A Low Cost Infrasonic Recording System

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***Abstract*—Infrasound is sound waves with frequencies below 20 Hz which are not audible to humans. But having said that there are various sources that exist in our environment which emit infrasound and these infrasound signals narrates interesting findings and warning to humans beings which are of utmost importance. At present equipments which are designed specifically to record and analyze infrasound is rare and the handfull of devices available to record infrasound are very complex to use and costly. Thus, an infrasound recording system, which is low in cost, accurate with the results produced and easy to use is needed. Therefore, this research is related to the design and development of an infrasound recording system with the aforementioned goals.**

***Index Terms*—Infrasound, Pre-Amplifier, A/D Converter, Anti-Aliasing Filter**

I. INTRODUCTION

AUDIBLE range for a healthy human being, categorized by frequency, falls in the range of 20 Hz - 20,000 Hz. Thus, as humans we have named sound signals which are less than 20 Hz as infrasound and frequencies higher than 20,000 Hz as ultrasound. This research concentrates on the lower side of signals which are called infrasound.

Although humans, never use infrasound for thier communication, there exist a handful of animals that use infrasound for their communication. Species such as elephants, whales, giraffes, lions and rhinoceros could be named as examples. Apart from that, volcanoes, avalanches, high speed winds, tornadoes and tsunamis could be named as other natural sources of infrasound. Recording and analyzing these infrasound sources would help in many ways to understand the behavior of them.

As mentioned above elephants use infrasound for their communication. Therefore, this unique feature of elephants could be used to study elephant behavior and also one could research on whether infrasound communication of elephants could be used to effectively detect the presence of elephants.

It is a well known fact that the human-elephant conflict is one of the major problems that exist in Sri Lanka. According to the Department of Wildlife Conservation, on an average 150 elephants and 65 people die owing to human-elephant confrontations and conflict each year[1]. With this alarming rate of death, the relevant authorities came up with electrical fences which has failed to live upto its expectation. The major reason for the failure of the electric fence was that the elephants adapted themselves to the fence. Another reason was the huge cost of maintenance. In the aftermath of the failure of electrical fences, zoologists have suggested the development of an early warning system to prevent elephant raids on villages. Various researches have been carried out by institutes the world over to find methods to detect an approaching elephant before it becomes visible to the naked eye. One such research pointed out the possibility of using the elephant-elephant communication (elephant rumbles), which lies beyond the threshold of human hearing, to detect the presence of a heard of elephants in close proximity. However, these sounds have to be recorded and analyzed precisely to prove their uniqueness in order to guarantee that the detection is fail-safe. But the problem is that the handful of equipments available for recording and analyzing of infrasound are costly and complex to use. Thus zoologists in countries such as Sri Lanka find it difficult to conduct their research on elephant infrasound. Addressing this problem is the main objective of this research.

The rest of this paper is organized as follows. The next section would provide insight into the related work regarding this research. The 3rd section would provide the entire design and implementation of the system and the 4th section provides results of two recordings conducted in real environments. The 5th section of this paper contains a cost benefit analysis and the 6th section of the paper describes the future work related to the project. The final section will contain the conclusion.

II. RELATED WORK

There exist a few instances where elephant infrasound has been recorded. One of the main projects related to elephant infrasound is the Elephant Listening Project (ELP)[2], which was initiated in the year 1999 by the Cornell University bioacoustics research program. The main outcome of this project was that these researchers were able to estimate the infrasonic rumble frequency of the African elephants which was stated as being between 5 Hz - 30 Hz.

In this project they have come up with the following system for infrasound recording. They have used a highly sensitive microphone[3] which has been directly connected to a pre-amplifier. Data that is captured from the microphone is logged in a laptop hard disk using a data acquisition board. The data acquisition board has been used for the analog to digital conversion as well as for the data logging process. These devices were placed at the top of trees to prevent them from being damaged by wild animals. Finally it should be stated that this device which they have customized for the recording of infrasound has a sample rate of 44.1 kHz which means that they have recorded data with CD quality sound.

Apart from the recording of infrasound in Africa, the Cornell University has also carried out a project on recording infrasound of Asian elephants[4]. This project has been done in the late 1980s. With regard to the equipment that they have used, it should be mentioned that they have used general radio microphones and the recording device they have used is a tape recorder.

