacity. Wireless structural monitoring system is a new technology developed through a previous FHWA small business innovation research (SBIR) contract to Invocon, Inc. in Conroe, Texas. This contract developed a commercially ready data acquisition system (Figure 5.2) to greatly reduce the level of effort required to instrument and obtain data from bridges. The system includes a small data acquisition and communication node connected to four strain gauges that can acquire data in digital form, and relay the data to a local base receiver attached to a personal computer. In this load test, five boxes were linked in a "smart" network to control the data acquisition process and find the path of least interference for data transmission. By using this system, the effort of instrumenting a bridge was reduced by more than half compared to hard-wired systems. This system is the prototype of a more advanced MITE-WIS (Multiple-Input Tiny Enhanced Wireless Instrumentation) and can store data in 2 Mbytes of non-volatile memory and later be downloaded via RF. The distance from unit (node station as shown in Figure 5.2) to receiver (base) of this test is about 50 feet. According to the specifications, the direct line-of-site (LOS) wireless distance is about 200 feet and no-LOS distance is about 100 feet. There is no “remote” component in this project.

Figure 5.1 – Placement of a FRP Deck Panel

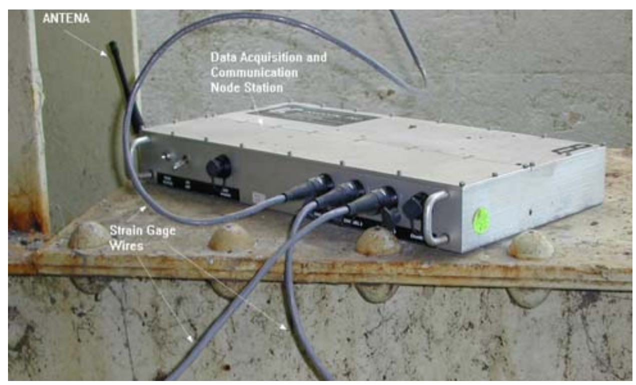


Figure 5.2 - Wireless Structural Monitoring System with Node Station hard-wired to the strain gauges but wireless to the Base Receiver through Antenna

Measurements were made on various elements, including FRP deck, of the bridge under live load (Figure 5.3). The field tests and associated finite element analyses may provide a higher confidence to the owner and users in the replaced deck of the MD24 over Deer Creek Bridge and for using this new material in the future.

Figure 5.3 - Bridge Testing Calibration of the New FRP Deck under Live Load

5.2 Case Study 2: Pilot Study using Microstrain of Bridge MD140 over MD27

Figure 5.4 – Microstrain Agile-Link Base Station

Microstrain product SG-Link® Wireless Strain Node is a direct strain gauge input datalogging transceiver for use in high speed wireless sensor networks. Base Stations (Figure 5.4) are designed to operate as an integral part of the Agile-Link™ high speed wireless sensor network, providing communication between the host PC, Single Board Computer or microcontroller and remote wireless nodes. A prototype of the UMD devised sensor is bonded to one of the second phase girders (girder numbers 1 through 5) of bridge MD140 over MD 27 (Figure 5.5). The bridge is 300 feet long. The sensor is then used to monitor bridge deflection during concrete pouring on the bridge deck. Figure 6 shows a comparison between the sensor output (blue) and the predictions of a finite element model (red). Reasonable agreement was observed. For a complete remote package, a more sophistic a base station with remotely reprogrammable wireless sensors for structural health monitoring (Arms, et al, 2004), as described in Section 3.13, can be built.

Figure 5.5 - Sensors on Girder 1 of Bridge MD140

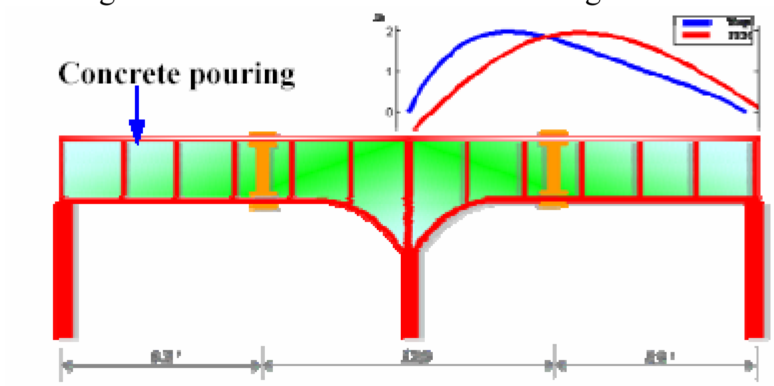


Figure 5.6 - Schematic Drawing of the Sensor Output

5.3 Case Study 3: Final Study using Microstrain of Bridge MD140 over MD27

A complete 32 channel telemetry system from Advanced Telemetric StrainLink wireless communication system (ATI, Spring Valley, OH) was used in this study. The telemetry system was integrated with the distributed sensors to transmit wirelessly the sensor data continuously monitoring the bridge performance and health. Figure 5.7 shows a typical arrangement of a segment of the wire sensor coupled with the wireless communication system.

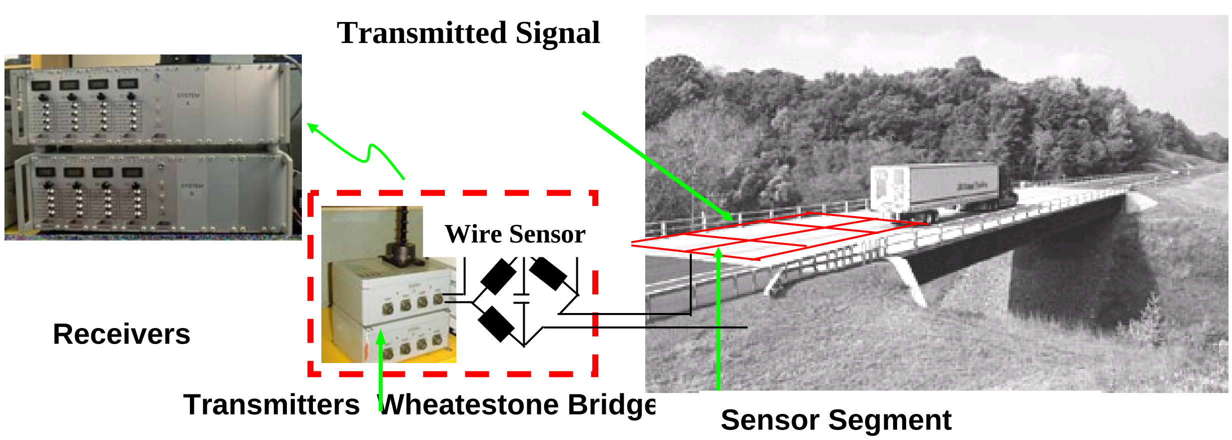


Figure 5.7 - Basic Components of wireless distributed bridge sensor system.

The testing equipment was prepared and connected to the steel sensors at the bridge site. The data acquisition equipment consists of two systems: The first system is at the bridge site and connected directly to the sensors and the second is at a reasonable distance from the first system that keeps it in a range to receive the wireless signal from the first system. The updated Model 3040D-16 Transmitters according to the specification can transmit up to 2 miles. Our testing distance is about 200 feet (Figure 5.8). The Model 3023M-2.4 Receiver monitors up to eight Transmitters. In this test, two were used. The final stage of this study covered the monitoring of the last portion of the bridge which included both dead and live load effects. In this stage the last third of the bridge deck which covers girders 12 through 15 was poured by concrete in three separate days. Data also were collected from the field in three different days. The first and second days were for concrete pouring and the third day was for truck load tests. The truck was driving over the girder such that the center line of the truck coincided with the center line of the girder in consideration. A sample record in Figure 5.9 shows the bridge responses under a fast speed truck.

Figure 5.8 – ATI Wireless Data acquisition system for data processing

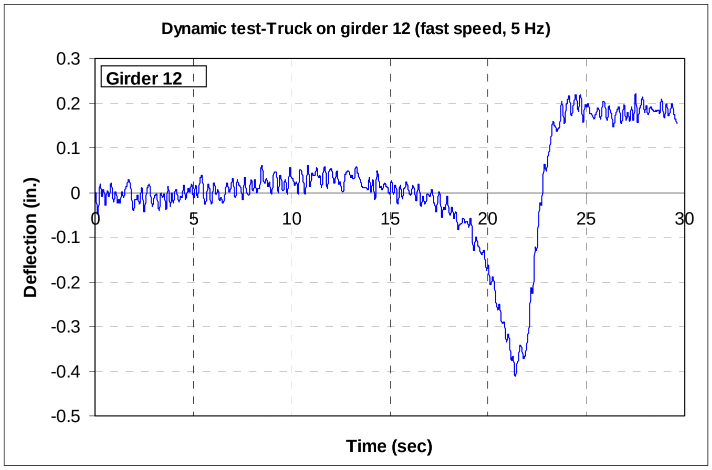


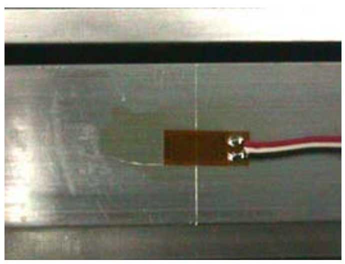
Figure 5.9 - Dynamic test on girder 12 when the truck was moving on girder 12

5.3 Case Study 4: Remote testing using Campbell CR5000

This case study was conducted in-house for a case with a portable, proto-type integrated remote (web based) bridge monitoring system which will be field-tested on at least one of our typical bridge sites.

Requirement of hardware and supplies are

(1) Sensors: A device for sensing a physical variable of a physical system or an environment, such as strain gauges, displacement transducers, inclinometers, crack and joint sensors, accelerometers, thermometers, fiber-optic sensors, MEMS…, etc. Strain gauges by Micro-Measurement, Vibration-wire gauges by Geokon and Accelerometer by PCB are adopted for this project.



