A Resource for the State of Florida

HURRICANE LOSS REDUCTION
FOR
HOUSING IN FLORIDA:

Section 4

Adapting Wireless Technology for the Wall of Wind: A Pilot Study

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SUMMARY

Hurricanes are among the most destructive and costliest of all natural disasters, and since the late 1980's with hurricane Hugo, and later with hurricane Andrew, the United States entered a cycle of more intense hurricane activity. The 2004 hurricane season resulted in insured losses in excess of $20.5 billion, with Florida accounting for 85% of that financial loss. The 2005 hurricane season was even more catastrophic with hurricane Katrina identified as one of the costliest and fatal natural disasters ever suffered by the U.S., and hurricanes Dennis, and Wilma also making landfall in Florida, and causing significant disruptions in the Panhandle and South Florida. As populations continue to increase in coastal regions where the threat is highest, so does the possibility for even greater disasters. This risk can be devastating for entire communities, for the insurance industry, which ultimately must pay for a significant portion of the incurred losses, for local and state government who have to struggle with the impact on their populations and economies, and for the nation as a whole. For these reasons it is essential to reduce the destruction expected from future events.

The implementation of affordable solutions to mitigate damage can only follow from a quantification of the wind forces causing this destruction, and models that relate wind forces to the capacity of man-made structures to resist them. An accurate description of fluctuating wind loads is the key to defining the ability of structural components to resist damage, and thus evaluate retrofits. True wind load characterization requires comprehensive full-scale measurements which are difficult to obtain given the random nature of hurricane occurrence. The Wall of Wind, currently being developed at FIU, offers a solution to this problem, since it will allow the mimicking of hurricane wind conditions on full-scale structures and components. The focus of this project was the development of wireless instrumentation to complement the ongoing Wall of Wind tests. A group of researchers at Florida Tech adapted a new wireless sensing system to allow affordable, rapid, reliable, and secure deployment of sensors on a variety of structures or sub-structures to be tested in the Wall of Wind. These tests will complement similar full-scale tests carrying on during hurricane and other extreme wind events, on full-scale coastal structures in Florida.

INTRODUCTION

Figure 1: The aftermath of Hurricane Katrina in Gulfport, Mississippi, 2005

The years 2004 & 2005 resulted in a number of hurricanes, including *Katrina*, that hit the mainland of United States (see Figure 1). They ranged from the windy to the devastating. A wireless system developed at Florida Institute of Technology was deployed during these hurricanes to measure the impact of high-speed winds on residential homes. The main quantity being measured was the pressure on residential home structures. The existing system consists of 23 pressure sensing remote units, one anemometer remote unit, a base unit connected to a data collector, which in this case is a laptop computer. A proprietary software running off of a laptop computer controls the system and collects data.

History of Wireless Sensor Development at Florida Tech

The team at Florida Institute of Technology started working on the project at the beginning of 2001. The first prototype consisted in separate transmitter/receiver pairs, sending digital data. Communication was unidirectional from the sensor to the base. Data was being converted through a separate Analog to Digital converter, collected by a BASIC program that generated data to be imported into a spreadsheet program for post processing. The transfer speed of this prototype was only two to three samples per second.

By mid 2001, the transmitter/receiver pair was replaced by a better one. The data collection was made through the parallel port of a PC at a speed of 380 samples per second, a significant improvement. This prototype was also unidirectional with only one unit. At the beginning of 2002, another significant change was made to the system. The separate transmitter/receiver pair was replaced by two transceivers, allowing a bi-directional communication between the sensor and the base. Since controlling the transceiver required a more complex operation, a PIC microcontroller was included in the remote unit for the first time. The prototype was still one remote unit and one base using the parallel port.

The system continued evolving along 2002, using printed circuit boards, switching from a parallel transmission to a serial one, and using LabVIEW for data collection and adding multiple sensors. With these changes, the system was capable of transmitting about 80 samples per second per sensor. The sensors could be identified with a number, allowing for the first time to work with multiple sensors, although only one prototype unit existed by then. In 2003, a PIC microcontroller was included also in the base unit. A final prototype consisting of a base unit and three remote units was successfully tested as the first multi-sensor version of the system. Optimization of the firmware and software allowed the system to reach the final data transfer rate of 700 samples per second. 20 other remote units were built along with a new sensing port and extensive sets of performance evaluation tests were conducted. By December 2003, the anemometer unit was built and incorporated into the system. The system now consists of 23 remote units, one anemometer unit and a base unit, which during operation is connected to the laptop that acts as a data collector.