Other than the research carried out to record infrasound of elephants, the other major research area regarding infrasound recording relates to volcanic activity monitoring.

One of the research projects conducted by the Royal Institute of Technology and the University of Gavle Sweden[5] has been able to record infrasound generated by volcanoes. The most interesting part of this research is that they have used condenser microphones for the recording of infrasound. The whole system used by them to record infrasound consists of a condenser microphone, a QF4A512 programmable signal converter[6] and a MSP430 micro-controller interfaced to a bluetooth device. The readings from the condenser microphone has been directly interfaced to the QF4A512 programmable signal converter. This signal converter is a small chip that contains programmable amplifiers, anti-aliasing filters, analog to digital converters and digital filters. The first process of the device is the amplification of the recorded signal. This has been done directly with the use of the programmable amplifier (the gain of the amplifier is programmable) in the QF4A512. Afterwards, the amplified data has not been directly digitized using the A/D converter. This is due to the errors that could occur (according to the Nyquist criteria) when the A/D converter samples the analog signal. Therefore they have used the anti-aliasing filter provided in the QF4A512 to mitigate the error that could happen at sampling. After the anti-aliasing filter, filters out the higher frequencies of the recorded signal, digitization of the analog signal is carried out. Thereafter the digitized data is sent through a digital filter. Normally in applications such as these, filtering is done prior to the digitization of data. But in this study the researchers have conducted the filtering on digitized data. The reason for this is that digitized data has no impact on noise. Apart from that another reason they have stated is that the components used for digital filtering is more reliable than analog devices.

In another study[7], wireless sensor networks has been used to monitor volcanic activity. The main reason behind the use of wireless sensor networks is that most of the devices used thus far for infrasound and seismic sensing have been bulky devices which consumes a lot of power. However, with the miniature size and low energy consumption of sensors makes them ideal for recording infrasound in hostile environments. Another advantage provided by the sensor network is the data transfer ability. If traditional sensors were placed then the research team would always have to visit the site to collect the logged data. But with a sensor network deployment we could very easily transmit the data wirelessly to a preferred location.

III. System Design and Implementation

The entire infrasound recording system (hardware and software) built in this project was named the Autonomous Recording Unit (ARU). This system consists of the following components. A speaker (infrasound sensor) as an analog input, an amplifier, an anti-aliasing filter, an analog to digital (A/D) converter and finally a PC application which is used to analyze the recorded signal.

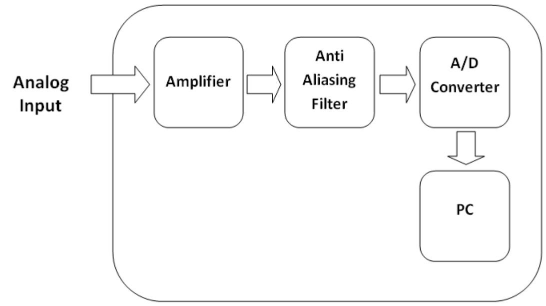

Fig. 1. Block diagram of the complete system which is named as the Autonomous Recording Unit (ARU)

A. The analog input

The analog input is the captured audio signal. Audio signals can be captured by microphones and speakers.

Normally microphones are used for capturing of audio signals. But for the ARU the decision was taken to use a speaker rather than a microphone. The reason behind this is that the speaker is more sensitive to low frequencies rather than the microphone as it is always better to have a larger surface to capture signals with long wave lengths (low freq). And another reason for the selection of the speaker instead of the microphone was that a speaker can be directly connected to the amplifier/filter circuit but a condenser microphone needs additional circuitry. Finally, it should be mentioned that the speaker has a better frequency response at lower frequencies when compared to a microphone. This was also a reason to select the speaker rather than a microphone.