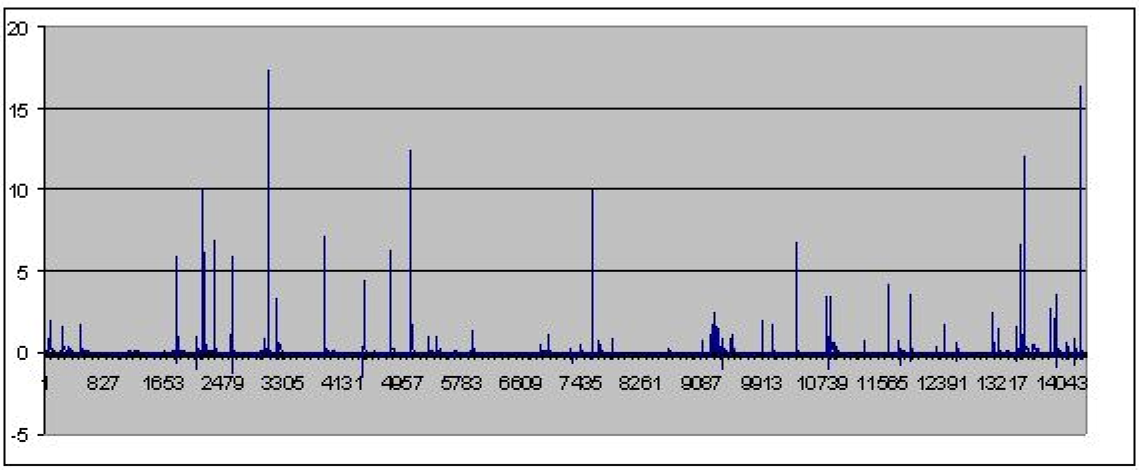
(2) Data acquisition system (DAQ): Data acquisition systems are products and/or processes used to collect information to document or analyze some phenomenon. In our application, CR5000 datalogger by Campbell Scientific is identified as the best suited system for our use. ENC10/12 is a 10”x12” weather-resistant enclosure to contain all the equipment. Besides the main equipment, two peripherals are required. One is 4 Full Bridge Terminal Input Modules for each channel. Another is the 4-channel Vibration Wire Interface.

(3) Power supply: Issues involve power generation (source of energy) power transmission (path of energy) and power storage (location of energy). BP24, a rechargeable 12 Vdc, 24 Ahr battery pack, is identified for power storage and SP10R, a 10-watt solar panel with an on-board voltage regulator, is identified for power generation. To reduce the cost, a car battery is used.

(4) Data Transmission: Issues are type of transmission (wire pairs, cables, microwave, and optic fibers), transmission rate (bits per second, bps), transmission bandwidth (frequency bandwidth, Hz), and transmission standard (interface standards: RS232, RS449). Telephone communication links and their peripherals are identified as the communication tool that allows interrogation of a datalogger from a remote computer. The Raven100 CDMA modem, an Airlink product made for use on Verizon cellular networks, is identified as the modem to be used.

(5) Data processing and data storage: The mission of processing involves signal de-noising and signal compression while storage includes interpretation.

The integrated system was used in the Tyding's Bridge field testing. Strain gauges were installed at four locations on the first (right) lane of the Tydings North Bound Bridge while the traffic was diverted away. Measurement was made and transmitted through the Verizon cellular networks to be viewed on a remote site. 12-minute raw data was extracted from gauge number 3 and is shown below.



PC9000 supplied by Campbell Scientific, Inc. for CR5000 DAQ system supports program generation, data collection, and real-time and historical data display either at the test site or a remote site. CR5000 itself is not wireless. But the CR211 or the CR216 Datalogger can measure the sensor(s) attached to it and then transmits its data wirelessly via its spread spectrum radio to a "master" datalogger, like the CR5000 and CR9000X. See Section 3.1.

6. Summary and Conclusion

In recent years, wireless technology has revolutionized digital communications. Wireless communications system may reduce problems of installation and maintenance of the wire system and suitable for certain application, like long span bridges. But a wireless system is not totally problem free. Noise and interference are two examples. But with the development of new technologies, especially in the telecommunication field, these problems can be resolved in the near future.

As stated in the beginning, the purpose of this study is to find state-of-the-art technology by the industry and research institutes which use intelligent wireless monitoring systems instead of conventional on-site bridge testing. The system could include (1) a practical plug-and-play battery-operated "wireless" data acquisition unit, and (2) state-of-the-art "wireless" data transmission and communication technologies. The second objective of this project is to investigate further and integrate the "off-the-shelf" wireless remote monitoring system with the latest technology for the project's use in the State of Maryland.

Based on the survey documented in this report, it is found that wireless communication, together with its applications and underlying technologies, as shown in Figure 6.1, is among today's most active areas of technology development. Figure 6.1 shows the requirement of hardware and supplies in (1) sensors, (2) data acquisition system (DAQ), (3) power supply, (4) data transmission, and (5) data processing and data storage

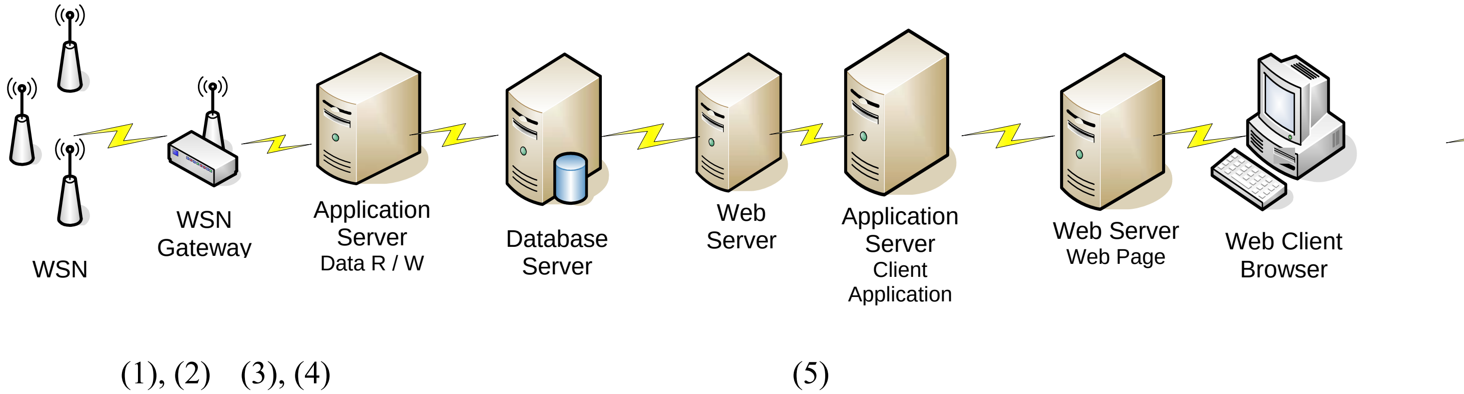


Figure 6.1 - Remote Wireless Bridge Monitoring System

Sensors are an important part to any measurement and automation application. In bridge application, possible sensors, which can be wired or wireless, are conventional strain gauges, displacement transducers (LVDT), inclinometers, crack and joint Sensors, accelerometers, and thermometers, or recently developed fiber-optic sensors, MEMS-based sensors, and GPS. The usage is based on the sensor's function and what to measure.

Survey of various wireless data acquisition systems has been conducted at the early stage of this project and the returned forms are listed in Appendix A, Market Survey Results. Chapter 3, Survey of "Off-the-Shelf" Wireless Structural Health Monitoring Systems, lists the capabilities of the surveyed system which are summarized in Table 6.1, Technologies and Applications of "Wireless" Structural Health Monitoring Systems by Manufacturers. All systems have their advantages and disadvantages. Based on future multi-purpose usage by the State on bridge applications, Campbell, Geokon (similar to Campbell system with interference on Geokon's vibrating wire sensor signals), Microstrain and NI systems were used in our applications and the plan is to use them in the future. But this does not exclude the usefulness of other systems for other applications.

Research has also been conducted by attending conferences, searching for references and discussing with peers. It is found that in, recent years, researchers from diverse backgrounds have achieved a lot by developing smart material or structures to monitor conditions, detect failure, control damage and adapt to changing environments. Chapter 4, Survey of Wireless Structural Health Monitoring Systems by Researchers, lists the known systems and their capabilities. Table 6.2, Technologies and Applications of "Wireless" Structural Health Monitoring Systems by Researchers, provides the summary of those researches. It is foreseen that once these technologies have matured, new tools that provide feedback on the state of the health of the civil infrastructure system will be available in the near future.

Table 6.1 - Technologies and Applications of "Wireless" Structural Health Monitoring Systems by Manufacturers			
Manufacturer	**Application**	**Wireless Communication technology**	**Capability of Data Acquisition Unit**
Campbell Scientific	*Manufactures a variety of data acquisition systems with versatile capabilities.* Provide monitoring for buildings, retaining walls, highway overpasses and bridge health monitoring.	Offers a full range of telecommunication options that allow interrogation of a datalogger from a remote computer. Telephone communication links or Remote RF or multidrop networks can be used separately or combined.	Offers a range of dataloggers from the most basic system with just a few channels to expandable systems that measure hundreds of channels. Scan rates can be programmed from a few hours to 100,000 times per second. Dataloggers can control external devices. Dataloggers can measure the sensor(s) attached to it and then transmits its data wirelessly via its spread spectrum radio.
Crossbow Technology	*Supplier of inertial sensor systems for aviation, land, and marine applications and other instrumentation sensors as well as a full solutions supplier in the wireless sensor networking arena and a manufacturer of smart dust wireless sensors.* Large scale defense, environmental, agricultural, and industrial monitoring and control, building automation, security and asset tracking applications.	Stargate - XScale Network Interface and Single Board Computer. Processor/Radio Modules.	Enables highly intelligent multi-sensing devices to dynamically and reliably self-organize in order to efficiently capture and send detailed physical data anywhere, anytime.
Geokon	Monitoring the safety and stability of civil and mining structures such as dams, tunnels, mine openings, foundations, piles, embankments, retaining walls, slopes, subway systems, underground powerhouses, bridges, culverts, pipelines, shafts, slurry wall excavations, braced excavations, tiebacks, nuclear waste repositories, ground water remediation schemes and the like.	Data is retrieved by telephone modems, solid state storage module, radios, or satellite transmission.	**Model 8001 LC-1 Single-Channel Datalogger** All types of vibrating wire sensors and their internal temperature sensors. 8000 readings can be stored before the oldest data is overwritten, remote readout capabilities. **Model 8020 MICRO-10 Datalogger** Reading practically all types of electrical sensors such as vibrating wire transducers, linear potentiometers, DCDTs, RTDs, thermistors, thermocouples, accelerometers, etc.

