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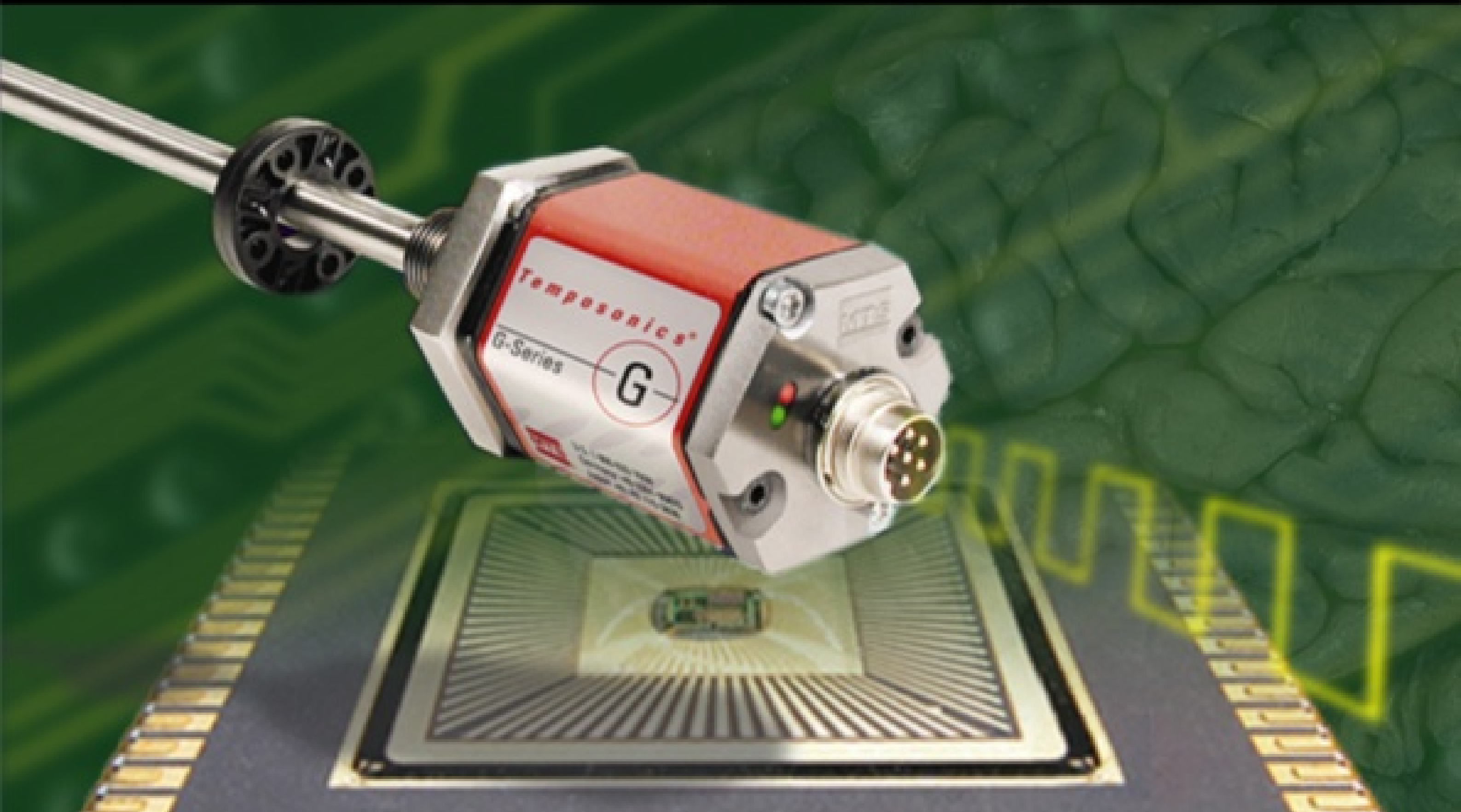

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Data Acquisition and Digital Filtering for Infrasonic Records on Active Volcanoes

