Real time Acquisition and Frequency Domain Analysis of Acoustic Patterns of Fluids for Applications in the Field of Homeland Security

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***Abstract*— This paper investigates acoustic patterns generated by different liquids in real time based on spectral analysis technique which finds a lot of relevance in various fields related to defense and homeland security. Some of the drawbacks with existing techniques include limitations with acquisition of well defined patterns for various liquids. To overcome these limitations, this paper describes a technique which involves generation of a single frequency tone in MATLAB with the help of a program and passing that signal through the liquid and then further capturing and analyzing the received signal using a virtual spectrum analyzer. Piezoelectric sensors are used for transmission and receiving the tone through the fluid. The arrangement discussed successfully captures acoustic patterns in non destructive way for five different liquids/solutions by exciting them with various single frequency tones. Thus a low cost system that exhibits consistency in results and can quickly acquire specific acoustic patterns for various fluids is developed that also facilitates easy-to-interpret measurement results.**

Keywords: Acoustic signal, frequency domain analysis, database

I. INTRODUCTION

An acoustic signal propagates as disturbance in the ambient pressure level through fluids such as air and water. Engineers tend to discuss these acoustic/sound pressure levels in terms of frequencies. Various analytic instruments such as the spectrum analyzers facilitate visualization and measurement of the acoustic signals as well as their characteristics. Resulting spectrogram is a graphical display of varying pressure level with frequency which gives a specific acoustic signal its defining character (also known as acoustic signature) when passed through particular medium/fluid.

The principle of acoustic signal analysis is based on the fact that if there is an object in the path of an ultrasonic signal, part or the entire signal is reflected back to the transmitter as echo and can be detected through the receiver. The difference in time between the signal being transmitted and the echo being received can be used to find the distance of the object [1]. So, if a 1 MHz ultrasonic signal is generated and transferred using a transducer placed against a container wall, the ultrasonic signal penetrates the wall and enters the container. The other transducer then receives the returning signal's echo to generate a waveform which can be analyzed in the frequency domain to obtain signature of acoustic signal passing through various mediums. This spectrum is compared with values in a database for acoustic verification with corresponding analysis of sealed container liquids [2]–[3]. Non destructive as well as non invasive techniques are required for verifying and monitoring of chemical munitions to meet the requirements of Chemical weapons. Referred to as Swept Frequency Acoustic Interferometry (SFAI), this technique (involving sweep/chirp excitation) determines the velocity as well as attenuation of sound in any fluid and can be adapted for a range of diagnostic applications, for example, in field of process control where analysis of acoustic properties of chemicals may provide appropriate feedback information [4]-[6].Various post war disposal sites contain bodies of water where discarded munitions can pose an environmental issue as well as lethal threat to the public. To clean up such areas, it is required to locate as well as discriminate man-made objects from natural objects. The recent research shows that low-frequency sound may be used to help finding these devices for removal of contaminants. This low-frequency sound can excite specific vibrations of the object, thus re-radiating sound back to the observer. This scattered sound called echo, emitted from the vibrating object and recorded at the receiver, is used to generate an acoustic pattern/signature of the object which can subsequently aid in distinguishing man-made objects from natural objects [7]-[8].

Referred to as acoustic resonance spectrometry, this method also finds its application in the quantification of active pharmaceutical ingredient (API) in semisolids such as creams, ointments, lotions etc. [9]-[11]. The method has accurately differentiated as well as quantified sample analytes in various forms such as tablets, powders and liquids. In emulsions and suspensions, the sound waves are scattered by suspended particles. These waves also undergo attenuation due to viscosity as well as thermal loss. Such factors contribute to increase the interference peak width which can thus be used to determine particle size distribution [12].

Another promising area of biomedical application of acoustic radiation force is stirring and mixing of micro volumes of liquids in micro fluidics. A new technique, called "swept frequency method", based on the use of radiation force in the standing acoustic wave is also being explored in various ways [13]. A cough analysis system for tracking the recovery of pulmonary tuberculosis patient as well as feature extraction for the differentiation of dry and wet cough is also explored [14]-[16]. A lab free method for assessing patient recovery particularly that may have drug resistant tuberculosis is investigated. Furthermore the detection of UTI infection in patients is also suggested using acoustic analysis. Presence of certain bacteria or diseases can alter the physical characteristics of certain pathological samples such blood, urine, bee or snake venom etc. which can lead to their rapid diagnosis. The method has been suggested to be highly adaptable and versatile in detecting minute changes in liquid characteristics. Another biomedical application is to non invasive monitoring physical characteristics of bones and joints which further may lead to diagnosis of any existing osteoporosis and arthritis in patients. Furthermore another paper investigates the effect of drill speed, burr type, burr style and stroke speed on the acoustics that are generated due to surgical drill when dissecting the squamous temporal bone region [17]-[18]. Various surgical procedures require surgeons to drill within the temporal bone region in order to reach to the various underlying anatomical structures and it is expected that the above parameters significantly affect the acoustic drilling signature of the tegmen and sigmoid sinus bone regions. Analyzing such a signature and using that information could provide an advisory aid for the early identification of anatomical landmarks and thus may reduce the number of temporal bone dissections required by the trainee surgeons during surgical procedures.