Table 6.1 - Technologies and Applications of "Wireless" Structural Health Monitoring Systems by Manufacturers (cont.)

Daytronic	Production line automated testing, remote safety monitoring, prototype evaluation, "real time" process control via closed-loop servo systems, and statistical analysis of both "real time" and "historical" data.	(There is no option found for acquire data wirelessly.)	Configurations range from simple multichannel dataloggers to factory-wide distributed tasking networks. Provides multiple individually configurable data displays along with real-time signal processing and process control functions—all completely independent of the host computer.
Digitexx Data Systems	Real-time data acquisition and processing for structural health monitoring, tall buildings, dams, bridges, and power generating facilities. Systems solutions for central monitoring for national arrays and regional sub-networks and distributed information data center.	Data Broadcasting over the Internet, Monitoring (E-mail, Web), Streaming (Internet/TCP)	**RTMS-2001RM Real-time Structural Monitoring System** A multi-channel real-time data acquisition and analysis system. With 10 channels, 16 or 24 -bit resolution, system has a sampling rate of up to 1,000 samples per second per channel. **PDAQ-8 Portable Data Acquisition System** With 8 or 16 recording channels, 16-bit resolution, system can record up to 20,000 samples per second per channel.
Computer Aided Solutions	Systems for a variety of measurement, test, logging, control and vision applications.	Modem Support	4 to 12 Universal Analog Sensor Channels, 12 Digital Channels, Ethernet, USB, RS-232, or RS-485 Communication with PC, Modem Support.
Smart Structures	Monitor various aspects of the structural health of the nation's bridge stock.	Wireless PVDF is a Multi-channel (8) wireless smart sensor unit. Operates in the 916 MHz frequency band. Coverage has a range of 300 feet with 33.6k baud – over large areas (several miles) are available.	Consists of a rack-mount UNIX-based PC (top rack) which controls a multifunction data acquisition card and modem and Signal conditioning modules and antialiasing filters in a separate enclosure (lower rack). System supports 32 channels and can be customized to support more channels.
Acellent Technologies	Developing novel sensor networking techniques for monitoring the integrity of composite and metal structures.	Currently working on miniaturizing its products, a real-time structural health monitoring system, and adding wireless capability	SMART Layers vary in complexity from 2 -sensor flat strips to multisensor 3-D shells. Can be surface-mounted on existing structures or integrated into composite structures during.

Table 6.1 - Technologies and Applications of "Wireless" Structural Health Monitoring Systems by Manufacturers (cont.)

Texas Measurements, Inc.	Markets strain gauges, measurement transducers, and associated instrumentation.	**TDS-102** Wireless transmission of measurement data by the onboard telemeter.	Their dataloggers/static strainmeters include up to 1000 channels, with LCD, built in battery and built-in telemetry MODEM in some models.
Bridge Diagnostics, Inc.	Bridge testing equipment and procedures for field testing.	NEW Wireless Structural Testing System (STS-WiFi) is based on the design of BDI-STSII data acquisition systems, it operates on standard 802.11 b/g broadband wireless communications, eliminating the need to run cables to each 4-channel node and back to the computer.	**Structural Testing System (BDI-STSII)** Allows a typical short-to medium-span bridge or similar structure to be instrumented and load tested with up to 64 sensors in less than a day. BDI Strain Transducers can be mounted to steel, concrete, or timber members with minimal surface preparation, and automatically identify themselves which eliminate the need to track channel numbers or calibration factors.
ATI Telemetric	Used extensively for powertrain testing, in automotive, aerospace and a variety of other R&D-related applications. Applications include highway bridges, railroad bridges, lock gates, amusement park rides, and coupling signals from rotating machinery.	The **2050B** series Transmitters can transmit most any type of sensor up to 500 feet; eliminating long cable runs. The 3024 Receiver monitors up to four Transmitters while the 3025 monitors up to eight.	Crystal-based and do not require tuning. Multiple channels to be used concurrently, with no cross-talk. RF output signal from the transmitters is relatively powerful which makes the system immune to electrical interference.
Geomation Inc.	Monitor temperature, pressure, flow, level, displacement and environmental parameters within and around dams.	Bridge wireless field networks to long range WANs. Communication options include radio, wireline, fiber-optic, telephone, microwave and satellite.	Built on an open-access SQL database, and supports customized development for your specific needs with Microsoft Visual Basic and the GEONET Developer's Kit.
MicroStrain Inc.	Medical instruments, health monitoring of civil structures (bridges, dams, buildings) and aerospace sensing.	Can wirelessly collect data and then share it through the internet.	System enables wireless data collection from up to 8 channels of sensor input. It can be triggered to initiate data collection remotely or by any specified sensor exceeding a programmable threshold.

Table 6.1 - Technologies and Applications of "Wireless" Structural Health Monitoring Systems by Manufacturers (cont.)			
Physical Acoustics Corporation (PAC)	Sensors, Systems and Software for Source Characterization. DSP for polyMODAL Wave Studies research and applications. Feature Extraction Knowledge-based Systems for Industrial use. Technology Transfer and Strategic Alliances to expand Acoustic Emission (AE). Educational Training and AE Certification.	PAC provides a virtual on-test-site remote monitoring through wireless LAN - Intranet connections.	•A sensor that converts a stress (sound) wave to an electrical signal • A low noise amplifier that raises the signal to a usable level • Signal processing electronics for feature extraction and waveform capture • Microprocessor, and DSP based parallel distributing processing instrumentation • Knowledge-based software for easy analysis, defect correlation and development of expert systems that comply with demanding AE Standards • Decision and feedback electronics to utilize the information
Kipp & Zonen, Inc.	Measurement and recording of meteorological and industrial parameters involving high-performance radiometers. Scientific solution systems to the climatology, agronomy, hydrology, public health and industrial markets.	Data logger systems that can collect data then by connecting these loggers to a computer through an ethernet port to get the data or to save it to a flash memory.	Weatherproof housing and connectors as standard. 4 or 8 channel versions with optional relay outputs.
Geospace Technolgies	Vibration Monitoring, deformation of buildings, dams, mines and bridges.	Newly developed a GSR wireless seismic data acquisition system	Manufacturer of advanced precision sensor products for high definition land and marine applications
National Instruments	Complete family of data acquisition devices for desktop, portable, and networked applications on several buses, including PCI, PCI Express, PXI, PCMCIA, USB, CompactFlash, Ethernet, and FireWire, and many operating systems, including Windows, Linux, Mac OS X, Pocket PC/Windows CE, and RTX	Wireless FieldPoint-to-PC link. Transmits up to 20 miles with line-of-sight antennas.	Handheld measurement hardware for PocketPC. Up to 16-bit accuracy, up to 500 kS/s sampling rate. Multifunction devices for PCMCIA. Handheld measurement application development with LabVIEW PDA.

Table 6.2 - Technologies and Applications of “Wireless” Structural Health Monitoring Systems by Researchers			
Researcher	**Application**	**Wireless Communication technology**	**Capability of Data Acquisition Unit**
Northwestern University's Basic Industrial Research Laboratory (BIRL)	Bridge health monitoring.	The use of one or more remotely mounted data acquisition systems linked by RF transceivers to a host computer connected to a phone line.	The Model 2100 is a very compact and self-contained data acquisition and analysis system consisting of compact, stackable modules with a common bus architecture. Complete signal conditioning for many analog transducers, including strain gages and tilt meters, are available in individual modules, capable of reducing the vast amounts of data generated in unattended bridge monitoring. A lithium battery-backed memory insures the safety of the data even if the host computer or RF transceiver should go down.
Stanford University/ University of Michigan	Structural health monitoring in civil structures.	Developed with a wireless sensor network server and several sensing units. Data server provides Internet connectivity so the sensor data or desired engineering analysis results can be viewed remotely from other computers over the Internet.	• Power consumption: 70-80 mA when active; 0.1 mA standby • Communication range: 90 m indoor, 300 m outdoor • 16 bit Analog-to-Digital conversion, 4 A2D channels • Local data processing • Point-to-multipoint, and peer-to-peer communication • Low hardware cost
Iowa State University	Bridge health monitoring.	•Data Acquisition Sub-System transfers the collected raw data wirelessly to the Gateway Sub-System. •GSS transfer the data through the internet to the data storage and client access which effectively monitor and evaluate structures continuously from a remote site.	•40 Fiber Bragg Grating (FBG) Sensors •Si425-500 Swept Laser Interrogator, a four channel interrogator capable of scanning up to 128 FBG Sensors per channel. Maximum scanning frequencies of the Si425-500 are 250 Hz/Channel for channels with less than 100 sensors, but 125 Hz for channels with more than 100 sensors. A scan rate of 31.25 Hz was selected. •built in color LCD display

Table 6.2 - Technologies and Applications of “Wireless” Structural Health Monitoring Systems by Researchers (cont.)			
Clarkson University	Continuous structural health monitoring.	The data acquisition modules connect to the network interface via an internal bus. The network interface module implements the network protocol based on IEFFF 802.15.4 standard. A 2.4G-Hz module CC2420 from Chipcon is used for the radio interface.	data acquisition models each provide up to six 12-bit analog-to-digital channels, two 12-bit digital-to-analog channels, 16 general purpose digital input/output channels, and up to 16M-bit of non-volatile EEPROM memory.
University of California, Berkeley	Structural health monitoring on the 4200-ft long main span and the south tower of the Golden Gate Bridge (GGB).	Data is communicated from nodes to the base station through wireless communication. The base station is a server providing a connection to the internet.	The data acquisition system performs three primary functions: sensing, signal processing and communication.
University of Southern California	Structural health monitoring on a large seismic test structure.	Consisting of tens of wireless nodes transmit time-synchronized structural vibration data to a base station.	• Implements a NACK-based hybrid hop-by-hop and end-to-end reliability scheme. • Uses certain techniques in data synchronization and data compression in transmission.
University of Dayton	Infrastructure Evaluation.	Computer-controlled site network of multiple-channel wireless transmitters throughout the structure.	Software-based virtual instrumentation program developed to control the system, acquire data, and monitor the results through a user-friendly graphical user interface.
University of Illinois at Chicago	The inspection of a deck beam bridge.	• Wireless sensors. • A simple Radio Frequency (RF) channel with Frequency Shift Keying (FSK) modification is employed.	**Wireless PVDF sensor** Up to 8 PVDF sensors can be connected to single unit, operating temperature range from -20 to +85 °C, PVDF Sensor Bandwidth of 50Hz, wireless operating range <500ft outside and <200ft inside. **Wireless MEMS Accelerometer** Acceleration input range of ±200mg, operating temperature range from -30 to