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Abstract: This paper presents the design of a digital data acquisition system for volcanic infrasound records. The system includes four electret condenser element microphones, a QF4A512 programmable signal converter from Quickfilter Technologies and a MSP430 microcontroller from Texas Instruments. The signal output of every microphone is converted to digital via a 16-bit Analog to Digital Converter (ADC). To prevent errors in the conversion process, Anti-Aliasing Filters are employed prior to the ADC. Digital filtering is performed after the ADC using a Digital Signal Processor, which is implemented on the QF4A512. The four digital signals are summed to get only one signal. Data storing and digital wireless data transmission will be described in a future paper. *Copyright © 2007 IFSA.*

Keywords: Volcanic Infrasound, Data Acquisition, Digital Filtering, Digital Signal Processor

1. Introduction

Infrasound refers to sound below 20 Hz. It is generated by a variety of events, both man-made and natural. Among the latter type, active volcanoes are efficient sources of infrasound. Volcanic eruptions are characterized by the acceleration of hot fluids from subsurface reservoirs into the atmosphere generating acoustic waves in the 1-20 Hz frequency range.

Researchers have recognized the merits of infrasound as a tool for the understanding of volcanic phenomena [1-3]. Infrasonic airwaves produced by active volcanoes provide valuable insight into the eruption dynamics and related phenomena. Infrasound also provides a special opportunity for the comparison of eruptive activity among different volcanoes because atmospheric pressure records are mostly independent of site-specific propagation effects [4].

However, infrasound propagating long distances is a complex phenomenon. It is strongly influenced by the detailed temperature and wind profiles. The infrasonic signal detected by traditional infrasound systems contains the combination of the source's infrasound power spectrum and the distortions introduced by the atmosphere. In order to extract the source characteristics from the collected data, advanced signal processing is required. In this paper we present a Digital Data Acquisition System (DDAS) for detecting, locating, and identifying infrasound sources at close range: from a few meters to a few km distances. At short distances, the atmosphere is a homogeneous medium that preserves the infrasonic waveform as it is generated by the source. We would like to place signal processing as close as possible to the sensors.

Two traditional Data Acquisition System (DAS) for deploying infrasound sensors are displayed in Fig. 1. The Swedish-Finnish Infrasound Network [5] uses a DAS as shown in Fig. 1 a). The signal output from a 3-microphone rectangular triangle array is analog and as it travels along the wires (75 to 150 m) it picks up interference. The acquisition unit is a PC. The current standard systems used in infrasound networks have limited portability. The block diagram in Fig. 1 b) was introduced in [6] as a wireless data acquisition system. The signal recorded by each element of the array is analog low-pass filtered below 20 Hz. The analog signal is then adapted to fiber optic cable by using a voltage-to-frequency converter. This frequency-modulated signal drives a high-power solid-state laser. Before the digital acquisition, the frequency modulated infrasonic signal is converted back to voltage by using a photo-diode receiver and is again low-pass filtered (<20 Hz) to remove the electronic noise introduce by the frequency-to-voltage conversion. The signal is then converted to digital. The installation of current measurement systems is complicated due to the laying of the optical fibers.

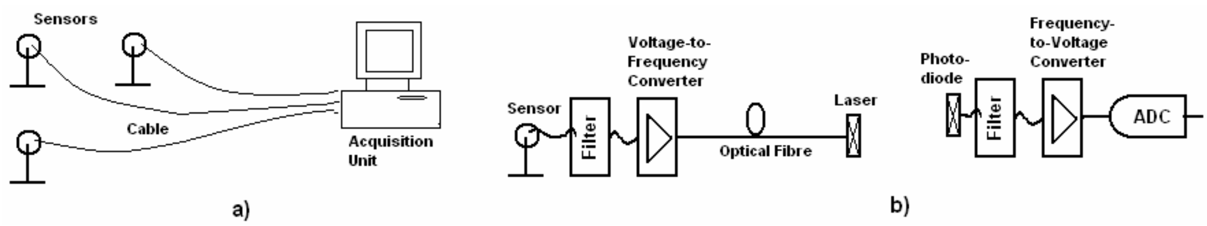

Fig. 1. Data Acquisition System used at Swedish-Finnish Infrasound Network (a) and a typical wireless DAS (b).