B. The amplifier

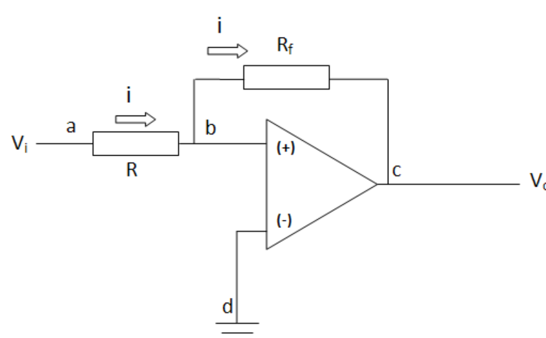

Fig. 2. Op-Amp IC based inverting type amplifier circuit

The input signal has to be amplified before it is filtered and sampled. The decision was taken to use an Operational Amplifier (Op-Amp) IC for the amplification purpose of the input signal. The main reasons to base the amplifier on an Op-Amp IC was the low cost and the simplicity of the them. Going into more detail, the amplifier was designed in such a way that it would have the gain of 220 times the input signal. Apart from that it should be mentioned that the amplifier designed is of the inverting type.

The model number of the Op-Amp IC used for the amplifier is TL084. This is a common low cost operational amplifier available in Sri Lanka.

C. The anti-aliasing filter

The main objective of using an anti-aliasing filter was to mitigate the problems that occur with the Nyquist criteria. When a signal is sampled, it should be guaranteed that the frequency components higher than the desired sampling rate should not enter the sampling device, or else the high frequency components may appear in sampled signal in the form of ”noise”, thus deteriorating the signal. This is a direct consequence of the phenomena known as Nyquist criterion. For this purpose, an anti-aliasing filter is employed to filter out unwanted frequency components of the input signal.

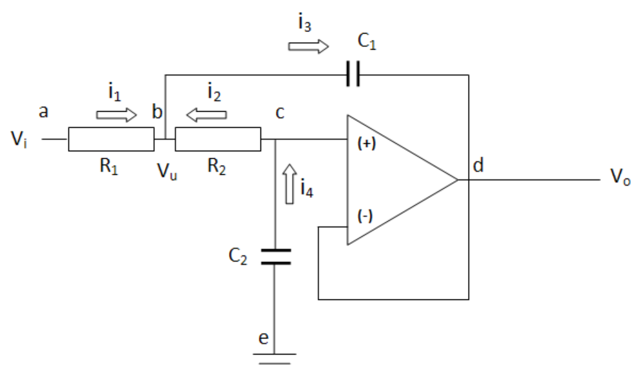

Fig. 3. 2nd order anti-aliasing filter circuit based on a Op-Amp IC

In other terms the anti-aliasing filter would act as a low pass filter and higher frequency signals (noise) containing in the input would be filtered.

The simplest way to come up with an anti-aliasing filter circuit is with the use of Op-Amp ICs. Here again the Op-Amp IC was selected because of its low cost, availability and simplicity. Finally, it should be mentioned that the Op-Amp IC model selected for the anti-aliasing filter circuit is TL084. This is the same Op-Amp that was used for the amplifier as well.

The choice of the filter type for the anti-aliasing filter was the Butterworth low pass filter. This filter was designed in such a way that it would represent a second order Butterworth low pass filter with the cut off frequency of 100 Hz.

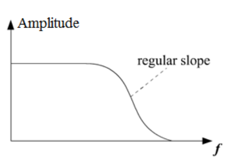

Fig. 4. Butterworh filter response

There exist many low pass filters which could be implemented successfully on hardware. But the main reason for us to choose the Butterworth filter was that it shows very few (none in the ideal case) ripples in its bandwidth (see figure [4]) whereas many other low pass filters depicts ripples on its bandwidth. But, it should also be mentioned here that the disadvantage of the Butterworth filter is that it does not have a sharp cutoff. But this will not be a problem as in this project there is no need of a strict cutoff for the low pass filter.

D. The A/D converter

The main objective of using an A/D converter is to interface the filtered signal into the PC. For this purpose the micro-controller PIC16F877A[8] was used. This micro-controller has a 10 bit A/D converter on the chip itself. Therefore, this PIC was chosen for the A/D conversion purpose. According to the information available on the manual of the PIC, the A/D converter has a sample time of $50\mu s$. The output of the PIC is interfaced to the parallel port of the PC. The decision of using the parallel port for interfacing the A/D converter was made because the A/D converter converts analog values into a 10 bit digital value, and to read it from the serial port (the other obvious choice to interface the device to the PC), two readings will have to be done because the serial port transfers 8 bits at a time. But using the parallel port we could read out a 10 bit value with one read to the port. For this purpose we used the 8 data lines and two other lines, namely the paper empty line and the select line, in the parallel port.

