Distributed wireless environmental noise monitoring systems

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Wireless technology extends the concept of PC based data acquisition beyond the limits of cables and wired infrastructure for new remote or distributed measurement applications. This is an overview of wireless networking basics and how to deploy reliable wireless measurement in a variety of outdoor or harsh environments for reliable and secure data acquisition systems. Case applications of distributed outdoor noise monitoring systems will illustrate networking layers and topologies for specific applications using IEEE 802.11 networks for reliable and secure wireless data acquisition systems. An example from France called SAVE (Surveillance of Acoustics and Vibration in the Environment) is a noise and vibration management system for construction site managers. It is based on multiple laptop based front ends placed throughout a construction site and connected wirelessly to a central supervisor for continual monitoring and reporting. Another example is a 10-node autonomous, distributed wireless monitoring system placed in various locations throughout the Historic Center of Mexico City. It takes permanent measurements of the noise levels and streams the data back to a main monitoring station every five minutes along with the measurements of noise produced during takeoff at the International Airport of Mexico City.

1 Introduction

Significant time and money has been invested into researching the use of wireless technology for remote monitoring. Yet, significant wireless deployments are just beginning to materialize in industry such as construction site management, traffic noise monitoring and building acoustics where running wires can be difficult. There are many advantages to eliminating cables in remote monitoring applications, but there are also many challenges. As standards such as Wi-Fi (IEEE 802.11) continue to mature, those challenges are being addressed.

IEEE 802.11 has a variety of advantages for remote data acquisition and data streaming for dynamic signal acquisition required for acoustic measurements as compared to other standards such as IEEE 802.15 (Zigbee) including range and security. IEEE 802.11 typically operates on 2.4 GHz and 5 GHz. Ranges from 30 to 100 meters with data rates from 54 to 600 Mbps are most common. The range depends on a variety of factors and can be extended significantly through a variety of network topologies and high gain antennas. In most current applications, a star topology is used with routers, switches, wireless access points, and wireless distribution systems (access points repurposed as repeaters) providing adequate coverage for the area being tested. Off the shelf mesh access points can extend this further.

Even if data is accessible to an unauthorized user, it is not necessarily intelligible. Data encryption on wireless networks has evolved significantly over the last decade from clear-text broadcasts to 128-bit cryptography. The Advanced Encryption Standard (AES) is now an NIST standard and a requirement for all U.S. government installations.

The advantages of using a standards-based wireless network include lower costs, interchangeable products from different suppliers, and established best practices. Also, standards such as IEEE 802.11 are readily incorporated with existing Ethernet-based systems. The IEEE ratified IEEE-802.11n-2009 on September 11, 2009 which offers significantly improved data rates (4 – 5 faster than 802.11g) and ranges for wireless local area networks with potential up to 100 Mbps comparable to wired networks. [1]

2 Construction Noise

Construction often generates community noise and vibration issues. The requirements for monitoring noise are growing and becoming more stringent. Construction sites can generate levels of vibration that can cause human annoyance and discomfort and possible building damage. Research on human response to vibrations suggests that people have an annoyance threshold far lower than any building's susceptibility to damage, even under the worst of circumstances, which is why it is important to have a system in place to monitor the effect of construction on the surrounding environment.

In France, as many other countries, legislation like the Public Health Code (Décret n° 2006-1099) regulates noise from construction sites. The construction company may also be subject to contractual obligations for monitoring. This makes it important to monitor noise and vibration to avoid misunderstandings and maintain the tranquility of the neighborhood by identifying problems in a timely fashion. A key element is that the environmental monitoring has to establish a level for the ambient for the site before the construction is introduced. [2]

2.1 Legislative Requirements for Monitoring

The acoustic requirements and analysis of a system for construction site management can be computationally intensive and are becoming more stringent. This can require more advanced instrumentation, data logging, analysis and reporting. When the Public Health Code on Neighborhood Noise in France was updated in 2006, limits were set on overall sound levels of no more than 5 dB(A) over the ambient during the daytime from 7 am to 10 pm and 3 dB(A) at night from 10 pm to 7 am. [1] Measures of ambient noise have to be made for at least 30 minutes and base figures have to be established for daytime and night-time operation. There are also specifications and adjustments for the duration of noise. [Table 1]

Table 1: Adjustments for duration of noise (T=Time)

T <= 1 minute	6 dB(A)
1 minute < T <= 5 minutes	5 dB(A)
5 minutes < T <= 20 minutes	4 dB(A)
20 minutes < T <= 2 hours	3 dB(A)
2 hours < T <= 4 hours	2 dB(A)
4 hours < T <= 8 hours	1 dB(A)
T > 8 hours	0 dB(A)

There are also new specifications on levels in 1/3 octave bands. For example, in the octave bands centered around 125 Hz and 250 Hz, the level over ambient noise in those frequency bands is 7 dB(A) and 5 dB (A) centered on the octave bands around 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz.

