ANALYSIS OF RAIN EFFECTS ON ULTRASONIC PROPAGATION

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SUMMARY

The study of ultrasonic waves propagation is made generally in homogeneous media. Nevertheless, in most of real applications the conditions of propagation move away from the ideal conditions and predicted results are not valid. In outdoor ultrasonic applications, it is necessary to study the influence of environmental conditions in the received echoes. The present work is focused on the study of ultrasonic propagation in air in presence of rain.

KEY WORDS: ultrasonic propagation, rain, finite differences.

1. INTRODUCTION

Atmospheric phenomena like rain, snow or hail can alter the features of ultrasonic propagation, and turn useless to ultrasonic systems that behave well in normal conditions, so it is necessary its study and characterization [1]. Wave propagation is a physical phenomenon described by a second-order partial derivative equation, where the dependent variables are functions of position and time. The analytical solution only can be obtained in very simple cases with simple geometries and homogeneous propagation environments. When the calculation domain has complex geometries or the propagation environment is nonhomogeneous, it becomes necessary to turn to approximate solutions obtained by means of computer numerical methods.

There are several applicable methods of computer simulation, being the most common finite differences, boundary elements and finite elements, and each one has its own advantages and disadvantages. All of them are based on turning the differential equation and the boundary conditions into a system of linear equations, using the discretization of the entire domain (finite differences and finite elements), or only of its boundary (boundary elements). Among them, the method of finite differences is perhaps the easiest to be implemented on computer; nevertheless, it has the disadvantage of being unable to approximate in a simple way irregular boundarys using regular meshes. The most used method nowadays is the method of finite elements, due to its flexibility to represent complex boundarys and its accuracy calculating the solution. There is abundant documentation of these methods and a wide range of software, both free and commercial.

In order to obtain a good approximation in the solution of the wave equation, it is necessary at least ten discrete elements in each wavelength. A common problem to all these methods is that the size of the resulting equation system increases enormously when the calculation domain grows, specially in three dimensions. This causes that with a single computer it is not possible to solve domains greater than a few wavelengths. In these cases it is essentail to solve the problem by domain decomposition, using several computers working in parallel.

Another problem that appears in the simulation of wave propagation in infinites environments, is that the need to limit the simulation domain causes that in its fictitious boundaries reflected waves take place. These nonexistent waves in an infinite real domain damages the solution in surroundings near these boundaries. In order to diminish this effect there are several techniques based on imposing special conditions in the edges of the simulation domain, that avoid the wave propagation towards the domain interior, or based on extending the domain using layers that absorb the wave progresssively in order to avoid the reflection (*Perfectly Matching Layer)* [2].

This paper presents the results obtained in the analysis of ultrasonic wave propagation in air with drops of rain by means of simulation using finite differences in time domain.

2. PHYSICAL PRINCIPLES

The equation that describes the propagation of a wave [3] comes given by the well-known expression:

$$\nabla^2 p = \frac{1}{c^2}\frac{\partial^2 p}{\partial t^2} \qquad (1)$$

where p is the sound pressure, c is the speed of wave propagation in the environment and t is the time. The speed of propagation is characteristic of each environment, coming determined in fluids by its density, temperature and pressure. In the general case it will be function of position and time, but in homogeneous environments it will be constant in all points of the space.

This equation has analytical solution only in problems where geometry is simple and the equation, along with the initial and boundary conditions, are easily integrables. If this is not possible, as it happens in the case that interests us, it is necessary to resort to computing methods that provide approximate solutions, using the techniques previously indicated.

3. ANALYSIS BY MEANS OF FINITE DIFFERENCES

The method of finite differences [4] consists of dividing the domain by means of a regular mesh, and to approximate the partial derivatives by differences. If *f(x)* is a scalar function, applying the Taylor's series around a point x_0 and rejecting higher order terms, the following expressions for the first and second order derivatives are obtained:

$$f'(x_0) \approx \frac{f(x_0+\Delta x) - f(x_0-\Delta x)}{2\Delta x} \qquad (2)$$

$$f''(x_0) \approx \frac{f(x_0-\Delta x) - 2f(x_0) + f(x_0+\Delta x)}{(\Delta x)^2} \qquad (3)$$

In the case of functions with several variables, similar expressions for the partial derivatives are obtained. Applying these expressions in two dimensions, and making $h=\Delta x=\Delta y$ y $\tau=\Delta t$ the equation (1) can be approximated in each point by:

$$\frac{P(x-h,y,t)+P(x+h,y,t)+P(x,y-h,t)+P(x,y+h,t)-4P(x,y,t)}{h^2} = \\ = \frac{1}{c^2}\frac{P(x,y,t+\tau)+P(x,y,t-\tau)-2P(x,y,t)}{\tau^2} \qquad (4)$$

From this expression *P(x,y,t+τ)* can be calculated:

$$P(x,y,t+\tau) = \frac{c^2\tau^2}{h^2}\{P(x-h,y,t)+P(x+h,y,t)+P(x,y-h,t)+\ldots \\ P(x,y+h,t)-4P(x,y,t)\} + 2P(x,y,t) - P(x,y,t-\tau) \qquad (5)$$