E. The software application

One of the most efficient signal processing applications available right now is Matlab[9]. This application provides all the functionalities for signal processing in computers. But having said that, it should also be mentioned that a user needs to have a solid background knowledge on computer programming in order to use Matlab effectively for signal processing.

But, our system is intended for the use of zoologists, physicists etc. who normally do not posses a good knowledge in computing. Therefore, our main objective of developing this system was to provide user friendliness together with most of the functionalities needed for signal processing. User friendliness was brought about by providing a well structured GUI.

The main feature of the software application can be listed as follows.

1) View recorded signals as well as filtered out signals.
2) Hi, Low and Band pass filtering with the use of IIR filters such as Butterworth and Chebyshev.
3) Save important sections of a signal recorded for future reference.
4) Conduct Fast Fourier Transformations (FFT) on recorded signals in order to view the frequency components.

One of the major considerations made in order to make the system user friendly was to provide a simple GUI, rather than making the user program what he/she need to perform. Another consideration we had to make was the amount of data to be shown at once in the application. This was considered because a data file for a 30 min recording would contain

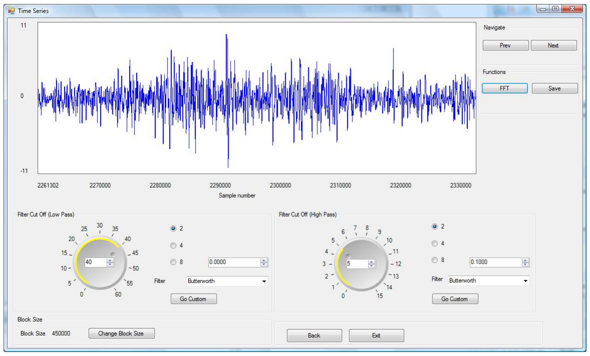

Fig. 5. The main window of the signal processing application

around 13 million data points and therefore plotting a graph with that size would make the system come to a halt. And also to perform filtering, zooming and FFT on a recorded signal which has millions of data points would have a performance effect on the system and in the worst case the system might crash. Thus because of this issue and because we cannot have an estimate of the hardware configuration of the PC that is going to run the application, we had to limit the number of data points that can be read in to the application at once. After several test runs on various kinds of PCs (different configurations) we decided that 800,000 (block of data) data points would be the maximum size for the application to read at once. Apart from that for the application to function smoothly it needs a PC with at least 512 MB RAM and a Pentium 4 or a equal processor. It should also be mentioned that though the signal (recorded data) is divided into blocks and read into the application, signal traversing and merging of blocks is provided.

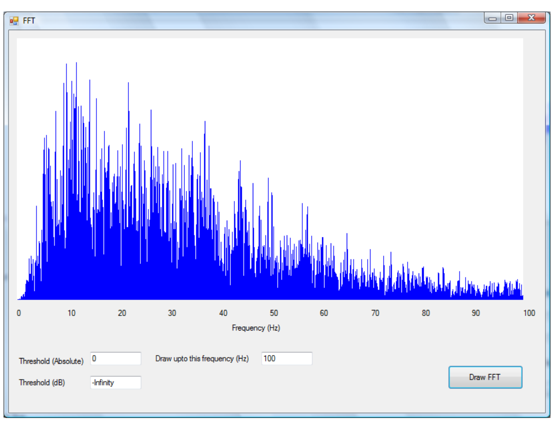

Fig. 6. The windows form related to the FFT functionality of the software application

IV. Test results

Two case studies were carried out in order to check the sensitivity of our system. One case study was carried out on elephants whereas the other case study was related to a diesel engine.