2.2 Construction Monitoring Solution

SAVE (Surveillance of Acoustics and Vibration in the Environment) was conceived by dB Vib Consulting and implemented by SAPHIR of France as a noise and vibration management system for construction site managers. It is based on National Instruments LabVIEW and the Sound and Vibration Measurement Suite, with multiple laptop based front ends using a Compact DAQ dynamic signal acquisition system to interface to an outdoor Type 1 level microphone, accelerometer and geophone. These are placed throughout a construction site or a suitable representative of the nearest structures not connected to the site. They are then connected wirelessly via 801.11g incorporated in the laptop to a central server to insure compliance with local regulation and contractual obligations.

The SAVE architecture consists of multiple noise and vibration monitoring stations or clients, a central server for supervision and a database for post processing of the data. It is designed to distribute the various tasks of monitoring for flexibility and performance. The monitoring stations are autonomous with respect to the central server allowing critical tasks such as alarms to be carried out locally in the event of a disruption of the network.

The noise and vibration monitoring stations contain a laptop computer in a weatherproof case connected wirelessly to a central server. This is connected to a NI-9234 24 bit Dynamic Signal Analyzer with the proper signal conditioning for providing power for IEPE devices via a USB carrier for the acquisition of noise (sound level and 1/3 octave analysis) and vibration from an outdoor microphone, accelerometer and a geophone. A NI-9481 High Voltage Relay output module is used for the activation of audio and visual alarms for immediate attention. (Figure 1)

Figure 1.Components of SAVE system

The central server is connected to the monitoring stations throughout the construction site in locations sensitive to noise and vibration. The system automatically detects and configures the monitoring stations, allows display of the data and alarms of several stations, downloads the files from the monitoring stations and allows remote access and the sending of alarms or notices to remote locations. The database allows post-processing of the data files for different applications and analysis. (Figure 2)

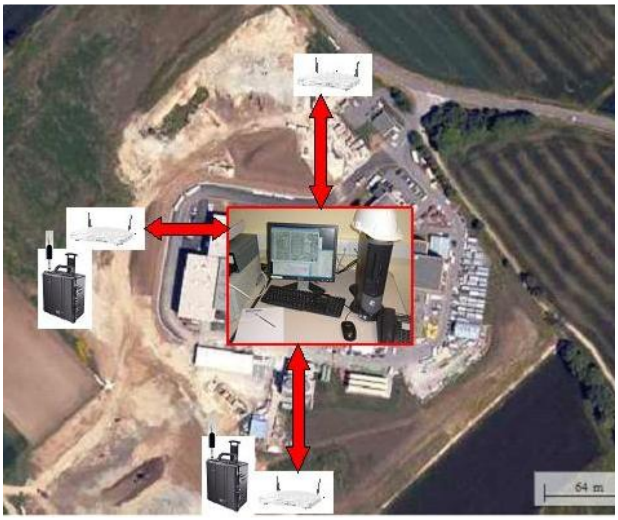

Figure 2.SAVE distributed throughout construction site.

The SAVE software was developed in LabVIEW with the Sound and Vibration toolkit for the front ends, central server and database due to its compliance with international standards for sound level measurements, weighting filters, octave analysis and human vibration measurements according to IEC 61260 (Electroacoustics - Octave-band and fractional-octave-band filters), IEC 61672 (Electroacoustics - Sound Level Meters), and ISO 2631(Mechanical vibration and shock -- Evaluation of human exposure to whole-body vibration).

3 Aircraft and Traffic Noise Monitoring in Mexico City

Noise levels from heavy automobile and aircraft traffic during morning and evening rush hours in Mexico City could potentially cause hearing loss. The Committee of Aerial Transport has proposed a new aircraft classification system in which the aircraft operator would pay a fee based on noise production, not weight or aircraft type. As a result, a novel computational model that not only measures noise production, but also identifies an aircraft based on the noise it generates was developed.

Identifying an aircraft based on the noise spectrum characteristics it generates is complicated in the real world because background noise, the weather, takeoff speed, and the aircraft's load can interfere with analysis. Recently, measurement equipment that uses neural networks to identify noise has appeared on the market, but it can only distinguish between jet aircrafts, propeller aircrafts, helicopters, and background noise. It wss decided to create a computational model to measure and interpret noise. Using only the noise created during the 24 seconds after takeoff, our system can correctly identify the aircraft.