Applying at every step time this expression to each point of the mesh inside the domain, and the boundary conditions in its the edges, as well as the initial condition for the pressure in all points, its temporary evolution would be obtained. To obtain a convergent algorithm is necessary to fulfil $c\tau < h$ (Courant's condition), that is to say, step time of the simulation must be smaller than the one required by the wavefront to travel from a point of the mesh to the adjacent at the speed of propagation. In addition, to approximate it sufficiently to the accurate solution, at least ten points in each wavelength of the sound pressure must be taken, that is to say, $h<\lambda/10$. These requirements cause that with conventional computers is only possible to simulate geometries of few wavelengths, and short temporary intervals, particularly in three dimensions, since the number of calculations and memory requirements increase quickly with the dimension of the problem.

4. RESULTS

In order to analyse the effect of rain in ultrasonic propagation in air, the echo coming from a flat object of 2 cm. of radio has been obtained by means of simulation by finite differences in two dimensions. This object is located in front of a flat ultrasonic emitter-receiver of 1 cm. of radio, at 50 cm. from it, on the radiation axis. The simulation domain is a square of 50 cm. of side.

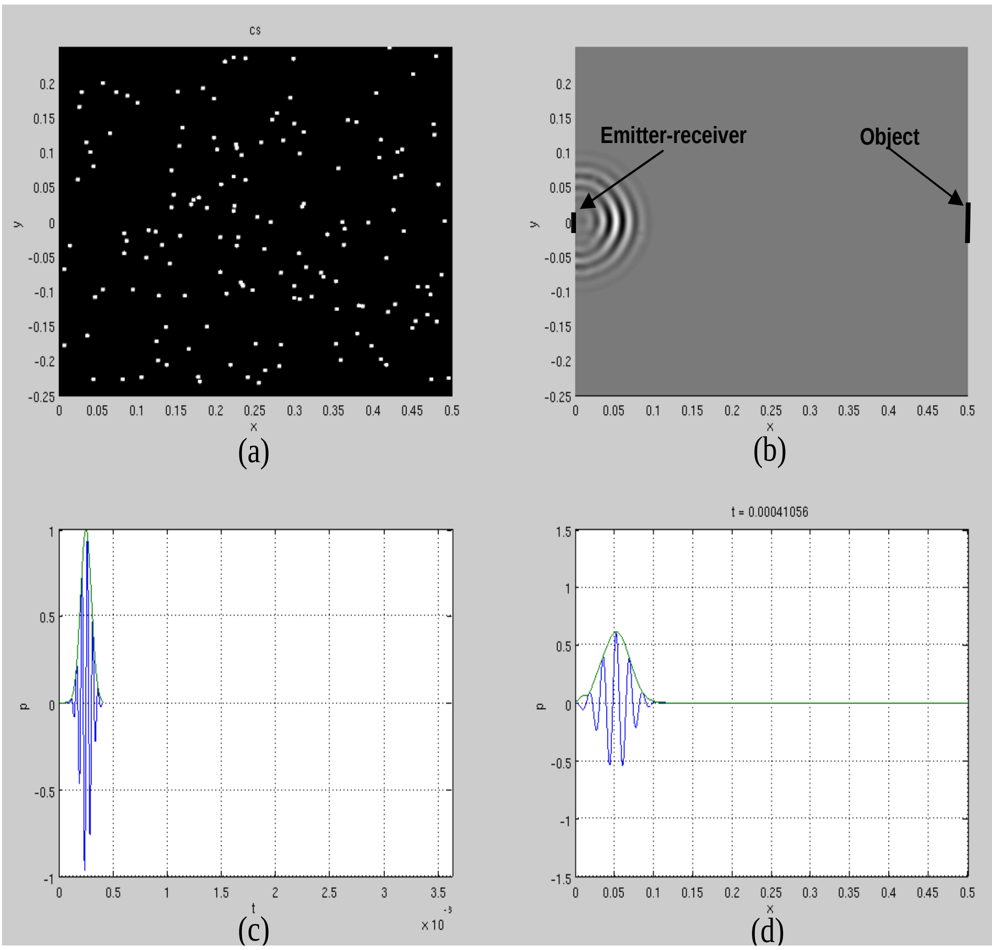
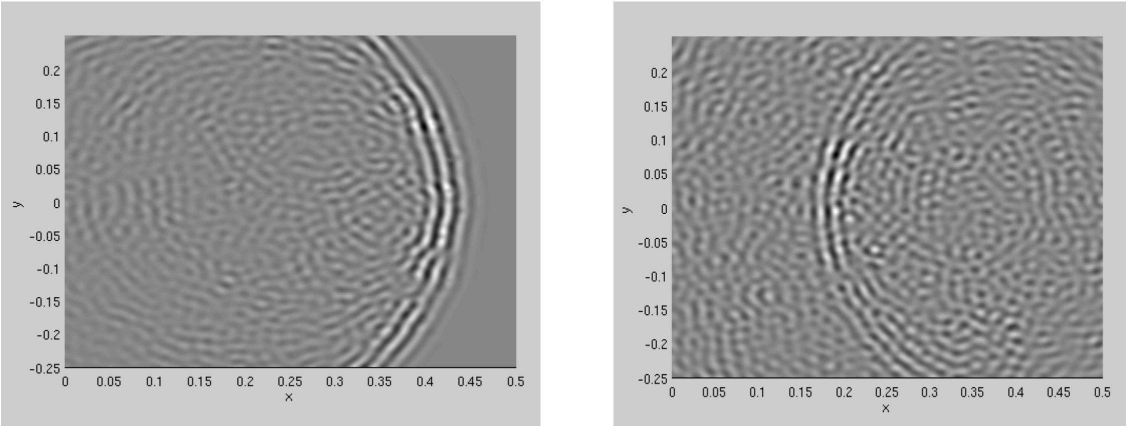