II. MATERIALS AND METHODS

The experimental set up of the developed prototype sensor system is shown in Fig.1.with the corresponding functional block diagram shown in Fig.2. It is a computer based portable system for the acquisition and inspection/analysis of acoustic patterns generated by passing single frequency tones through various fluids. It consists of a computer with MATLAB, system with fluid and piezoelectric sensors and another computer with a virtual spectrum analyzer.

A. Computer with MATLAB

A personal computer with MATLAB software installed on it is used. With the help of MATLAB programming, various single frequency signals are generated followed by transferring the respective analog voltages corresponding to these signals to the stereo speaker port of the computer using “Winsound”, which is further interfaced to sensor 1using connector jack.

B. System with Fluid and Sensors

A plastic container placed on a stable rubber base is used to carry the fluid for which the acoustic patterns are to be analyzed. The container has a rubber lid with two holes carrying two plastic tubes going inside the container. Each plastic tube is carrying a piezosensor (which is already varnished) with appropriate wiring connections coming out of the container. One of the sensors (sensor 1) is connected to the jack which goes into the stereo speaker audio port of the computer with MATLAB and the other (sensor 2) is connected to the jack which goes into the microphone audio port of computer with virtual spectrum analyzer.

C. Computer with Spectrum Analyser (SPAN)

The spectrum analyzer used here is by the name “Voxengo Span” which is a real-time FFT spectrum analyzer plug-in for various audio production applications. It can easily be downloaded from http://www.voxengo.com/. SPAN comes with a very flexible “mode” system thus providing with the facility of setting up various spectrum analyzer preferences. FFT window overlap percentage, Fourier block size in samples, spectrum's visual slope can also be specified and adjusted. It can display two different channels/group spectrums at the same time as analysis for multi-channel is supported.
Color of the spectrum can also be changed according to taste and requirement.

With the help of programming in MATLAB, single frequency sound signals (500hz, 1000Hz, 1500Hz) are generated, amplified and their analog output is transmitted to the stereo speaker audio port of the personal computer. The sound port of this computer is interfaced with a piezoelectric sensor 1, placed on one of the plastic tubes inside the container containing liquid, with the help of a connector jack. The sensor 1 picks up the analog output voltage of generated signals, which is then eventually passed through the fluid as pressure wave and is received as analog voltage of the transmitted signals on the other sensor called sensor 2. Such signals are eventually fed into the spectrum analyzer on the other computer via its microphone port to obtain their spectrum display.

Five different standard liquids/solutions (such as tap water, saline solution, Glucose solution etc.) each in same quantity of 650 ml at room temperature (25°C) are used here. The analysis of characteristics of resulting spectra for all five fluids/solutions will be the focal point of this methodology. A lot is expected to be explored out of these acoustic patterns of the fluids and have been described in the results and discussion sections.