3.1 System Design

Dr. Jose Luis Sánchez, of the National Polytechnical Institute developed a 10-node autonomous, distributed and wireless monitoring system and is working on deploying this in 2009. The system was based on an industrial PC using LabVIEW for the application program, the Sound and Vibration toolkit and USB-9234's dynamic signal analyzer. This is compliant with international standards for sound level measurements, weighting filters, octave analysis according to IEC 61260 (Electroacoustics - Octave-band and fractional-octave-band filters) and IEC 61672 (Electroacoustics - Sound Level Meters), The system uses a ½" prepolarized IEC 61672 Class 1 type microphone with a windscreen, rain protection and bird mounted spike mounted 4 m. above the road surface. The system is contained in a weatherproof case with an uninterruptible power supply to prevent loss of data if the power drops. The system is designed so it can keep collecting data locally for up to 14 days.

Even though each node is connected to the city's electrical system, we use an uninterruptible power supply to prevent data loss. The node measures noise levels every 30 seconds and the system can collect data locally for up to 14 days. The government plans to use the data to identify the times and locations in Mexico City with the highest noise level, create noise maps, and implement regulatory actions to control the noise and promote a healthier environment for its citizens.

The system can record traditional metrics used for road traffic noise, such as continuous equivalent sound level (Leq), and it can also record fractional octave analysis and measure prominent tones. In addition, the system can transfer WAV files to a central server to study transient signals that may trigger alarms, which helps identify isolated sound sources that interfere with accurate measurements. (Figure 3)

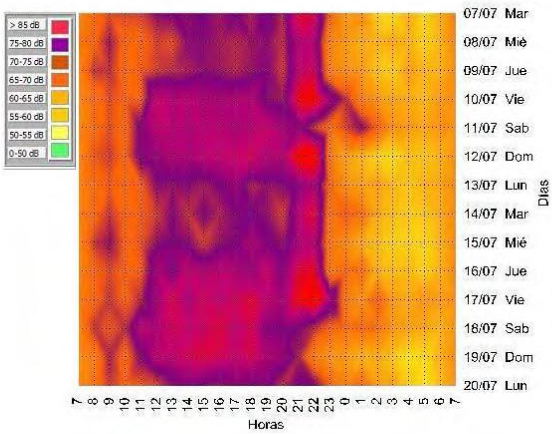

Figure 3: Noise Patterns From Two Weeks data in the City Square of México City

It was originally planned to use the public Wi-Fi that the government installed in 2008, but some nodes had to be converted to a slower 3G system provided by a wireless carrier. Although speech and data services and be used simultaneously on the 3G network, it has significantly slower data transfer rates.

The control center has a static IP address. Each node has a dynamic address assigned by a DHCP server. The control center is similar to a server and the nodes are similar to a client. The nodes attempt to open a TCP connection, and if the control center receives this connection request and the node's validation key, it accepts the connection. (Figure 4)

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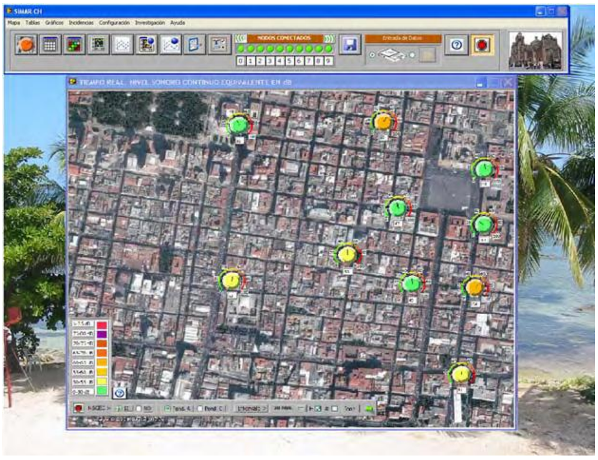

Figure 4:Control Center server interface

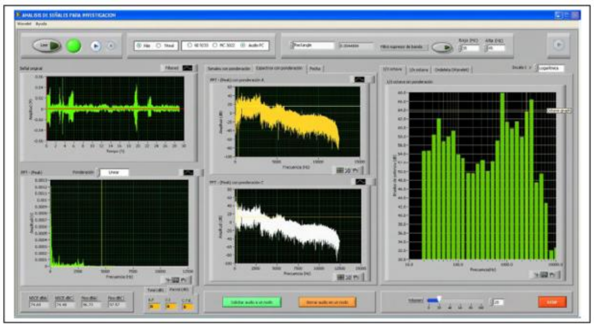

Figure5: Signal analysis of audio that exceeds thresholds

3.2 Reducing Spectral Resolution

A system block diagram was created for pattern generation and recognition. Takeoff noise was considered a non-stationary transient signal because it starts and ends at a zero level and has a finite duration. Most of the signal's energy is below 2 kHz. In this case, we notice the background noise more strongly at the ends of the signal because the aircraft-generated noise masks it in the middle portion.