The remote units can measure pressure, temperature, and calibration voltage and received signal level of the signal. The anemometer remote unit can measure wind velocity and direction. All remote units communicate with the base unit. All data sent to the base unit is forwarded to the data collector where it is stored. The main recorder program is run off the data collector.

Before the recording process starts, relevant parameters can be set on the recorder program such as sampling rate and the parameters recorded on the two channels. During the recording process, the remote units can be observed on the recorder display. After the recording process, data stored can be analyzed using a post processor software for information about how the remote units performed during the recording.

Past Hurricane Deployment and Performance Testing

The above system was installed on houses in the path of 5 major hurricanes that hit the state of Florida during 2004 and 2005, which were Charley, Frances, Jeanne, Dennis and Wilma. The locations of installation were a house in satellite beach for hurricanes charley, Frances and Wilma, a house in Santa Rosa beach for Hurricane Dennis and a house located in Jupiter for Hurricane Wilma. The sensors were set up for recording continuous data for up to fifty two hours starting at 11.40 am (EST) on August 13,2004 for Hurricane Charley, at 3:15 pm on 9/3/04 for Hurricane Frances, at 2:28 pm on 9/25/04 for Hurricane Jeanne at 11:30 pm on 7/9/05 for Hurricane Dennis, and, at 6:03

pm on 10/24/05 for Hurricane Wilma. Each sensor sampled data at 20 samples per second, which was saved as a binary file in the laptop hard drive. The 2004 and 2005 Florida hurricanes provided the opportunity to test the wireless system on a house in a real field environment. The deployments proved the feasibility of hurricane measurements using the wireless sensing system, and they illustrated the potential of this new technology, but they also showed the many obstacles still facing the system. The period of continuous recorded data between the sensors varied greatly between 1 to 52 hours when each sensor was sampled at 20 samples/second. Signal dropouts due to rapid battery discharge, signal noise due to bad antennas to transceiver connections, and some interference problems due to weak signal were found to be some of the issues which needed attention. These issues have been addressed in the next generation prototype system and are described here. Some improvements to the data processing software WDAS POSTPROC were also made to facilitate easy export of the MatLab graphics files to other software

After removal of the remote units from the house roof, for analysis of the pressure data, the post processing software called WDAS POSTPROC is used. It produces variable time averaged series plots of wind speed, direction, and local surface pressures using calibration constants. The averaging time can be varied from 50 ms to one hour. A house data analysis program, WINDPLOT, also gives contours of absolute pressures over the roof of the instrumented house. A separate Matlab analysis program was developed to perform advanced statistical analysis of the post processed time series signals such as auto correlation, cross correlation, and power spectrum.

From the hurricane deployments, on an average, useful data were obtained only from fewer than half the number of deployed sensors. Communication problems like signal interference (due to low signal levels) and transmitter lockouts due to rapid discharging of batteries were found to be a common source of problems for the sensors with shorter records.

The current phase's task was therefore, to trouble shoot and fix the existing system problems so that in due course all the current wired systems can be replaced by the wireless system. This was done in a 2-step process; first identifying the source of faults and taking corrective measures, as described below and the second task is to develop a new generation of remote units that are accurate, faster, have longer range with better transceivers and are more reliable. Wind tunnel and wall of wind tests play a critical role in this process. Preliminary calibration of the sensors can be done at low wind speeds in the wind tunnel, while the wall of wind provides a unique opportunity to test the sensors in a full scale environment similar to the one to be experienced during a real hurricane.

In June 2005, a battery charger was built that could charge up-to 24 remote units simultaneously. A battery testing software was also created which could measure and display the discharge rates of up-to 8 remote units simultaneously.

Trouble shouting of existing system

The problems in the first generation of the wireless system were identified and investigated. The objective here was to define what areas needed to be improved in the next generation system which is the purpose of this research project. The following tasks were performed:

- Analyze the transceiver, which forms the core of communications. This being the most probable cause of communication errors prevalent in the current system.
- Troubleshoot remote unit problems, which result in inconsistent system performance such as remote unit's failure to communicate when system is started. As will be explained in the debugging section below, this could occur due to a variety of reasons.
- Improve the immunity of the system against other ambient interferences.
- Introduce system maintenance measures such as antenna wire crimping, cleaning of the printed circuit boards, battery condition testing etc.

