Indoor Ultrasonic Simulator for Moving Objects Using Fractional Delay Filters

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***Abstract*—In this paper is presented a method to improve conventional ultrasonic simulators. The goal is to include the source and/or receiver arbitrary movements into the simulation by using a method based on fractional delay filters. This method allows to simulate accurately the Doppler effect, not only in the direct signal, but also in each reflected version of it. Results have shown that it is possible to simulate precisely the Doppler effect and model accurately the signal reflections.**

I. Introduction

Indoor ultrasonic acoustic propagation due to receiver and/or source movement presents similar problems to those experienced in radio frequency systems, such as multiple reflections, Doppler effect and propagation attenuation [1], [2]. Therefore, a good ultrasonic indoor simulator will be useful to evaluate the indoor environment influence on ultrasonic communication systems or location systems.

Commercially available simulators, e.g. ODEON [3], are very expensive, difficult to operate and since they are not open source it would be impossible to adapt them to ultrasonic frequencies. However, there are examples of freely available simulators, e.g. [1], but they usually do not take the Doppler effect into account. Nevertheless, in [2] a simulator that includes the Doppler effect in sound is presented. Although, this simulator is only for linear and constant speed movements and it does not include the multiple-reflection effect.

In this paper we present a method that takes into account the source and receiver movement in order to extend conventional ultrasonic simulators by using fractional delay filters. Those simulators must provide all the received signal delays and attenuations [4] for each source and receiver position over time.

This paper is organized as follows: in the next section a brief description of a previously developed Room Acoustic Simulator that can provide the needed information for the suggested method will be presented. In section III we will present the proposed method. At the end a Doppler effect simulation and an experimental multiple-reflection effect result will be presented.

II. Room Acoustic Simulator

The simulator implemented by the authors and presented in [4], is an indoor acoustic simulator that assumes specular reflections and aimed to simulate ultrasonic signals propagation. For that purpose a hybrid method based on the image source method and ray tracing validation was used [5]. Moreover, this simulator computes the time delay and attenuation (due to dispersion, atmosphere absorption and source/receiver beam function) for each reflected signal as a function of the signal frequency, temperature, pressure, humidity and source/receiver direction. Moreover, this simulator can be easily modified to give a set of signal delays and attenuations for each source and receiver position over time.

III. Fractional delay implementation

Fractional delay filters have many applications in signal processing and communication systems, such as signal interpolation and changing the signal sampling frequency. In this paper we use the Lagrange fractional delay filter to implement a signal delay of a non integer value [6]. The interest in this particular type of filters is based on the simplicity of updating the filter coefficients by a close-form equation [6]. Figure 1 presents the system operation diagram. The source signal enters into a delay buffer with size N. This size must be chosen in order to accommodate the maximum possible delay. Therefore, it can be computed by $N \geq L_{max} \times (R+1)$ where, L_{max} is the maximum distance between two possible locations in the room and R is the maximum number of times that a wave can be reflected. After that, by using the simulator to get the set of delay and attenuation for the instant, n the fractional delay filter can be applied. Furthermore, the filter must be moved to the position that produces the desired integer delay part and the filter coefficients must be computed to get the desired fractional delay part. This process must be repeated for each delay-attenuation pair as Figure 1 suggests. After this process end the system moves to the next output sample.

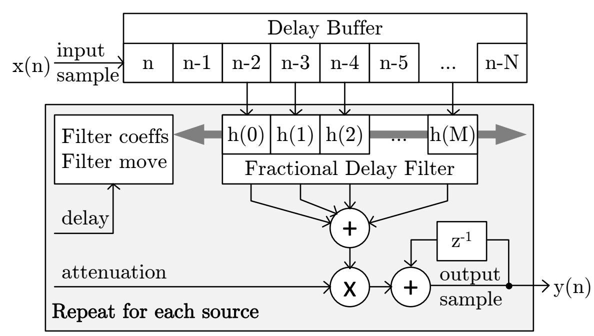
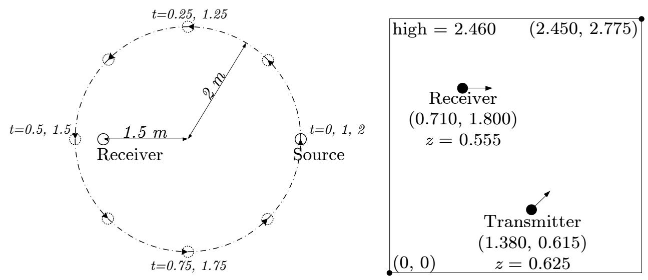


Fig. 1. System operation diagram.