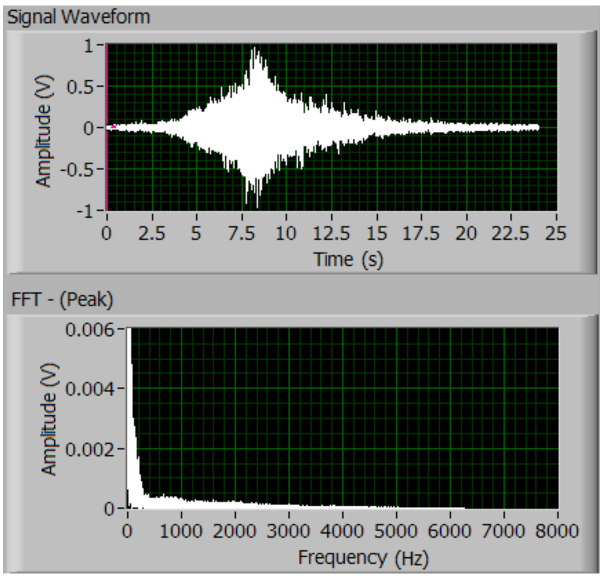

Figure 6: Typical Noise and Spectrum Signal of a 747 taking off.

For all aircraft noise, it was observed the typical form of the amplitude spectrum was from 0 to 5,000 Hz. A sampling frequency of 11,025 Hz was chosen in order to reduce the number of samples taken in 24 seconds to 264,600 samples. In other aircraft noise analyses, the recommended sampling frequency is 25 kS/s and D-, C- and A-weighting filters.

It was decided to reduce the spectral resolution because the amplitude spectrum has 132,300 harmonics, which would result in very complex processing. In addition, the primary interest was in gathering data about the spectral form.

Any method to reduce spectral resolution introduces a tolerance in the initial and final times within the measurement interval of aircraft noise. For example, a feed forward neural network is trained with one noise pattern, which was acquired from zero seconds from the aircraft takeoff until 24 seconds later. In run time, if the aircraft takeoff noise is acquired from 5 seconds until 24 seconds, this 5 second time displacement will have little effect on the spectral form if its spectral resolution has been reduced. A median filter (moving average filter) creates a typical form of the aircraft's takeoff noise spectrums. The decimation of average spectrum, with a rate X, conserves the spectral form of an aircraft's takeoff noises.

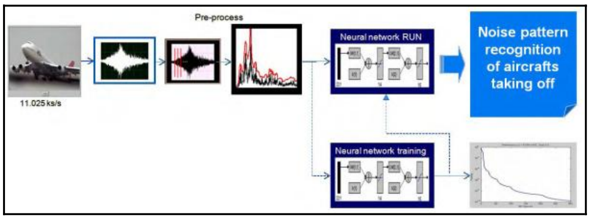

Figure 7: System block diagram for pattern generation and recognition.

The 10-node system successfully measures the noise produced during takeoff by airplanes at the International Airport of Mexico. The system makes many different types of spectral analyses and obtains the most-used statistical indicators for noise measurement, expressed in dB(A) or dB(C). They can store the data collected by the system and later come back to perform more in-depth analysis. This allows the determination of potential health risks from this noise, and gain an idea of how noise levels fluctuate throughout the day.

In the future, we would like to measure the differences of the yield when applying this technique after segmenting the original signal. We also plan to test new parameters to create the neural network.

4 Conclusion

Wireless technology extends the concept of PC based data acquisition for acoustics beyond the limits of cables and wired infrastructure for new remote or distributed measurement applications. Both systems described here are examples of autonomous monitoring stations with respect to the central server allowing critical tasks such as alarms to be carried out locally in the event of a disruption of the network. The architectures for monitoring and archiving make it adaptable to other applications where continual monitoring of noise and vibration needs to be implemented in a distributed environment.

Acknowledgments

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