Table 6.2 - Technologies and Applications of "Wireless" Structural Health Monitoring Systems by Researchers (cont.)			
			+85 °C, sensitivity of 100mg/V, accelerometer bandwidth range 0.1-100Hz, wireless operating range <500ft outside and <200ft inside.
University of Illinois at Urbana	Structural health monitoring and damage detection.	Smart sensor nodes with embedded microprocessors and wireless communication to the base station.	The measurement range to be from 1 to 2000 micro strain.
TransTech Systems, Inc.	Bridge Health Monitoring: • Dynamic calculation of Military Load Classification (MLC) • Real-time condition assessment • Remaining life information estimation	Bridge mounted portion, referred to as the Local Processing Module transmit data over a wireless Ethernet link to the Remote Processing Module.	This module will contain the hardware and software to process the sensor signals and calculate the required information on MLC, remaining life and damage/deformation. The module will also store the processed data, with appropriate interfaces to standard military communication equipment. An intelligent data acquisition system that includes necessary signal conditioning to obtain the data, digitize it, multiplex it and transmit it over a wireless Ethernet link.
The Western Transportation Institute (WTI) at Montana State University	Evaluating MDT's highway bridge deck designs.	Data from each bridge is periodically transmitted to WTI through the Internet via a network of RF400 Spread Spectrum radios based at the Saco School.	The bonded and embedded gauges require Wheatstone Bridge arrangements designed and fabricated by WTI. Corresponding voltages are routed through a single AM16/32 multiplexer. Vibrating wire strains and temperatures are read using a single AVW1 Vibrating Wire Interface coupled with an AM16/32 multiplexer.

7.0 References

1. Invocon, Inc. <http://www.invocon.com>
2. Campbell Scientific, Inc. < http://www.campbellsci.com>
3. Crossbow Technology, Inc. <http://www.xbow.com>
4. Geokon, Inc. <http://www.geokon.com>
5. Daytronic Corp., <http://www.daytronic.com>
6. Digitexx Data Systems, < http://www.digitexx.de>
7. Computer Aided Solutions, < http://www.computeraidedsolutions.com>
8. Smart Structures LLC, < http://smart-structures.com/index2.htm>
9. Acellent Technologies, Inc., < http://www.acellent.com>
10. Texas Measurements, Inc., < http://straingage.com>
11. Bridge Diagnostics, Inc. < http://www.bridgetest.com/index.html>
12. Atlantic Telemetrics International (ATI), <http://www.atitelemetry.com>
13. Geomation Inc., < http://www.geomation.com>
14. MicroStrain, Inc., < http://www.microstrain.com/default.aspx>
15. Physical Acoustics Corporation, < http://www.pacndt.com>
16. Kipp & Zonen, Inc., <http://www.kippzonen.com>
17. Geospace Technologies, < http://www.concordtech.com>
18. National Instruments, < http://www.ni.com>
19. Arms, S.W., Galbreath, J.H., Newrad, A.T., and Townsend, C.P. (2004), "Remotely Reprogrammable Sensors for Structural Health Monitoring," *Conference of Structural Materials Technology (SMT): NDE/NDT for Highways and Bridges,* 14-17 September 2004, Buffalo, NY
20. Prine, David, (1996) **"**Remote-controlled Bridge Monitoring - Global Remote Monitoring System Ensures Safe Operation of 65-year-old Lift Bridge," *Roads & Bridges* November 1996
21. Wang, Y., K. H. Law, and J. P. Linch, (2005) "Design of Low Power Wireless Structural Monitoring System for Collaborated Computational Algorithm," *Proceedings of SPIE 12th Annual International Symposium on Smart Structures and Materials, Vol. 5768,* San Diego, CA, March 7-9, 2005
22. Wipf, T.J., B. M. Phares, L.F. Greinmann, D.J. Hemphill, J.D. Doormink, P. Lu, (2006) "Remote Continuous Evaluation of a Bridge Constructed Using High Performance Steel," Report to Iowa Department of Transportation by the Center for Transportation Research and Education, Iowa State University, Ames, IA, May 2006
23. Sazonov, E, K. Janoyan, R. Jha, (2004) "Wireless Intelligent Sensor Network for Autonomous Structural Health Monitoring," *Proceedings of SPIE 11th Annual International Symposium on Smart Structures and Materials, Vol. 5384,* San Diego, CA, March 15-17, 2004
24. Kim, S, S. Pakzad, D. Culler, J. Demmel, G. Fenves, S. Glaser, M. Turon, (2007) "Health Monitoring of Civil Infrastructures Using Wireless Sensor Networks," *Environmental Health Perspectives,* September 2007
25. Paek, J, K. Chintalapudi, R. Govindan, J. Caffrey, S. Masri, (2005) "A Wireless Sensor Network for Structural Health Monitoring Performance and Experience" *Second IEEE Workshop on Embedded Networked Sensors, EmNetS-II*, 2005

26. Farhey, D.N., (2006) “Integrated Virtual Instrumentation and Wirelss Monitoring for Infrastructure Diagnostics,” Structural Health Monitoring, An International Journal, 2006; 5; 29
27. Wang, R., Singh, V, and Wang, M.L., (2005) “In-Service Inspection of Deck Beam Bridge,” *Proceedings of SPIE 11th Annual International Symposium on Smart Structures and Materials, Vol. 5765,* San Diego, CA, March 7-10, 2005
28. Nagayama, T.; Ruiz-Sandoval; M., Spencer, B.F. Jr; Mechitov, K.A., Agha, G., (2004) “Wireless Strain Sensor Development for Civil Infrastructure,” First International Workshop on Networked Sensing Systems (INSS), 2004
29. TransTech Systems, Inc, (2002) Final Technical Report *Feasibility of a Bridge Health Monitoring System (BriHMS)* , Prepared for U.S. Tank-Automotive and Armaments Command under contract DAAE07-99-C-L069, April 30, 2002
30. Smolenski, P., (2004) “Field Instrumentation and Live Load Testing to Evaluate Behaviors of Three Reinforced Concrete Bridge Decks,” A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science, Montana State University, Bozeman, Montana, May 2004

APPENDIX A – Market Survey Results

A market survey was conducted to collect information about the latest technology in the field of health monitoring and data acquisition systems. The survey was sent to 30 companies selected based on the information posted on their websites. Among the 30 companies who received the survey either by e-mail or by fax, 18 of them had the chance to respond and fill the survey.

1. Acellent Technologies

DATA ACQUSITION SYSTEM			
1. General Information			
Manufacturing and contact information		Amrita Kumar	408-745-1188
Description of technology		Using Piezoelectric material, structures are interogated and scanned on a periodic basis to locate and size structural changes:damage, delamination, corrosion, errosion, and cracking.	
Feature	Data acquisition, processing, and archiving		
	List compatible sensors	PZT, fiber optic, strain, temperature, magnetic-restrictive	
	Communication	X Direct ☐Cell phone ☐ RF spread spectrum ☐ Ethernet ☐Voice-Synthesized phone ☐Wireless ☐Optically ☐Infra red ☐ Multi drop ☐RF UHF/VHF ☐ PDA ☐ Telephone ☐Satellite ☐ Short haul ☐Other	
2. Cost (Range)			
Hardware		Data acquisition system	SMART layer that is epoxied onto the structure
		Communication system	Plug and cable
Software		Description	Analyzes data to indicate areas of change
		Cost	Please call 408-745-1188
Labor		Installation	2 part epoxy and coating
		Use	Once installed, only need to plug and scan
Power supply		☐Rechargeable battery X AC available ☐ Alkaline battery ☐ Solar panel ☐Other, please explain……..	
3. Limitation			
	Life expectancy	Life of the structure, typically 20 years	
	Measurement accuracy	Depending on structure and sensor spacing.. typically about ¼" damage sizes for 12" sensor spacing	
	Environmental condition	Depends on coating	
	Data storage/transfer/processing	Data transferred and stored on laptop then can be transferred	
	Wireless distance	NA	
	Other		
4. Implementation Needs			
Power source		120V AC or 220V corded connection	
Accessibility (Direct access to sensors installation and data acquisition)		Connector for layer is placed in an accessible location	
Level of technical expertise to operate the unit		Lowest possible level.. plug and scan	
Other			
5. Availability			
Upon agreement.			
6. ON-Going or Completed Bridge Related Project and Reference			
On-going research with an independent laboratory is testing on mock joints and will be moving to field-testing.			

7. Notes

If you require any further product information, please feel free to contact Amrita Kumar at 408-745-7924 or Rob Hannum at 408-745-7924

8. Warranty and Guarantee

Typical warranty is 5 years.

2. ATI Telemetric

DATA ACQUSITION SYSTEM			
1. General Information			
Manufacturing and contact information		Phil Merrill (937) 862-6948	
Description of technology		Wireless data transmission using 900 Mhz and 2.4 Ghz transmission	
Feature	Data acquisition, processing, and archiving	Remote transmitters connect directly to strain gages or most any other type of sensors, and transmit point to point or multi-point	
	List compatible sensors	Strain Gage, LVDT, thermocouple, voltage, piezoresistive, piezoelectric, string potentiometers and many others.	
	Communication	☐ Direct ☐Cell phone X RF spread spectrum X Ethernet ☐Voice-Synthesized phone X Wireless ☐Optically ☐Infra red ☐ Multi drop X RF UHF/VHF ☐ PDA ☐ Telephone ☐Satellite ☐ Short haul ☐Other	
2. Cost (Range)			
Hardware		Data acquisition system	Typically $3900
		Communication system	$30,900 for 16 channels
Software		Description	Windows compatible, easy to use
		Cost	Included with hardware
Labor		Installation	Usually not required. $1650/day +
		Use	
Power supply		XRechargeable battery X AC available X Alkaline battery X Solar panel X Other, please explain……..	
3. Limitation			
	Life expectancy	20 years	
	Measurement accuracy	.1% worst case non-linearity.	
	Environmental condition	Completely weatherproof	
	Data storage/transfer/processing	Depends on channel count. 400 samples/second typical	
	Wireless distance	Up to 10 miles	
	Other		
4. Implementation Needs			
Power source		Receivers can be powered from 12 VDC or 110 VAC. Transmitters usually have rechargeable batteries.	
Accessibility (Direct access to sensors installation and data acquisition)			
Level of technical expertise to operate the unit		Relatively low	
Other			
5. Availability			
Upon agreement. 4 weeks typical			
6. ON-Going or Completed Bridge Related Project and Reference			
Please contact Dr. Amr M. Baz in University of Maryland's Mechanical Engineering Department. Dr. Baz has an ATi 32 channel bridge monitoring system. Dr. Baz can be			

reached at (301) 405-5216.