A. *Information regarding graphs*

1) Time domain graph:

- X Axis: Represents the sample number of the data sample, sampled at 7500 samples/second. In order to transform the X Axis to the real time scale each value should be divided by 7500.
- Y Axis: Represents the magnitude of the signal at a given time. This is largely relative due to amplifier gain, filter gain and the distance between the source and the infrasound sensor. Therefore the Y axis values may change from data set to data set. Anyway it will not affect the frequency distribution of the dataset.

2) Fourier transform graph:

- X Axis: Represents the frequency.
- Y Axis: Represents the absolute magnitude of a given frequency. As with the Y Axis of the time domain graph the Y Axis in the FFT graph is also largely relative. Therefore, the values for the Y Axis has been omitted.

B. *Elephant Infrasound*

Recordings were carried out at the Dehiwala zoo. At the time of recording there were three Asian elephants and one African elephant. The infrasonic sensor was directed at all four of them.

We low passed filtered the recorded signal with a 4^{th} order Butterworth bandpass filter with the lower cutoff at 40 Hz and the higher cutoff at 5Hz.

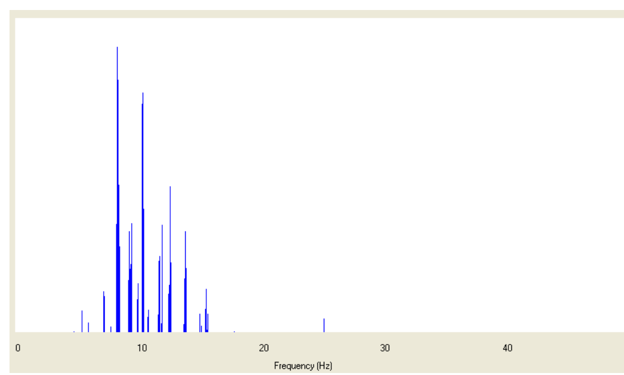

Fig. 8. FFT graph for the elephant call in figure [7]

In a portion of the filtered output represented in figure [7], we could very clearly see that there is an infrasonic signal from data sample 9360000 - 9405000 (which is roughly 6 sec). The FFT of the signal seen in figure [8] depicts that the dominant frequency components of the signal lie in the range of 7 Hz - 15 Hz with its peak at around 8 Hz - 12 Hz.

In another suspected sample which is represented in figure [9], we could very clearly see an dominant signal which spans a duration of 7 seconds. The signal is visible from sample number 16650000 to sample number 16700000. The FFT of the signal represented in figure [10] yields that the dominant frequency components of this signal lie in the range of 8 Hz - 22 Hz with its peak at around 10 Hz - 13 Hz.

In previous published researches[2] it has been found out that the elephant infrasound calls are within the frequency range of 5 Hz - 35 Hz and their typical duration is between 2 - 10 seconds. It is clear that the data samples above perfectly

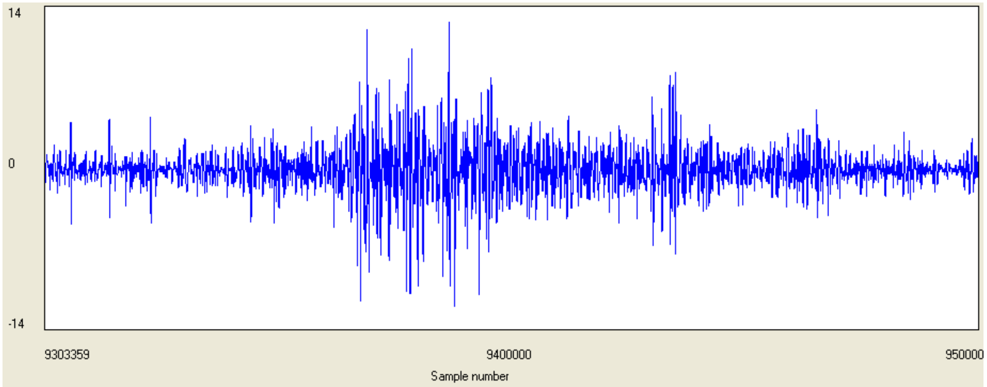

Fig. 7. The time domain graph for a suspected infrasound call of an elephant [Sample One]. The rough estimate for the time duration of the signal is around 6 seconds