IV. Doppler Effect

In order to evaluate and test the proposed method, two different tests were performed. The first test has the main goal of verifying the correct Doppler effect implementation due to the source movement. For that purpose Figure 2(a) presents the used environment. The second test has the main goal of verifying the multiple reflections implementation accuracy. For that purpose the environment in Figure 2(b) was used.



(a) Doppler effect. (b) Multiple reflections.

Fig. 2. Environments to test the Doppler effect and multiple reflections.

A. Multiple-Reflection Effect

The Doppler effect was validated by using the simulation environment of Figure 2(a) where the receiver is static and the source has a circular movement with one turn per second (this turn speed was chosen to intensify the effect). Moreover, the receiver and source beam was set to an omnidirectional configuration. Furthermore, we have used a sinusoid of 40 KHz as the source signal. Figure 3 presents the spectrum over time for the received signal. The first thing to be noticed is the signal cross, as the source is keeping moving. This only occurs at the variation of distance from positive to negative and vice-versa (at $t = 0, 0.5, 1, 1.5$ and 2). Moreover, when the source is far away from the receiver the variation of distance changes slowly (e.g. around 1 s). Therefore the frequency also changes slowly and the other way around. This results are in agreement with the Doppler effect theory [2].

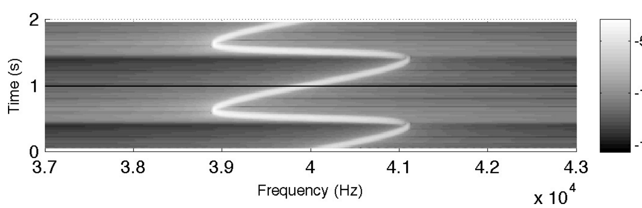


Fig. 3. Simulation result of the Doppler effect test.

B. Experimental results

The multiple reflection performance was validated using an experimental test in the room of Figure 2(b), where the walls have a reflection coefficient of almost 1 for ultrasounds. Moreover, two Murata transceivers were used, a MA40S4S transmitter and MA40S4R receiver. Therefore, a linear chirp signal, from 39 to 41 KHz, with 1.3 ms of duration was used.

The received signal envelopes, experimental and simulated, where computed using the Hilbert transform - see Figure 4. Moreover a 12th-order filter was chosen as a compromise between the simulation accuracy and the simulation time.

The experimental and simulated envelopes match pretty well. We can also see that after 20 ms, the experimental and simulated signals start to diverge, this could be due to the room measurement imprecisions and the maximum number of times that a wave can reflect.

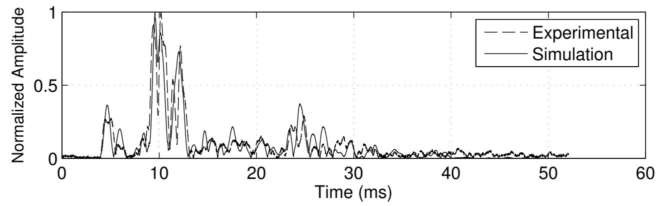


Fig. 4. Experimental and simulated envelope outputs.

V. Conclusion

From the results of both tests we can conclude that the method can be used to extend an ultrasonic simulator in order to accommodate the source and receiver movements. By experimental validation this method proved to be a good approximation for a real indoor environment. Therefore, this method in combination with the implemented simulator will be useful to test the behavior of communication and ultrasonic location systems in indoor environments. The proposed method is also simple and easy to implement with other simulators, which are able to provide the delay and attenuation of each reflected signal for any receiver and source trajectory position.

Acknowledgments

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This simulator is available at the URL:
http://www.ieeta.pt/locus/locusim/

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