Dr. Andrzej Nowak at University of Michigan Civil Engineering Department. Dr. Nowak has an eight channel system. Dr. Nowak can be reached at (734) 764 9299 or nowak@engin.umich.edu

7. Notes

I would welcome the opportunity to meet with anyone interested in our systems. I can be reached at (937) 862-6948 or pmerrill@atitelemetry.com**. My name is Phil Merrill**

8. Warranty and Guarantee

3. **Computer Aided Solutions**

DATA ACQUSITION SYSTEM			
1. General Information			
Manufacturing and contact information		Computer Aided Solutions	Pete Martin 440-729-2570
Description of technology		Portable, stand alone data loggers	
Feature	Data acquisition, processing, and archiving	Yes	
	List compatible sensors	Standard analog sensors and vibrating wire	
	Communication	X Direct XCell phone X RF spread spectrum X Ethernet ☐Voice-Synthesized phone XWireless ☐Optically ☐Infra red X Multi drop XRF UHF/VHF X PDA X Telephone XSatellite X Short haul ☐Other	
2. Cost (Range)			
Hardware		Data acquisition system	$1700 - $3700
		Communication system	$0 - $1500
Software		Description	Windows based, DeLogger
		Cost	$395
Labor		Installation	User provided
		Use	
Power supply		XRechargeable battery XAC available ☐ Alkaline battery X Solar panel XOther, please explain……Internal lead acid gel cells..	
3. Limitation			
	Life expectancy	10 years	
	Measurement accuracy	.15 - .3 %	
	Environmental condition	-45 to + 70 Deg C, IP45 rated	
	Data storage/transfer/processing	Internal = 166,000 stored readings, memory expansion options available	
	Wireless distance	Depends on radio modem type and antenna config (up to 5-10 miles line of sight)	
	Other		
4. Implementation Needs			
Power source		Internal battery, external battery, AC, Solar panel	
Accessibility (Direct access to sensors installation and data acquisition)		Small devices, configurable	
Level of technical expertise to operate the unit		Basic Windows PC skills, instrumentation	
Other			
5. Availability			
Upon agreement. Ex stock			
6. ON-Going or Completed Bridge Related Project and Reference			
Colusa Bridge, California JIRI STRASKY, PH.D.,P.E., 176 CORTE ANITA, GREENBRAE, CA 94904, TEL. (415) 464-0447, FAX (415) 354-3348 E-mail: j.strasky@usa.net			

http://www.datataker.com/applications/appnote01.html http://www.datataker.com/applications/appnote08.html http://www.datataker.com/applications/index.html - general page for app notes
7. Notes
8. Warranty and Guarantee
3 year warranty

4. **Daytronic Corporation**

DATA ACQUSITION SYSTEM			
1. General Information			
Manufacturing and contact information		Daytronic Corporation	Matt Vagedes – (800) 668-4745
Description of technology		System 10 Data Acqusition and Control System	
Feature	Data acquisition, processing, and archiving	True Analog Signal Conditioning, A/D, Signal Processing, and Process Control, Analog Peak Capture & Hold, Real-Time Limit Monitoring	
	List compatible sensors	Thermocouples/Strain Gages/LVDT's/Frequency/Voltage/Load Cells	
	Communication	X Direct ☐Cell phone ☐ RF spread spectrum X Ethernet ☐Voice-Synthesized phone ☐Wireless ☐Optically ☐Infra red ☐ Multi drop ☐RF UHF/VHF ☐ PDA ☐ Telephone ☐Satellite ☐ Short haul ☐Other	
2. Cost (Range)			
Hardware		Data acquisition system	$2,725.00 - $17,195.00
		Communication system	$495.00 - $2,950.00
Software		Description	LabView Driver, UtiliPAC410, XLogger410
		Cost	$495.00 - $1,950.00
Labor		Installation	$1,200/day (Including Travel & Lodging)
		Use	
Power supply		☐Rechargeable battery X AC available ☐ Alkaline battery ☐ Solar panel ☐ Other, please explain……..	
3. Limitation			
	Life expectancy	10-15 Years	
	Measurement accuracy	0.02% of full scale typical, following calibration	
	Environmental condition	Operating Temperature Range: +5°C - +50°C Operating Relative Humidity: 95% maximum (Noncondensing)	
	Data storage/transfer/processing	Single-and multichannel data-transfer modes to RS-232, Internal Data Storage 250GigaByte, Interface Types (RS-232, RS422, IEE-488, etc), 2500-3000 Channels per second processing	
	Wireless distance		
	Other	A/D Resoultion: 16-bit (0.0015% of full scale)	
4. Implementation Needs			
Power source		90-130 or 180-260 VAC (47-63 Hz)	
Accessibility (Direct access to sensors installation and data acquisition)		Yes	
Level of technical expertise to operate the unit		Low – Medium (knowledge of Data Acquisition is helpful)	
Other			
5. Availability			
Upon agreement. 3-4 Weeks from receipt of Purchase Order			
6. ON-Going or Completed Bridge Related Project and Reference			

Non at present

7. Notes

www.daytronic.com

8. Warranty and Guarantee

1 Year on all parts & labor

5. **Digitexx Data Systems, Corp.**

DATA ACQUSITION SYSTEM Digitexx Data Systems, Corp, RTMS-2001R Real-Time Monitoring System			
1. General Information			
Manufacturing and contact information		Dan Radulescu, VP/Engineering	dan@digitexx.com cell 626 379-8173
Description of technology		Internet-Based Data Acquisition, Data Broadcasting and Data Analysis Real-Time System.	
Feature	Data acquisition, processing, and archiving	PC Based System, National Instruments Platform, LabView Windows 2000 Industrial Grade computer, Hard Drive, UPS,	
	List compatible sensors	All sensors with up to 10Vdc output	
	Communication	X Direct X Cell phone ☐ RF spread spectrum ☐ X Ethernet ☐Voice-Synthesized phone X Wireless ☐Optically ☐Infra red ☐ Multi drop ☐RF UHF/VHF X PDA X Telephone X Satellite ☐ Short haul ☐Other	
2. Cost (Range)			
Hardware		Data acquisition system	16-bit 32, 64 channels, up to 1000 SPS **$55,000-65,000** 24-bit resolution, 40 channels, up to 500 SPS **$75,000**
		Communication system	Server/Client, Publish/Subscribe TCP/IP interface
Software		Description	The Server Software has three main threads: Local Monitoring/Recording, Data Distribution, Data Acquisition.
		Cost	Included and priced with the system
Labor		Installation	Depending on the size of the project, number of sensors, site condition and access restrictions.
		Use	**? ?**
Power supply		☐Rechargeable battery X AC available ☐ Alkaline battery ☐ Solar panel ☐Other, please explain……..	
3. Limitation			
	Life expectancy	15 years	
	Measurement accuracy		
	Environmental condition	Needs a relatively dust-free room and +5º C	
	Data storage/transfer/processing	Hard Drive, External Data Storrage devices as required. Client site data can be processed and analyzed with number of popular software packages. Data format is Digitexx or ASCII.	
	Wireless distance	Line of Site required; Distance as available in the market at the tme of installation.	
	Other	For real-time appliation and data distribution to at least 5 clients via the Internet a DSL line or a LAN is needed.	
4. Implementation Needs			
Power source		110 VAC required, UPS in case of power loss up to 3 hours autonomy. The Central unit provides power for sensors.	
Accessibility (Direct access to sensors installation and data acquisition)		Standard configuration is cable connection from sensors to the central unit.	
Level of technical expertise to operate		Electronic technician, computer literate.	

the unit	
Other	Maintenance and troubleshooting can be done remotely when the system is connected to the Internet.

5. Availability

Upon agreement. Delivery is between 6 & 8 weeks

6. ON-Going or Completed Bridge Related Project and Reference

With Professor Sami Masri (USC), California State (CGS/CSMIP) and CALTRANS a Real-Time system was installed for 2½ years on the Vincent Thomas Bridge. Paper was published in the Smart Materials and Structures, **13 (2004) 1269-1283**, ***Application of a Web-Enabled real-time structural health monitoring system for civil infrastructure systems.***
A 32-channel Data Acquisition and real-time ready system was delivered to Professor Yunfeng Zhang, Lehigh University for bridge and other civil structures monitoring.

Number of other systems are installed and in operation for over 3 years on tall buildings, test model structures and a 90-meter high windmill power generator. Please check our web site www.digitexx.com

7. Notes

8. Warranty and Guarantee

Warranty is 12 Months from delivery.