What we need is a portable, easy to install, low cost, low power consuming, rugged system that can be used in a hostile volcanic environment. Monitoring and recording infrasound from active volcanoes places unusual demands on a DAS. While the sampling rate requirement is modest, 45 Hz, the combination of the need of portability and the difficult volcanic environment presents challenges.

1.1 Proposed Solution

In order to address the problems set forth above, a Digital Data Acquisition System (DDAS) as shown in Fig. 2 is proposed. The design of this DDAS features data taking from four element microphones, analog signal conditioning, analog to digital conversion, digital filtering and storage of the data before it is sent out using wireless means. The data storage and wireless techniques will be presented in future paper. This design approach is based on the QF4A512 Programmable Signal Converter developed by Quickfilter Technologies [7-8]. The QF4A512 handles four sensor signals simultaneously.

The MSP430 microcontroller from Texas Instruments provides the adder and control and communication functions.

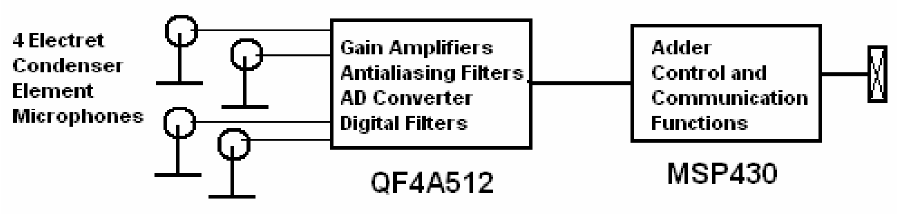

Fig. 2. Block Diagram of Digital Data Acquisition System.

2. Architecture and Essential Features

The system essentially consists of three distinct elements - sensor, ADC and filtering - with each element having its own features of interest.

2.1 The Electret Condenser Element Microphones

Infrasonic studies on active volcanoes have become more common with the introduction of inexpensive Electret Condenser Element Microphones (ECEM) [4, 6]. Such sensors are not specifically designed for infrasound monitoring and usually they show a reduced response at frequencies below 20 Hz. However, ECEM are used in many infrasound networks around the world and they are easy to install, robust and exhibit low-power consumption.

The infrasonic sensors used in our DDAS are four MCE-200 element microphones from Panasonic. These element microphones have a flat response function in the audible band (from > 20 Hz to 16 kHz) and operation in the infrasound band (below 20 Hz) is outside the manufacturer's specified range of operation. The four redundant ECEM help to achieve heightened signal-to-noise ratio and provide robustness in case one of them should fail. We should note that these element microphones could be replaced with any better infrasonic sensors.

2.2 Analog to Digital Conversion

The functional circuit blocks for processing the signals from the ECEM are shown in Fig. 3. The first link is a signal conditioning analog front-end Programmable Gain Amplifiers (PGA) and Anti-Aliasing Filter (AAF). The second link is the all important Analog to Digital Converter (ADC) itself. The ADC can be programmable to cover a wide range of frequency inputs. The third link represents a piece of signal processing in the form of digital Finite Impulse Response (FIR) filter. The last link shown in Fig. 3 is a microcontroller that performs addition of the four signals, control, communication and other intelligent functions.

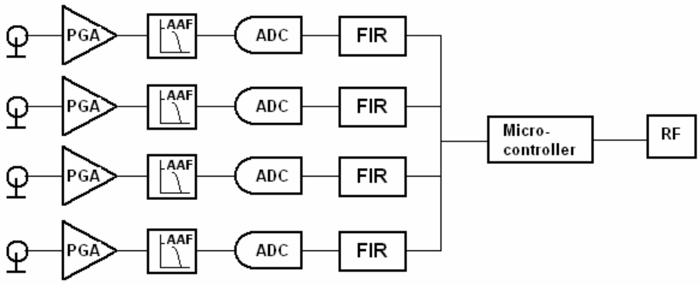

Fig. 3. Functional circuit blocks for DDAS.