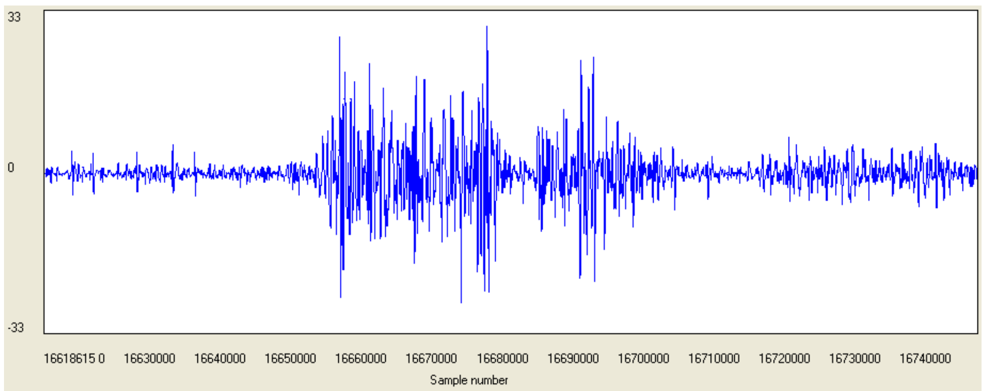

Fig. 9. The time domain graph for a suspected infrasound call of an elephant [Sample Two]. The rough estimate for the time duration of the signal is around 7 seconds

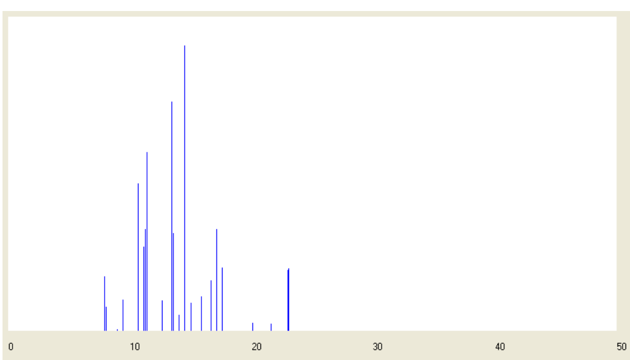

Fig. 10. FFT graph for the elephant call in figure [9]

match the published figures. Another remarkable point is that the data samples above roughly depict the same pattern both in time domain and in the frequency domain. Therefore it is very likely that they are from the same source. Finally, it could be concluded that the above to samples are likely to be infrasound calls of elephants.

C. Diesel Engine

The recordings related to the disel engine was carried out at the University premises. The diesel engine selected was the electricity generator (diesel) used at our University.

The recorded signal was filtered by a 8^{th} order Butterworth low pass filter with the cutoff of 20 Hz. The results of filtering yields an infrasound rich signal which is represented in figure [11]. Once we extract the FFT of the signal, which is represented in the figure [12], we could see that the predominant frequencies of the recorded signal lie in the range 0 Hz - 1 Hz which are considered as very low frequencies. Going into more detail it should be mentioned that there is a diminishing long harmonic series visible in the signal. This is shown in figure [13]. Apart from that the opening and closing of the cover of the generator is clearly visible in figure [11] marked by the locations A and B.

V. Cost Benefit Analysis

The total cost for the entire hardware component was less than Rs. 3500.00 (SL). Apart from that, the software application developed will be released under the GNU public license which implies that any user could use it for free of charge without any restriction.

When comparing our infrasound recording system with the low cost solution provided by [5], it should be mentioned that their completed system costs around \$ 200.00 (US), which is around Rs. 20,000.00 (SL). Therefore, when comparing with the cost, our system is more cost effective. Apart from that it should be mentioned that both systems have been able to record signals with frequency components less than 1 Hz.