Anemometer Calibration

Wind tunnel calibration

The anemometer was calibrated, measuring velocity of the vane anemometer versus recorder reading. The resulting graph has a slope of about 1 bit/m/s. The range of the testing was from 2 m/s to 20 m/s. The calibration procedure was performed in a wind tunnel and consisted of first placing the cup anemometer inside the wind tunnel. This is connected to the anemometer box unit, which has all the communication capabilities of a remote unit. The rest of the equipment consisting of the base unit and laptop computer is switched on and set up to record the anemometer readings of wind speed velocity followed by the switching on of the anemometer. The anemometer performed as per standard expectations, giving an output of values which when plotted yields a slope of 1 second per meter. Figure 2 shows the graph of the anemometer calibration.

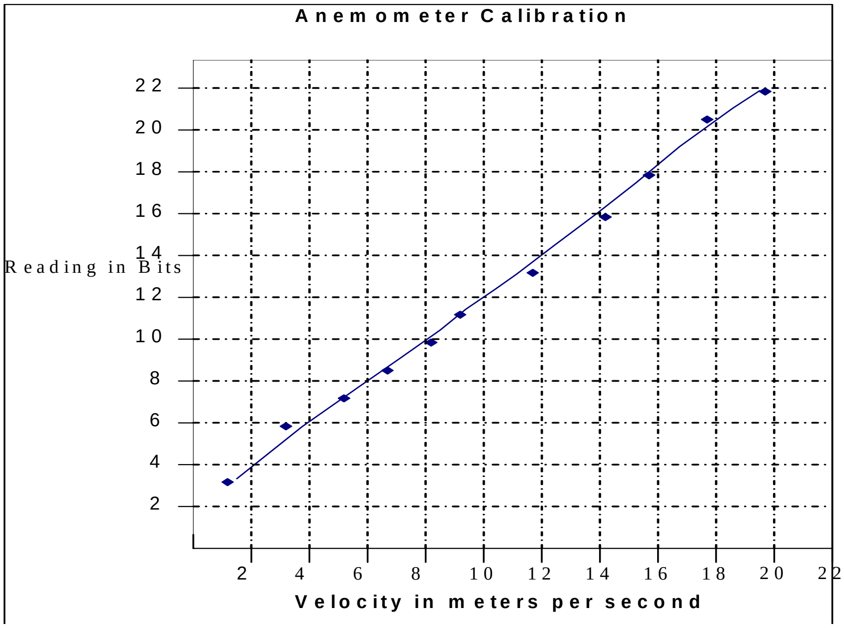

Figure 2: Plot of Anemometer Calibration

Wall of Wind calibration

The calibration performed with FIU Wall of Wind is shown in Figure 3. With the wall of wind it is possible to test the instrumentation in actual hurricane wind conditions. In this case, wind speeds of up to 130 mph were simulated in tests run Fall 2005.