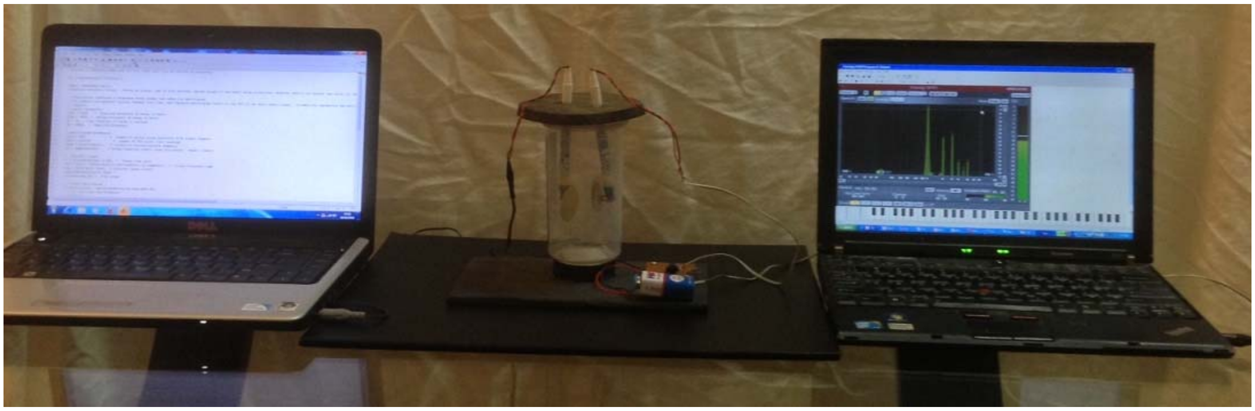

Fig 1: Experimental set up

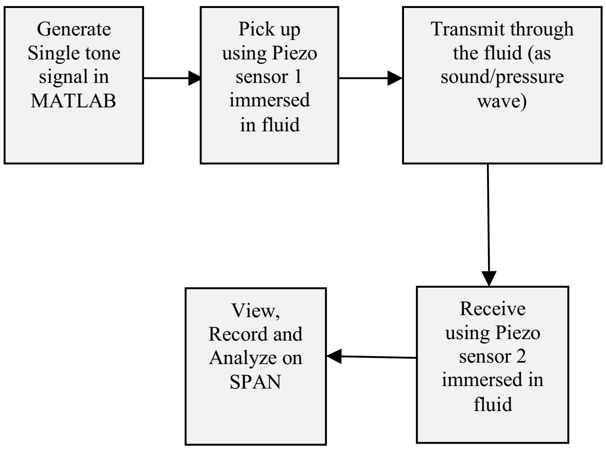

Fig 2: Functional block Diagram for developed system

III. Results and Discussions

The review of adopted methodology is made by using five different liquids as reference mediums. FFTs of the received signals after passing 500 Hz, 1000Hz, and 1500Hz tones respectively through the reference mediums are recorded and analyzed using "Voxengo SPAN".

The procedure is repeated multiple times with all the three frequencies on all five solutions in order to ensure consistency and validity of the results. Fig.3. shows FFT of the received signal for solution A at 1000Hz tone. Fig.4. shows FFT of the received signal for solution B at 1000Hz tone. Fig.5. shows FFT of the received signal for solution C at 1000Hz tone. Fig.6. shows FFT of the received signal for solution D at 1000Hz tone. Fig.7. shows FFT of the received signal for solution E at 1000Hz tone. A detailed frequency domain analysis and the relative comparison for all the five liquids/solutions are discussed ahead.

It is clearly visible in Fig.3 that a well defined peak is obtained at 1000Hz depicting a definite value of spectrum's highest accessible power in decibels, with corresponding harmonics at respective frequencies when single tone signal of same frequency is passed through solution A. The experiment is run 20 times and same result is achieved during every trial, which ensures repeatability behavior. Fig. 4 through Fig.7 gives the definite power values (in decibels) and corresponding harmonics for other reference liquids, at 1000Hz tone. Again, to ensure repeatability, each frequency tone (500Hz, 1000Hz, and 1500Hz) is passed 20 times per liquid and same results are obtained during each trial in every set of experimentation. All results are visually summarized in table 1. and can be used further for reference in future segregation of liquids. From the work conducted to date, tests demonstrate the ability of the proposed methodology to rapidly and effectively capture acoustic patterns with the necessary accuracy and reliability Although, all efforts were made to remove any environmental disturbances, but more controlled environments are being evaluated and therefore a more detailed validation is in progress.