6. Dynamag LtD

<table>
<tr><th colspan="4">DATA ACQUSITION SYSTEM</th></tr>
<tr><th colspan="4">1. General Information</th></tr>
<tr><td colspan="2">Manufacturing and contact information</td><td>Dynamag LtD</td><td>Kubranska 67/102, 91101Trencin
Slovak Republic</td></tr>
<tr><td colspan="2">Description of technology</td><td colspan="2">Contact free measuring of the forces and tensions in prestressed components (diam. from 10mm up to 250mm) of concrete constructions, based on the magnetoelastic principle</td></tr>
<tr><td rowspan="3">Feature</td><td>Data acquisition, processing, and archiving</td><td colspan="2">Remote/manual control, basic data processing on board, up to 1000 measurements archiven in flash memory</td></tr>
<tr><td>List compatible sensors</td><td colspan="2">Dynamag system use own sensors</td></tr>
<tr><td>Communication</td><td colspan="2">■ Direct ☐Cell phone ☐ RF spread spectrum
■ Ethernet ☐Voice-Synthesized phone ■Wireless ☐Optically
■ Infra red ☐ Multi drop ☐RF UHF/VHF ☐ PDA
☐ Telephone ☐Satellite ☐ Short haul
☐Other</td></tr>
<tr><th colspan="4">2. Cost (Range)</th></tr>
<tr><td colspan="2" rowspan="2">Hardware</td><td>Data acquisition system</td><td>> 4000 USD (basic portable unit, 4channels)</td></tr>
<tr><td>Communication system</td><td>direct – in price of basic unit</td></tr>
<tr><td colspan="2" rowspan="2">Software</td><td>Description</td><td>basic SW for remote control and data transfer</td></tr>
<tr><td>Cost</td><td>in price of basic unit</td></tr>
<tr><td colspan="2" rowspan="2">Labor</td><td>Installation</td><td>depends on application, general low</td></tr>
<tr><td>Use</td><td>personal cost</td></tr>
<tr><td colspan="2">Power supply</td><td colspan="2">■Rechargeable battery ■AC available ☐ Alkaline battery
■ Solar panel ☐Other, please explain……..</td></tr>
<tr><th colspan="4">3. Limitation</th></tr>
<tr><td rowspan="6"></td><td>Life expectancy</td><td colspan="2">sensors unlimited, measuring units > 10 years</td></tr>
<tr><td>Measurement accuracy</td><td colspan="2"><1% (depends on calibration)</td></tr>
<tr><td>Environmental condition</td><td colspan="2">sensors – any, unit – standard industrial conditions</td></tr>
<tr><td>Data storage/transfer/processing</td><td colspan="2">min. 256kB Flash on board, transfer 19600 Bd</td></tr>
<tr><td>Wireless distance</td><td colspan="2">ADAM module, cca 1000m</td></tr>
<tr><td>Other</td><td colspan="2"></td></tr>
<tr><th colspan="4">4. Implementation Needs</th></tr>
<tr><td colspan="2">Power source</td><td colspan="2">24V / 1Amp max.</td></tr>
<tr><td colspan="2">Accessibility (Direct access to sensors installation and data acquisition)</td><td colspan="2">sensors – access unnecessary, unit – access only for technical inspection and service</td></tr>
<tr><td colspan="2">Level of technical expertise to operate the unit</td><td colspan="2">high school</td></tr>
<tr><td colspan="2">Other</td><td colspan="2"></td></tr>
<tr><th colspan="4">5. Availability</th></tr>
<tr><td colspan="4">Upon agreement.</td></tr>
<tr><th colspan="4">6. ON-Going or Completed Bridge Related Project and Reference</th></tr>
<tr><td colspan="4">Nuclear power plant Temelin, Czech republic, Jiangyin bridge over the Yangtze River China, Ashidagawa Cable Stayed Bridge Hiroshima Prefecture, Japan, Cable Stayed Bridge in Bratislava, Slovakia, etc.</td></tr>
<tr><th colspan="4">7. Notes</th></tr>
<tr><td colspan="4"></td></tr>
</table>

8. Warranty and Guarantee

measuring units – 2 years (standard warranty)
sensors - lifetime

7. **Geomation, Inc.**

DATA ACQUSITION SYSTEM			
1. General Information			
Manufacturing and contact information		Geomation, Inc. (www.geomation.com)	Pierre Choquet, VP Sales & Corp. Development
Description of technology		Low-Power Field RTUs (OutDAQ) for field monitoring of geotechnical and structural sensors	
Feature	Data acquisition, processing, and archiving		
	List compatible sensors		
	Communication	X Direct X Cell phone X RF spread spectrum X☐ Ethernet X ☐Wireless X☐ Multi drop X ☐RF UHF/VHF X☐ Telephone X ☐Satellite X☐ Short haul	
2. Cost (Range)			
Hardware		Data acquisition system	
		Communication system	
Software		Description	
		Cost	
Labor		Installation	
		Use	
Power supply		☐Rechargeable battery ☐AC available ☐ Alkaline battery ☐ Solar panel ☐Other, please explain……..	
3. Limitation			
	Life expectancy	20 years	
	Measurement accuracy		
	Environmental condition	95 % Humidity, not condening, -40 to + 70 deg. C	
	Data storage/transfer/processing		
	Wireless distance		
	Other		
4. Implementation Needs			
Power source		7-30 VDC, Solar panels, AC, Batteries	
Accessibility (Direct access to sensors installation and data acquisition)			
Level of technical expertise to operate the unit			
Other			
5. Availability			
Upon agreement.			
6. ON-Going or Completed Bridge Related Project and Reference			

7. Notes
8. Warranty and Guarantee
1 Year

8. **MicroStrain Inc**.

DATA ACQUSITION SYSTEM			
1. General Information			
Manufacturing and contact information		MicroStrain Inc 310 Hurricane Lane, Unit 4 Williston Vt 05495	802-578-9544 Sales@microstrain.com
Description of technology		Wireless sensor system	
Feature	Data acquisition, processing, and archiving	Wireless data acquisition system	
	List compatible sensors	Most analog sensors	
	Communication	☐ Direct ☐Cell phone ☐ RF spread spectrum ☐ Ethernet ☐Voice-Synthesized phone X Wireless ☐Optically ☐Infra red ☐ Multi drop ☐RF UHF/VHF ☐ PDA ☐ Telephone ☐Satellite ☐ Short haul ☐Other	
2. Cost (Range)			
Hardware		Data acquisition system	$500-700 per node
		Communication system	$700 – base station
Software		Description	Depends on requirements
		Cost	Depends on requirements
Labor		Installation	Depends on site
		Use	
Power supply		X Rechargeable battery X AC available X Alkaline battery X Solar panel ☐Other, please explain……..	
3. Limitation			
	Life expectancy	10s of years	
	Measurement accuracy	Depends on sensor	
	Environmental condition	None	
	Data storage/transfer/processing		
	Wireless distance	70m standard 300m and over optional	
	Other		
4. Implementation Needs			
Power source		Not necessary	
Accessibility (Direct access to sensors installation and data acquisition)		Only required for installation	
Level of technical expertise to operate the unit		Low	
Other			
5. Availability			
Upon agreement. Depends on quantity. Stock to 2 weeks for small quantities. Large quantities in 4 weeks			
6. ON-Going or Completed Bridge Related Project and Reference			
Ben Franklin Bridge			

Unable to publicize other applications without consulting clients
7. Notes
8. Warranty and Guarantee
12 months

9. **National Instruments**

DATA ACQUSITION SYSTEM			
1. General Information			
Manufacturing and contact information		National Instruments	Felicy Colbron (800) 433-3488 x 30029
Description of technology			
Feature	Data acquisition, processing, and archiving		
	List compatible sensors	Thermocouple, Strain, load cells, Thermistors,	
	Communication	X Direct ☐Cell phone ☐ RF spread spectrum X Ethernet ☐Voice-Synthesized phone ☐Wireless ☐Optically ☐Infra red X Multi drop ☐RF UHF/VHF X PDA ☐ Telephone ☐Satellite ☐ Short haul X Other: USB	
2. Cost (Range)			
Hardware		Data acquisition system	$400 – 250,000
		Communication system	PCI, USB, Ethernet, PXI, SCXI
Software		Description	LabVIEW, LabWindows/CVI, Measurement Studio
		Cost	$1195 - $4299
Labor		Installation	Done by customer or 3ard party company
		Use	
Power supply		X Rechargeable battery XAC available X Alkaline battery ☐ Solar panel ☐Other, please explain……..	
3. Limitation			
	Life expectancy	Depends on the specific products Mean Time Between Failure is available on most items	
	Measurement accuracy	Depends on the product you choose anything from 8 – 24 Bit Resolution	
	Environmental condition	Most for Lab enviornment some for industrial	
	Data storage/transfer/processing	Most use a computer to external disk drive. Only PXI has this included in the system	
	Wireless distance	We can work with various 3ard party vendors so it depends	
	Other		
4. Implementation Needs			
Power source		Some will work with power from computer others need some type of external power source	
Accessibility (Direct access to sensors installation and data acquisition)		ALL	
Level of technical expertise to operate the unit		Depends on the developer's knowledge and preference	
Other			
5. Availability			
Upon agreement. – Depends on the products chosen			
6. ON-Going or Completed Bridge Related Project and Reference			
For information Contact:			

Mark Lewis - (301) 258-5269 (phone)
7. Notes
8. Warranty and Guarantee
All Data Acquisition hardware has a 1 year warranty.

10. **Physical Acoustics Corp**

DATA ACQUSITION SYSTEM			
1. General Information			
Manufacturing and contact information		Terry Tamutus	Physical Acoustics Corp
Description of technology		Acoustic Emission, Ultrasonics, Acousto/Ultrasonics and Vibration	
Feature	Data acquisition, processing, and archiving	PC based systems for Acoustic Emission, Ultrasonics, Acousto/Ultrasonics and Vibration	
	List compatible sensors	Acoustic Emission, Ultrasonics, Acousto/Ultrasonics and Vibration	
	Communication	X Direct x Cell phone x RF spread spectrum x Ethernet x Voice-Synthesized phone x Wireless x Optically ☐Infra red ☐ Multi drop ☐RF UHF/VHF x PDA x Telephone x Satellite ☐ Short haul ☐Other	
2. Cost (Range)			
Hardware		Data acquisition system	$2,000 to $500k
		Communication system	Low cost
Software		Description	Windows based programs for NDT
		Cost	@$2000 depending on number for channels
Labor		Installation	
		Use	
Power supply		X Rechargeable battery X AC available ☐ Alkaline battery X Solar panel ☐Other, please explain……..	
3. Limitation			
	Life expectancy	Many years	
	Measurement accuracy	Extremly	
	Environmental condition	NEMA4- and Instrincally safe	
	Data storage/transfer/processing	Disk to ether	
	Wireless distance		
	Other		
4. Implementation Needs			
Power source			
Accessibility (Direct access to sensors installation and data acquisition)			
Level of technical expertise to operate the unit		Can be remotely controlled and supervised, so low skill level needed	
Other			
5. Availability			
Usually in stock to 3 weeks			
6. ON-Going or Completed Bridge Related Project and Reference			
On going 1. FHwA Corrosion Monitoring Project for NYC Suspension Bridges			