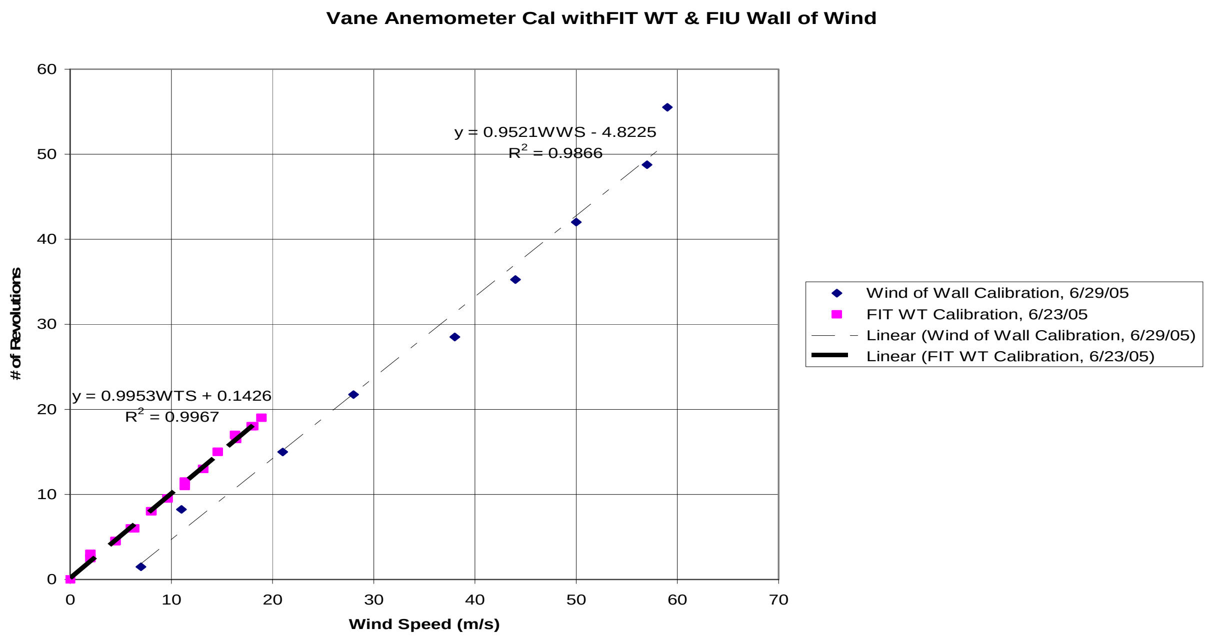

Figure 3: Anemometer calibration with FIU Wall of Wind

SYSTEM IMPROVEMENTS

This section explains the measures taken to improve the current system and the components in the new generation of remote units. As a result, the cost, size, and efficiency of the data collection system has been improved.

The remote units now run off of +5 volts. The benefits of this are a reduced component count due to the elimination of the need for level shifting and amplification of the pressure transducer output. Another benefit is the use of a new LDO regulator which has an on-board shutdown function, eliminating two MOSFETs and associated components from the old design. The lower voltage requirement also means a smaller battery and lower total current drain.

The new, smaller pressure transducer (MPX4115AP) now operates on five volts, and the output can be directly tied to the A-D converter of the microprocessor (PIC16F876-20), requiring only a single filter cap for noise.

The transceiver (BIM3-64) has been replaced, and is now capable of running at a faster baud rate when communicating with the distant remote units.

Both base and remote unit microprocessors have been upgraded from a 4MHZ clock crystal to a 20MHZ clock crystal, speeding up the overall operation.

The base unit no longer uses serial communications with the computer. For speed and ease of data transfer the parallel port is now used.

An embedded, single board computer is being used to collect and store data, eliminating the need for a laptop on site. A simple, fast, DOS-based system is used for transferring the data from each remote to a large hard drive. The data can be accessed on site with an interfacing laptop, but the laptop is disconnected and removed from the site during normal operations. The single board computer can be backed up with a large 12 volt battery.

The need for a connector between the antenna and remote circuit board has been eliminated; reducing the chances of poor connections hampering RF operations. The RF cable is soldered directly to the PC board, and a cable tie is used for stress relief.

A new method of accessing the remotes has been implemented. The remotes are arranged in 5 separate, addressable groups of 6. When the base unit addresses a group, each remote in that group transmits its data in turn. The data consists of 6 samples each. Each time a group is accessed, every remote in the system takes a sample simultaneously and saves their samples in order to be transmitted when its group is addressed. The result is 37 samples per second per unit, using 30 units. As the software is refined, this sample rate may increase.

The figures below show the resulting circuits for the base and the remote units.