The signals output from the ECEM are analog and can vary in voltage and frequency range depending on the type of event. These signals are then amplified and the amount of gain chosen can be 1x, 2x,…, 8x. Next the signals are converted to digital via a 16-bits ADC. To prevent errors in the conversion process, low-pass Anti-Aliasing Filters are employed prior to the ADC. The operating frequency of the ADC is also selected specifically for the signal frequency coming from the sensor. Digital filtering is performed after the ADC using a Digital Signal Processor (DSP). This filtering is more accurate than the filtering of the analog signal before the ADC. Each signal path has a dedicated 512 tap digital FIR filter capable of providing high levels of filtering functionality. The four filtered signals are then added at a Microcontroller, which can send the resulting signal through an RF network.

2.3 Digital Filtering

The basic function of a filter is to pass frequencies of interest (Pass band) while attenuating everything else (Stop band). Traditional systems perform their filtering function in the analog domain (i. e., prior to digitizing by the ADC). In our approach, filtering is performed after the signal has been converted to ones and zeros using a Digital Signal Processing (DSP), which offers a number of rather compelling advantages. First, the DSP approach completely eliminates noise pickup and also avoids component tolerance and drift issues that plague analog components. Second, DSP solutions are inherently more reproducible and reliable than their analog counterparts. Finally, digital solutions are easy to design, debug and reconfigure.

Fig. 4 shows the filter response and impulse response of the FIR filter implemented in our experiment. There are a few factors to consider on filter implementation. See Table 1. Most basic is the degree of attenuation between the pass band and stop band. In our example, a filter with 60 dB of attenuation reduces the amplitude of unwanted frequencies by a factor of 1000. Another key factor is the selectivity, or quality, of the filter as measured by the slope of the roll on and off. The Parks-McClellan filter type offers sharp transition bands at the expense of some pass band ripple, 1 dB. Another factor is the number of taps. Each filter can have up to 512 taps; each tap corresponds to the familiar multiply-and-accumulate (MAC) operation at the core of DSP inner loops.

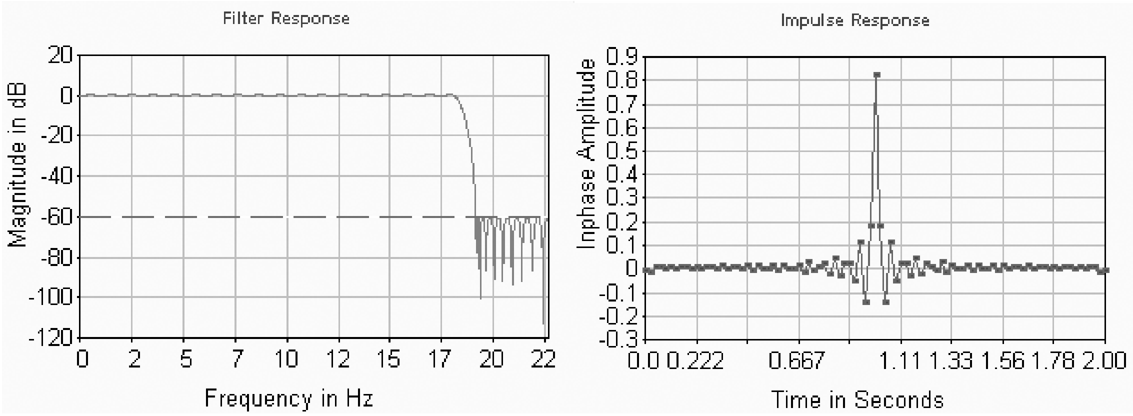

Fig. 4. Filter response and impulse response.

Table 1. FIR filter.

Filter Type	Parks-McClellan
Sampling Frequency	45 Hz
Number of Taps	91
Coefficient Mode	20 bit quantized
Ripple	1 dB
Attenuation	60 dB
Pass band Upper	18 Hz
Stop band Lower	19 Hz

3. Results of the Experiments

The system has passed extensive laboratory and field tests (e.g. with man-made explosions). The upper graphs in Fig. 5 shows the waveform of an infrasound signal generated by opening a door and its parametric amplitude spectrum that uses a bar plot. The Fourier procedure is used to estimate the frequencies and component count. The signal of a man-made explosion and its parametric amplitude spectrum are shown by the lower graphs in Fig. 5. These two signals were recorded by our DDAS. It can be seen that the proposed DDAS operates satisfactorily in the infrasound band (below 20 Hz).