2. U of Pittsburg, concrete beam testing
3. U of Texas, Composite Bridge Testing
4. U of South Carolina
5. U of California SD composite bridge testing
6. Large Suspension Cable bridge in Philadelphia (customer confidential)

Completed

7. Woodrow Wilson, Washington D.C.
8. Brooklyn Bridge, NYC
9. Manhattan Bridge, NYC
10. Queensborough Bridge, NYC
11. Williamsburg Bridge, NYC
12. Dunbar Bridge, West Virginia
13. Bryte Bend Bridge, Sacramento, CA
14. I-10 Mississippi River Bridge, LA
15. I-205 Willdmetter River, OR
16. Route 1 Occoquan River, VA
17. St. Louis Bridge, MI
18. Ship Canal Bridge
19. Bay Bridge, San Francisco, CA
20. Harris Bridge, PA
21. Texas Inter-coastal Canal Bridge
22. Knapps Narrow Bridge, MA
23. Route 95 Bridge, CT
24. Martin Luther King Memorial, TX
25. West Lynn Bridge, OR
26. Poplar Street, St. Louis, MO
27. I-10 Mississippi River Bridge, LA
28. Cecil Rd Bridge, UK
29. Lowestoft Lift Bridge, UK
30. Irwell Bridge, UK
31. Banbury Bridge Coventry, UK
32. Creswell Viaduct, UK
33. Avonmouth Steel Box Girder, UK
34. Southern Interchange Bridge, UK
35. Trechelin Viaduct, UK
36. Post-tensioned concrete beams, Japan
37. Impact echo, concrete bridges, Japan
38. AE&AE/UT of RC beams, Japan
39. Fatigue damage in RC bridge, Japan

7. Notes

8. Warranty and Guarantee

1 year warranty of system and 90 days on sensors

11. Smart Structures

DATA ACQUSITION SYSTEM			
1. General Information			
Manufacturing and contact information		Smart Structures	217-892-3333
Description of technology		Smart Bridge Structural Health Monitoring System	
Feature	Data acquisition, processing, and archiving	Smart SHMS	
	List compatible sensors	Any kind of sensors	
	Communication	☐ Direct ☐Cell phone ☐ RF spread spectrum ☐ Ethernet ☐Voice-Synthesized phone ☐Wireless ☐Optically ☐Infra red ☐ Multi drop ☐RF UHF/VHF ☐ PDA ☐ Telephone ☐Satellite ☐ Short haul ☐Other Any type of communication strategy	
2. Cost (Range)			
Hardware		Data acquisition system	USD10000
		Communication system	USD10000
Software		Description	Smart Data Retriever
		Cost	USD5000
Labor		Installation	It depends on the scope of SHMS
		Use	
Power supply		☐Rechargeable battery ☐AC available ☐ Alkaline battery ☐ Solar panel ☐Other, please explain…….. All of above	
3. Limitation			
	Life expectancy	20 yrs	
	Measurement accuracy	1 Mpa (less than 3% errorness)	
	Environmental condition	Not specifically required	
	Data storage/transfer/processing	expandable	
	Wireless distance	200m	
	Other		
4. Implementation Needs			
Power source		AC or DC	
Accessibility (Direct access to sensors installation and data acquisition)		Fully Automated remote control	
Level of technical expertise to operate the unit		Calibration is needed	
Other			
5. Availability			
Normally 6weeks to 2months or upon agreement.			
6. ON-Going or Completed Bridge Related Project and Reference			
(i) 26 projects in Japan (ii) 4 projects in China (iii) 3 projects in US (iv) etc			

7. Notes
This SHMS enable to monitor the actual stress of the structure.
8. Warranty and Guarantee
One year.

12. **Texas Measurements, Inc.**

DATA ACQUSITION SYSTEM			
1. General Information			
Manufacturing and contact information		Texas Measurements, Inc.	sales@straingage.com
Description of technology			
Feature	Data acquisition, processing, and archiving	Depends on sensor and application.	
	List compatible sensors	We have multiple sensors available depending on the application needs.	
	Communication	☐ Direct ☐Cell phone ☐ RF spread spectrum ☐ Ethernet ☐Voice-Synthesized phone ☐Wireless ☐Optically ☐Infra red ☐ Multi drop ☐RF UHF/VHF ☐ PDA ☐ Telephone ☐Satellite ☐ Short haul ☐Other	
2. Cost (Range)			
Hardware		Data acquisition system	Depends on sensor and application.
		Communication system	
Software		Description	Depends on sensor and application.
		Cost	Depends on sensor and application.
Labor		Installation	N/A
		Use	N/A
Power supply		☐Rechargeable battery ☐AC available ☐ Alkaline battery ☐ Solar panel ☐Other, please explain……..	
3. Limitation			
	Life expectancy		
	Measurement accuracy		
	Environmental condition	Depends on sensor and application.	
	Data storage/transfer/processing	Depends on sensor and application.	
	Wireless distance	N/A	
	Other		
4. Implementation Needs			
Power source			
Accessibility (Direct access to sensors installation and data acquisition)			
Level of technical expertise to operate the unit		Depends on sensor and application.	
Other			
5. Availability			
Upon agreement.			
6. ON-Going or Completed Bridge Related Project and Reference			

7. Notes
Our company, Texas Measurements, Inc., deals primarily with sensors. We have no wireless devices.
8. Warranty and Guarantee

13. **Crossbow Technology, Inc.**

DATA ACQUSITION SYSTEM			
1. General Information			
Manufacturing and contact information		Crossbow Technology, Inc.	408-965-3300
Description of technology		Wireless Sensor Networking Products	
Feature	Data acquisition, processing, and archiving	See attached product reference chart	
	List compatible sensors	See attached product reference chart	
	Communication	☐ Direct ☐Cell phone ☑ RF spread spectrum ☐ Ethernet ☐Voice-Synthesized phone ☑ Wireless ☐Optically ☐Infra red ☐ Multi drop ☐RF UHF/VHF ☐ PDA ☐ Telephone ☐Satellite ☐ Short haul ☐Other	
2. Cost (Range)			
Hardware		Data acquisition system	MICA Mote Hardware
		Communication system	RF transmission
Software		Description	MoteWorks Academic User License
		Cost	$595 USD/user (current promotion includes training)
Labor		Installation	-
		Use	-
Power supply		☐Rechargeable battery ☐AC available ☑ Alkaline battery ☐ Solar panel ☐Other, please explain……..	
3. Limitation			
	Life expectancy	See 'Mote Battery Life Calculator'- Estimate is 3-5 years http://www.xbow.com/Support/appnotes.htm	
	Measurement accuracy	See datasheets, dependant on model	
	Environmental condition	See datasheets, dependant on model	
	Data storage/transfer/processing	See datasheets, dependant on model	
	Wireless distance	See datasheets, dependant on model	
	Other	See datasheets, dependant on model	
4. Implementation Needs			
Power source		See datasheets, dependant on model	
Accessibility (Direct access to sensors installation and data acquisition)		See datasheets, dependant on model	
Level of technical expertise to operate the unit		-	
Other		-	
5. Availability			
Upon agreement. Standard lead-time is Stock to 5 days ARO			
6. ON-Going or Completed Bridge Related Project and Reference			

7. Notes
8. Warranty and Guarantee
One-year Warranty

14**. Bridge Diagnostics, Inc**

<table>
<tr><th colspan="4">DATA ACQUSITION SYSTEM</th></tr>
<tr><th colspan="4">1. General Information</th></tr>
<tr><td colspan="2">Manufacturing and contact information</td><td>Bridge Diagnostics, Inc.
Phone (303) 494-3230
Fax (303) 494-5027</td><td>5398 Manhattan Circle #100
Boulder, CO 80303-4239
www.bridgetest.com</td></tr>
<tr><td colspan="2">Description of technology</td><td colspan="2">Wireless Live Load Structural Testing System. In final stages of development. Prototypes lab tested, production version available Summer 2006.</td></tr>
<tr><td rowspan="3">Feature</td><td>Data acquisition, processing, and archiving</td><td colspan="2">Extremely simple-to-use bridge testing system, similar in function to existing BDI Structural Testing System, except wireless using WiFi technology. Comes complete with strain transducers and wireless remote load position sensor. (see www.bridgetest.com for existing STS specifications)</td></tr>
<tr><td>List compatible sensors</td><td colspan="2">BDI Strain Transducers (or other full wheatstone bridge sensors), LVDT displacement sensors, peizoresistive accelerometers, others.</td></tr>
<tr><td>Communication</td><td colspan="2">☐ Direct ☐ Cell phone ☐ RF spread spectrum
☐ Ethernet ☐ Voice-Synthesized phone ☐ Wireless ☐ Optically
☐Infra red ☐ Multi drop ☐ RF UHF/VHF
☐ PDA ☐ Telephone ☐ Satellite ☐ Short haul
☐ Other</td></tr>
<tr><th colspan="4">2. Cost (Range)</th></tr>
<tr><td colspan="2" rowspan="2">Hardware Cost range = $1,500 to $2,000 per channel. Includes transducer, load indicator, and Software.</td><td>Data acquisition system</td><td></td></tr>
<tr><td>Communication system</td><td>Combined with A/D in compact unit.</td></tr>
<tr><td colspan="2" rowspan="2">Software Included in system cost.</td><td>Description</td><td>WinSTS for Win XP</td></tr>
<tr><td>Cost</td><td></td></tr>
<tr><td colspan="2" rowspan="2">Labor. Customer installs, usually bridge test with 56 to 64 channels completed in one day.</td><td>Installation</td><td></td></tr>
<tr><td>Use</td><td></td></tr>
<tr><td colspan="2">Power supply Each 4-channel unit uses readily-available rechargeable battery, included.</td><td colspan="2">☐ Rechargeable battery ☐AC available ☐ Alkaline battery
☐ Solar panel ☐Other, please explain。..</td></tr>
</table>

3. Limitation		
	Life expectancy	8 – 10 years, all sensors re-useable, should be recalibrated periodically
	Measurement accuracy	Accuracy including transducers plus/minus 2.5%
	Environmental condition	Water resistant, designed for adverse field conditions.
	Data storage/transfer/processing	1,000 Hz max sample rate, special option 10,000 Hz. Data buffered to PC during test.
	Wireless distance	Several hundred feet.
	Other	Actual battery life approx. 6Hrs continuous. However, in field use, most time will be spent in standby, making battery life several days.