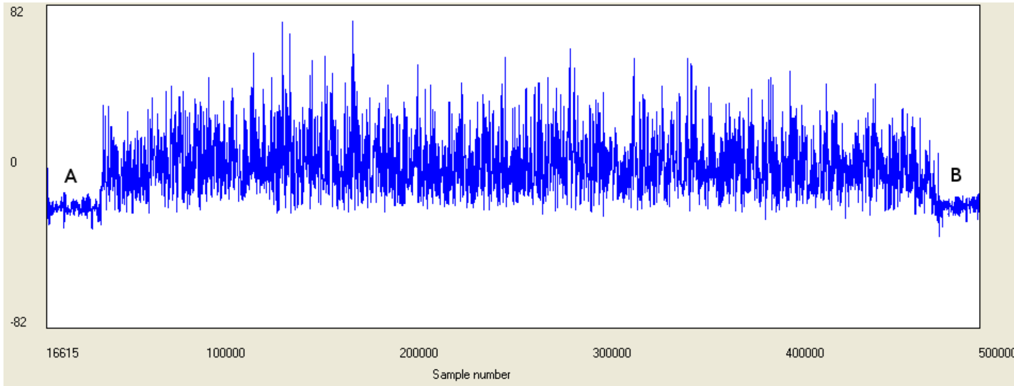

Fig. 11. The time domain graph for the infrasound signal emmited from a diesel engine

Fig. 12. FFT of the infrasound signal emmited from the diesel engine representing only the fundamental freq.

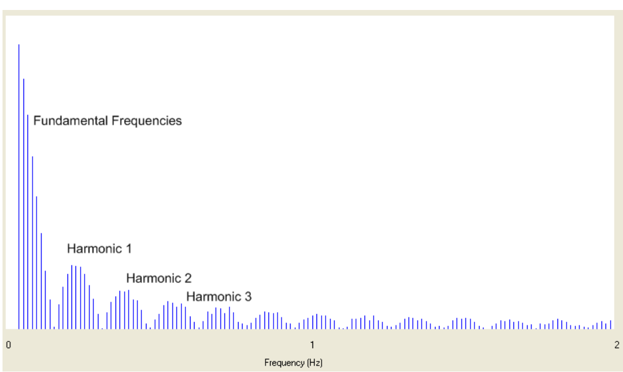

Fig. 13. FFT of the infrasound signal emmited from the diesel engine representing the fundamental freq. plus the harmonics

Therefore, precision wise both systems are in par with each other.

VI. Future work

Wireless sensor networks are fast becoming a vital component of our day to day life. The miniature size and the data transfer ability (no need to visit the sensors to collect data) of these networks makes them an ideal candidate for sensing applications. The ARU system designed and developed for this research could be extended to be a part of a wireless sensor network. As mentioned previously the hardware components of the ARU consists of an infrasonic sensor, an anti-aliasing filter and an A/D converter. The sensor and the anti-aliasing filter of the ARU could be interfaced into a sensor mote. Going into more detail it should be mentioned that sensor motes contain A/D converters inbuilt in them and connecting the output of the anti-aliasing filter to the A/D converter (input) of the mote would create an infrasound sensor node. A collection of these sensor nodes would create a sensor network that could be deployed in a large area to sense infrasound. An infrasound sensor network would come in handy in many instances. For an example these infrasound sensor networks could be deployed for volcanic activity monitoring and avalanche monitoring. Apart from that the zoologists also could deploy these networks in jungles to monitor infrasound signals for a longer period of time. Finally, it should be mentioned that if zoologists confirm that elephant infrasound could be used to detect the presence of an elephant, the electric fence could be replaced by a sensor network monitoring infrasound and relaying information to villages that border wild life sanctuaries. Apart from integrating the ARU to a wireless sensor network, it should be mentioned that the infrasound sensor, the amplifier and the anti-aliasing filter could be modified with very few adjustments to the system. Finally, it should be mentioned that though we used a PC to log the recorded samples, the ARU could be extended such that it will contain a flash memory in order to log the recorded values. This feature could also be added to the system by the addition of a simple circuit.

VII. Conclusion

The main objective of this research was to provide a low cost, user friendly infrasound recording system for zoologists in Sri Lanka to carry out their research work on elephant infrasound. Laboratory tests and real life recordings were carried out in order to prove the ability of the system to record and analyze infrasound. Thus, with the promising results that were obtained during recordings prove that this system could be used by zoologists to carry out their research work on elephant infrasound. Apart from that it should be mentioned that this system could be used to record and analyze infrasound of any other source as well.

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Fig. 14. Images taken at a recording at the dehiwala zoo