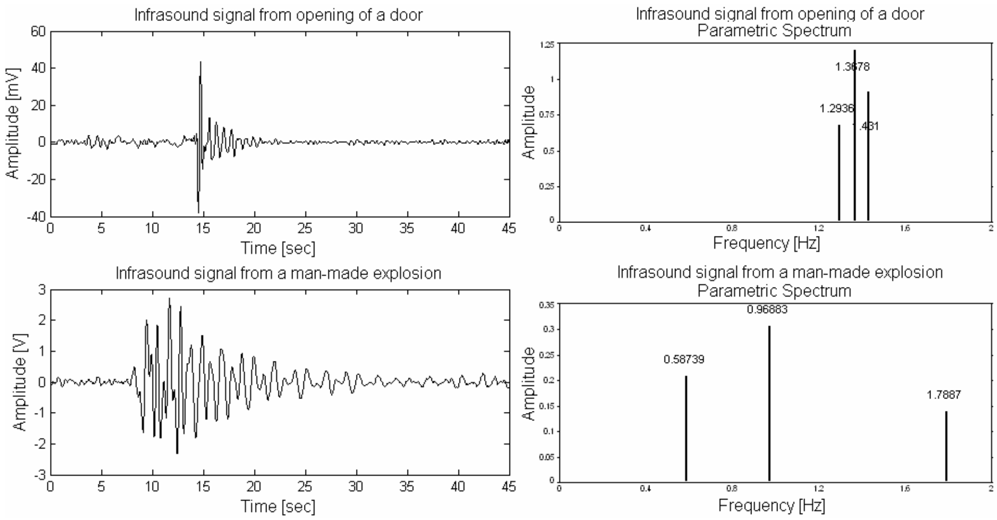

Fig. 5. Infrasound signals and their parametric spectrum.

Experimental results are shown in Fig. 6, which displays a comparison of the infrasound signal generated by a man-made explosion and recorded by our DDAS versus the same signal recorded by traditional DAS. It can be seen that the proposed DAS matches the performance of the traditional DAS.

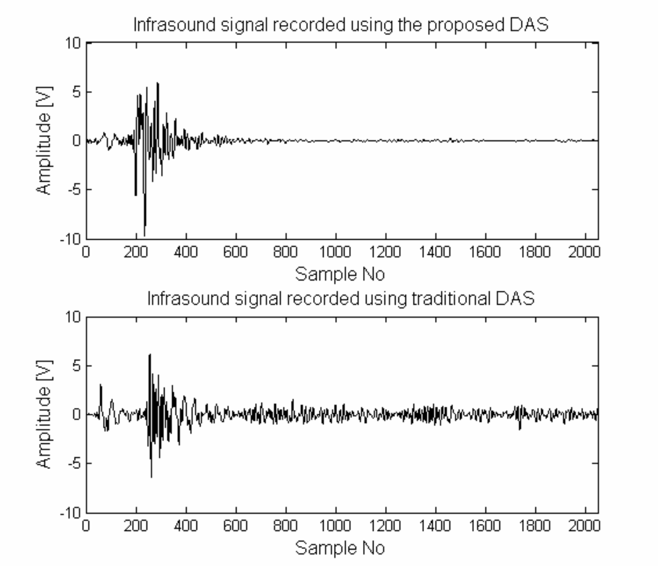

Fig. 6. Signals recorded using DDAS and traditional DAS.

4. Conclusions

The data acquisition approach described in this paper provides the required performance for active volcanoes research experiments. The integrated DDAS, which employs a QF4A512 programmable signal converter from Quickfilter Technologies and a MSP430 microcontroller from Texas Instruments, successfully addresses present waveform resolution and data processing demands. The full capacity of the present DDAS configuration with respect to data storage and digital wireless transmission has not been required in our experiments to date.

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Contributions are invited on all aspects of research, development and application of the science and technology of sensors, transducers and sensor instrumentations. Topics include, but are not restricted to:

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- Virtual instruments;
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