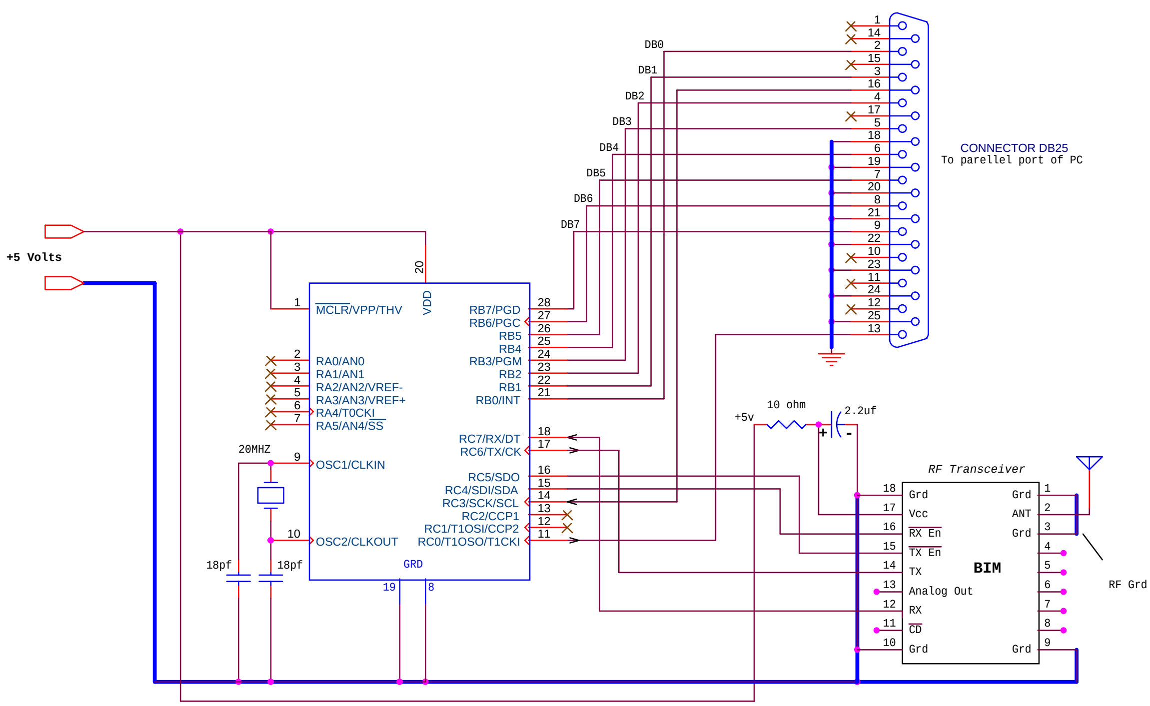

Figure 4: 2006 System – Base Unit

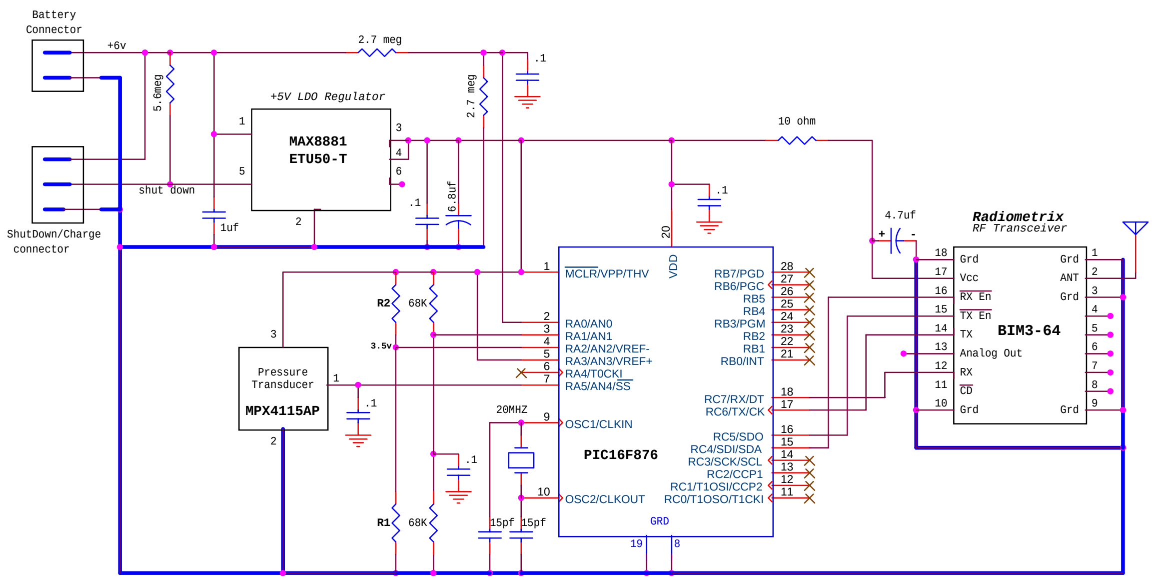

Figure 5: 2006 System – Remote Unit

Pressure Transducer

The pressure transducer to be used in the new generation of remote units is the MPX-4115 pressure sensor from Motorola. The MPX-4115 sensor is designed to sense absolute air pressure in altimeter or barometer applications. The MPX-4115 sensor has thin film resistor networks to provide a high level analog output and temperature compensation. Since it is an absolute pressure transducer, no reference pressure is required for operation. The high reliability of sensing measurements makes the MPX-4115 sensor a highly attractive choice for pressure sensing measurements. The MPX-4115 could thus be summarized as an integrated silicon pressure sensor, which is on-chip, signal conditioned, temperature compensated and calibrated.