4. Implementation Needs	
Power source	Charge batteries prior to test w/supplied 110/220V chargers. 12VDC power to power PC located below bridge.
Accessibility (Direct access to sensors installation and data acquisition)	Need to be able to install sensors on superstructure, and 4 sensors plug into each wireless unit placed within 20。ヌ of sensors.
Level of technical expertise to operate the unit	Field Technician can install and implement system with one-day training. Very similar to existing BDI STS.
Other	

5. Availability

Available in Summer 2006

6. ON-Going or Completed Bridge Related Project and Reference

See attached forms.

7. Notes

Expandable 4 to 64 channels in groups of 4 channels. BDI Intelliducer technology allows each sensor to identify itself to system, eliminating channel tracking and cal factor application issues as they are all handled in the background. Systems includes AutoClicker wireless Truck Load Position Indicator, BDI Strain Transducers (Intelliducers) as specified, WinSTS 3 Testing software, batteries, chargers, mounting tabs, communication radios, transit cases. Everything required for field live load test.

8. Warranty and Guarantee

BDI repairs any manufacture issues for no charge for 5 years. Software upgrades no charge.

15. **Campbell Scientific, Inc**.

DATA ACQUSITION SYSTEM			
1. General Information			
Manufacturing and contact information		Campbell Scientific Inc.	Logan UT 435-750-9553
Description of technology		Rugged, Stand-Alone DC powered Data Acquisitions sytems	
Feature	Data acquisition, processing, and archiving		
	List compatible sensors	Any Sensors	
	Communication	☑ Direct ☑ Cell phone ☑ RF spread spectrum ☑ Ethernet ☑ Voice-Synthesized phone ☑ Wireless ☐ Optically ☐ Infra red ☑ Multi drop ☑ RF UHF/VHF ☑ PDA ☑ Telephone ☑ Satellite ☑ Short haul ☐ Other	
2. Cost (Range) $1400 to $26,000			
Hardware CR1000 up to the CR9000X		Data acquisition system	Various models starting at $1400.00 up to $25,000
		Communication system	Ethernet on some models cost an additional $350.00
Software PC9000 or LoggerNet.		Description	Program and support software. To load programs, monitor measurements in real-time and to collect the data to a PC.
		Cost	$495.00 to $595.00
Labor Typically 1 day to set up in the field.		Installation	1 day of labor, an additional day to test sensors.
		Use	
Power supply Included with CR9000X, extra for the CR1000, CR3000.		☑ Rechargeable battery ☑ AC available ☐ Alkaline battery ☑ Solar panel ☐ Other, please explain……..	
3. Limitation			
	Life expectancy	15 to 30 years had been the typical life of our dataloggers being used 24/7.	
	Measurement accuracy	0.03% to 0.25% depending on model type and temperature range of environment under test.	
	Environmental condition	-40 to +70 or –55C to +85C (CR1000) in non-condensing environment.	
	Data storage/transfer/processing	Internal data storage, optional Flash data storage. Internal processing (rainflow, FFT, standard deviation, time series, max min, ETC.	
	Wireless distance	Line of site up to 15 miles with RF401 or Freewave radios.	
	Other		
4. Implementation Needs			
Power source		CR9000 requires AC power or large solar panels, other models will require 20 watt solar panel.	
Accessibility (Direct access to sensors installation and data acquisition)			
Level of technical expertise to operate the unit		Units program in a Basic like syntax. PC9000 has a very easy to use Program Generator. LoggerNet includes our ShortCut program builder.	
Other			
5. Availability			
Upon agreement. Delivery is typically 2-3 weeks from receipt of purchase order.			
6. ON-Going or Completed Bridge Related Project and Reference			
The CR9000(X) has been used and continues to be used extensively by the Leigh University ATLSS Research Center for ongoing bridge monitoring projects and lab tests. The CR1000 datalogger is resold by Geokon, Slope Indicator, RocTest, and Bridge Diagnostics for bridge and structural monitoring and slope stability monitoring. The CR1000, CR3000 and CR5000 loggers support Vibrating Wire sensors, the CR9000X does not.			

16. **Geokon Inc**.

DATA ACQUSITION SYSTEM			
1. General Information			
Manufacturing and contact information		Geokon Inc	603-448-1562
Description of technology		Manufactuer of Geotechnical Instruments and Loggers	
Feature	Data acquisition, processing, and archiving	Logger is Based on The Campell Scientific CR10X Module	
	List compatible sensors	Vibrating Wire, Resistance, and Semiconductor (4-20mA, mV/V and etc)	
	Communication	☑ Direct ☑ Cell phone ☑ RF spread spectrum ☑ Ethernet ☑ Voice-Synthesized phone ☐ Wireless ☐ Optically ☐ Infra red ☑ Multi drop ☑ RF UHF/VHF ☑ PDA ☑ Telephone ☑ Satellite ☑ Short haul ☐ Other	
2. Cost (Range) Depends on how many sensors and options requested			
Hardware		Data acquisition system	Logger($5000.00) Multiplexer ($840.00)
		Communication system	$1000.00 to $1500.00
Software Multi Logger		Description	Windows based
		Cost	Multi logger ($1000.00)
Labor		Installation	Minimal Labor (Sensor Connection/ Programming)
		Use	
Power supply 12V		☑ Rechargeable battery ☑ AC available ☐ Alkaline battery ☑ Solar panel ☐ Other, please explain........	
3. Limitation			
	Life expectancy	Depends on the environment. Geokon has that are 20 years old and still running	
	Measurement accuracy	(Analog) 0.1% Full Scale (Frequency) 0.01% of reading	
	Environmental condition	Nema 4 Enclosure	
	Data storage/transfer/processing	2 MB Memory	
	Wireless distance	Depends on site (typically 1Mile for radios).	
	Other	1 Logger Can handle 8 Multiplexers with 256 channels	
4. Implementation Needs			
Power source		AC/DC	
Accessibility (Direct access to sensors installation and data acquisition)		The Direct Access and connection is within on the multiplexer or logger.	
Level of technical expertise to operate the unit		Very little training is required. Familiarity with Microsoft Windows	
Other		A Multiplexer may be need to expand the number of sensors	
5. Availability			
Upon agreement. Typically 2 week lead time from date of the order			
6. ON-Going or Completed Bridge Related Project and Reference			
Please see the attached			
7. Notes			
We also offer a single channel logger with radio options			
8. Warranty and Guarantee			
Please see the attached			

17**. Kipp & Zonen Inc**.

Attention: Yaser Taradat, Ph.D.

DATA ACQUSITION SYSTEM

1. General Information		
Manufacturing and contact information		Kipp & Zonen, Inc / Robert Dolce 800-645-102 x. 38
Description of technology		Solar radiation & Surface IR flux
Feature	Data acquisition, processing, and archiving	Kipp offers single and multi-channel data loggers and performs system integration
	List compatible sensors	CNR1, NR Lite, CMP3, CGR3, SP Lite, LOGBOX, COMBILOG
	Communication	☒ Direct ☐ Cell phone ☒ RF spread spectrum ☒ Ethernet ☐ Voice-Synthesized phone ☐ Wireless ☐ Multi drop ☐ RF UHF/VHF ☐ PDA ☐ Telephone ☐ Satellite ☐ Short haul ☐ Other
2. Cost (Range)		
Hardware	Data acquisition system	14 or 16 bit models available
	Communication system	RS232 or RF wireless
Software	Description	
	Cost	included
Labor	Installation	$ 1,100 – Per day plus travel/hotel/meal
	Use	
Power supply 12 VDC		☒ Rechargeable battery ☒ Solar panel ☐ AC available ☐ Other, please explain........ ☐ Alkaline battery
3. Limitation		
	Life expectancy	~ 20 yrs
	Measurement accuracy	Depends on selected model type
	Environmental condition	All Conditions / Global
	Data storage/transfer/processing	
	Wireless distance	
	Other	
4. Implementation Needs		
Power source		solar/IR flux Sensors (none) / Data loggers (12 V
Accessibility (Direct access to sensors installation and data acquisition)		Yes
Level of technical expertise to operate the unit		nominal / phone or onsite support available
Other		
5. Availability		
Upon agreement. 4 weeks		
6. ON-Going or Completed Bridge Related Project and Reference		
7. Notes		
8. Warranty and Guarantee		
All Kipp & Zonen Manufactured sensors are warranted for two years (parts and labor). All Kipp logger product are warrantied for one year.		

18**. GeoSpace Tech.**

DATA ACQUSITION SYSTEM		
1. General Information		
Manufacturing and contact information		Tim Allmendinger
Description of technology		geophones seismometers
Feature	Data acquisition, processing, and archiving	
	List compatible sensors	Geophones, seismometers
sensors	Communication	☑ Direct ☐ Cell phone ☐ RF spread spectrum ☐ Ethernet ☐ Voice-Synthesized phone ☐ Wireless ☐ Optically ☐ Infra red ☐ Multi drop ☐ RF UHF/VHF ☐ PDA ☐ Telephone ☐ Satellite ☐ Short haul ☐ Other
2. Cost (Range) depends on natural frequency $25-1000		
Hardware	Data acquisition system	
	Communication system	
Software	Description	
	Cost	
Labor	Installation	
	Use	
Power supply		☐ Rechargeable battery ☐ AC available ☐ Alkaline battery ☐ Solar panel ☐ Other, please explain……..
3. Limitation		
	Life expectancy	many years
	Measurement accuracy	depends on specs
	Environmental condition	outdoors
	Data storage/transfer/processing	
	Wireless distance	
	Other	
4. Implementation Needs		
Power source		no power required
Accessibility (Direct access to sensors installation and data acquisition)		
Level of technical expertise to operate the unit		very little expertise
Other		
5. Availability		
Upon agreement.		
6. ON-Going or Completed Bridge Related Project and Reference		
7. Notes		
geophones output velocity data set		
8. Warranty and Guarantee		
6 months		

7. Notes
8. Warranty and Guarantee
Three year warranty on all dataloggers (excludes batteries). All dataloggers guaranteed to meet our published accuracy specifications for the given temperature range.