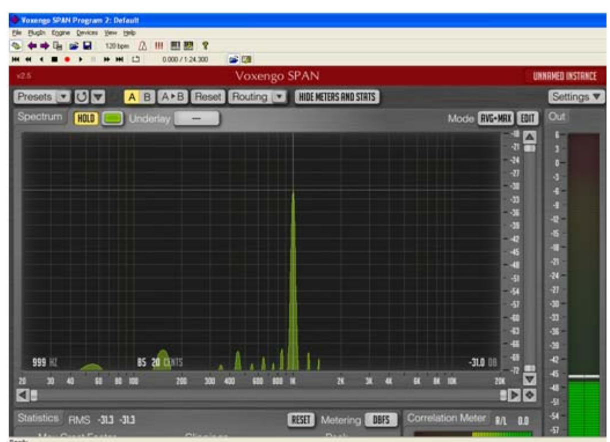

Fig 3: FFT of received signal through solution A at 1000Hz tone

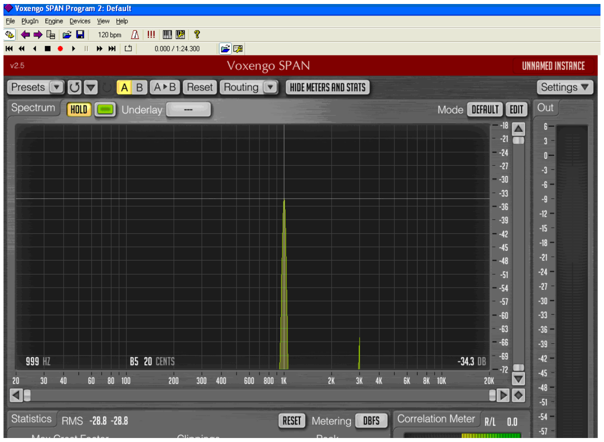

Fig 4: FFT of received signal through solution B at 1000Hz tone

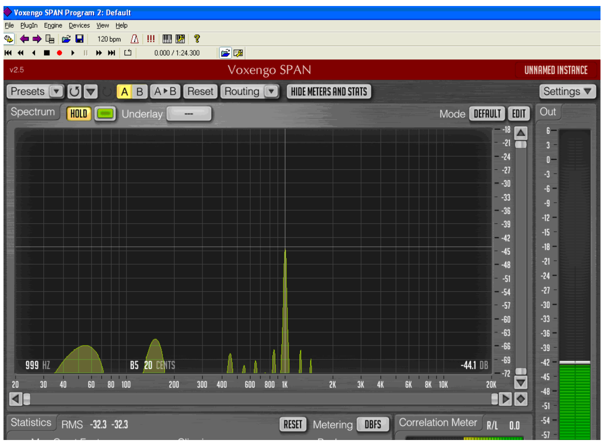

Fig 5: FFT of received signal through solution C at 1000Hz tone

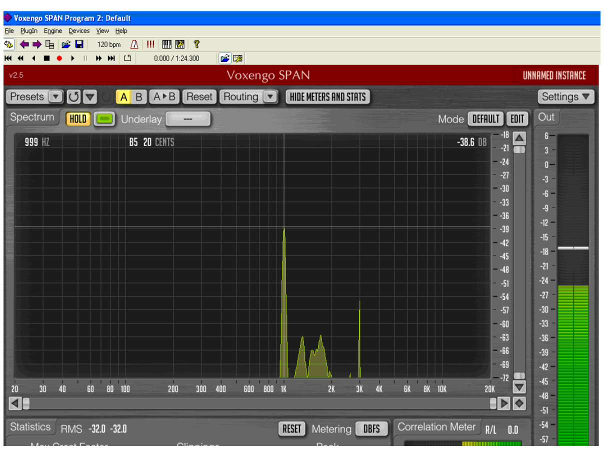

Fig 6: FFT of received signal through solution D at 1000Hz tone

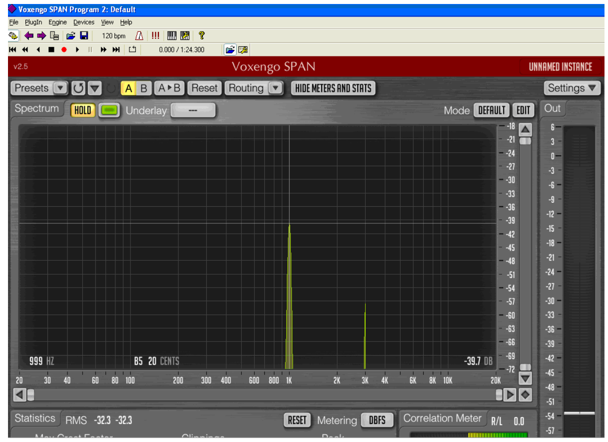

Fig 7: FFT of received signal through solution E at 1000Hz tone

TABLE I. SUMMARY OF RESULTS FOR THREE SINGLE FREQUENCY TONES

S. No:	Medium	Spectrum's Highest Accessible Power Value (in dB) at Input Single Frequency Tone of			Number of Trials
		500Hz	*1000Hz*	*1500Hz*	
1	Solution A	-59.0	-31.2	-28.0	20
2	Solution B	-56.3	-34.3	-26.5	20
3	Solution C	-60.6	-39.7	-32.4	20
4	Solution D	-51.8	-44.1	-33.8	20
5	Solution E	-59.4	-38.6	-23.1	20

IV. CONCLUSION

From the work conducted to date, tests have demonstrated the potential of the developed system to be able to acquire and analyze the acoustic patterns of liquids successfully in real time as well as non destructively and hence can be used further to identify and classify liquids. The most satisfying aspect is consistency in results taken over repeated trials. Aim is towards building a repository/database of readings for numerous liquids and thus stepping on more and better non invasive set ups so as to apply the methodology on sealed containers. More rigorous statistical evaluation will be conducted in future so as to include more advanced statistically based discrimination algorithms to sample data more effectively in order to discriminate dangerous liquids from consumable liquids for defense purposes. The capability for acoustic classification and discrimination of liquids will be better quantified as the repository grows. Efforts are also underway to inspect the quality of results by placing the sensors in different positions inside as well as outside the container like placing them on the opposite sides, same side, placing only sensor 2 in fluid after varnishing it etc. Aim is towards sophisticated, sensitive and accurate equipment which can further be standardized and miniaturized for various practical applications in defense field.

Also detection of presence and quantification of particular ingredient in a pharmaceutical drug will be addressed in future work. Therefore, it is clear that there is a lot of effort and energy required to improve upon use of technological advancements in each element of acquisition, translation and analysis before the eventual objective is accomplished.

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