The operating range of the integrated pressure sensor is 15 to 115 kilo Pascal (Kpa) of pressure or 2 to 16.7 in Pounds per square inch (Psi) units as compared to the previous transducer's range of 2 to 15 psi units. The corresponding output voltage range of the new transducer is from 0.2 to 4.8 volts, allowing easy system integration into a 5 volt system. The output of the transducer is temperature compensated between –40^{0}C and 125^{0}C, which is a higher range compared to the old transducer's range of -18^{0}C to 63^{0}C. The compensation ensures that the output will vary within certain limits given by the manufacturer. Stability with temperature does not depend only on the transducer, but also on the signal conditioning circuit, which in the case of the new remote unit is more reliable and efficient. A temperature sensor works alongside in each remote unit to allow for future corrections if needed in both remote units.

The response times of both the new and old pressure transducer are 1 millisecond, which is faster than what is required for the current application (10 ms at 100 Hz). This guarantees little distortion in the signal. Both devices are ratiometric within specified excitation, which is especially important when operating with batteries, since the voltage provided, will vary with the battery charge.

Transceiver

A strong potential for the role of transceiver in the new generation of remote units is the BIM3-64 technologies. This transceiver works at frequencies of 914.5 MHz, which falls within a free licensing band in the USA. The module integrates all the components needed for wireless transmission. Only an external antenna is needed to have it ready for use, saving space and time.

The device drains typically 26 milliamperes (ma) in transit mode and 10 ma in receive mode, which is higher than the old transceivers' transmit and receive mode current consumptions, which were 15 and 13 milliamperes respectively. The transceiver will go into sleep mode when not used, consuming less than 100 nanoamperes (na), compared to 50 nanoamperes by the old one. The maximum range of transmission claimed by the manufacturer is 120 meters open field range, a significant improvement over the previous transceiver used, as it has double the range compared to it. Thus, the transceiver is a significant improvement over the previous transceiver used, albeit with slightly more current draw. The new transceiver has TTL/CMOS compatible Input/Output (I/O), which is fully shielded for maximum sensitivity and reduced electromagnetic interference/radio frequency interference, features which were not present in the old transceiver.

Battery

All remote units will be powered with a Power Sonic PS-630, a 6-volt rechargeable sealed lead acid battery, with a charge capacity of 3.5 amp-hours. This battery weighs 620 grams, much lighter than its predecessor, the PS-1220 battery from Power Sonic, which weighed 900 grams. The new battery's 3.5 amp-hours means that the performance time of the new battery is a significant increase over the older battery's 2.2 amp-hours operating time. Also, the new battery's 6-volt system eliminates the need for a voltage regulator (as was needed by the old circuit due to the old battery having a 12 volt output), reducing circuit complexity and hence improving the efficiency of the overall system.

CONCLUSIONS

The goal of the project was to develop a wireless pressure sensor and anemometer system that could be used to instrument components or houses tested in the wall of wind. The first part of the project tasks consisted of troubleshooting the various problems and improving the performance of the current system. The resulting measures improved the system's performance in terms of recording time, less communication errors and more reliable performance resulting in a more predictable performance. However, in order to improve the system's key parameters such as communication data rate and range of distance between remote unit and base unit antenna, the current transceivers needed to be replaced with a newer, faster transceiver with a higher data rate and longer distance range. The need to build a new generation of remote units and base unit was further accentuated by the fact that replacement parts for the transceiver currently used are no longer available, making the current system less reliable for continuous deployment. In line with the above needs, a new system is being built, which will be followed by its testing and calibration in the wall of wind. The new system design consists of a circuit which is smaller and has less parts, incorporates a 6 volt system leading to the use of smaller, higher performance battery (PS-630 from powersonic), uses a pressure transducer with better pressure measurement range and a more powerful transceiver with higher specified communication data rate and communication distance range leading to a more efficient and reliable system. The new system will consists of 30 remote sensors. It could considerably simplify and speed up the set up of instrumentation by eliminating wiring, and simplifying data acquisition. This system could be used to instrument component and structures as part of a test program in the wall of wind.

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