Figure 1



(a) (b)

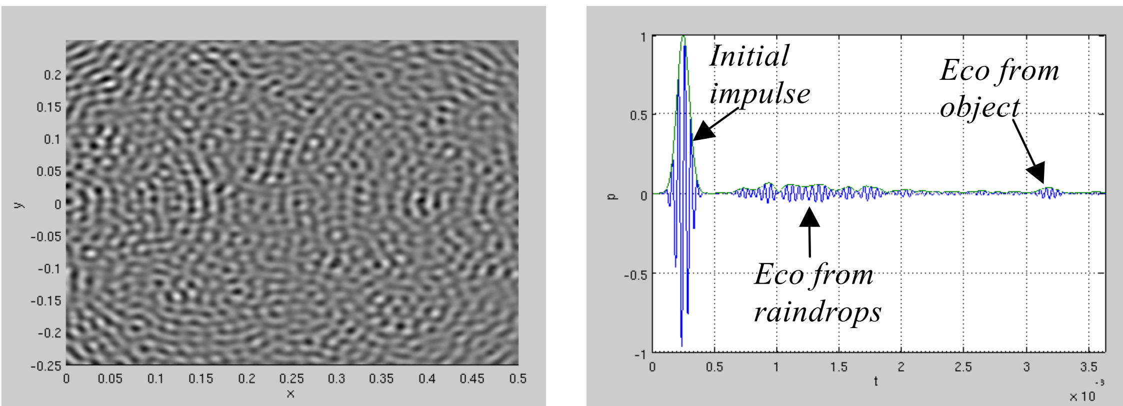
Figure 2

The emitted ultrasonic impulse is a sine wave of 20 KHz, modulated by a Gaussian function. The drops of rain are suposedly spherical and they are distributed of random form in the domain, being its radios of 1, 2 and 3 mm, what includes practically all the range of sizes of real drops. Since the maximum speed of a rain drop is close to 11 m/s, much lower than the speed of sound in air, these are assumed as static to facilitate the simulation.

In figure 1a a random distribution of raindrops of 3 mm. of radius, in the simulation domain, can be observed. Figure 1b shows the distribution of sound pressure a moment after beginning the simulation. The emitted ultrasonic impulse takes place in figure 1c and the distribution of pressure in the axis of radiation at that moment appears in figure 1d.

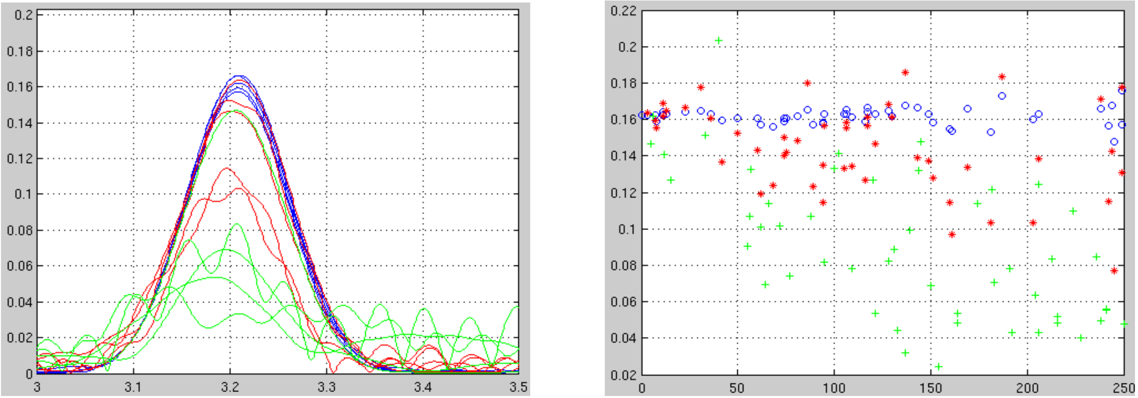
Figure 2a shows the distribution of sound pressure just before affecting the object. In figure 2b the wave can ve observed in its way back towards the emitter, after suffering a reflection in the object. In both cases the wave dispersion due to multiple reflections in raindrops can be observed.

The final distribution of sound pressure, when the simulation finishes, can be seen in figure 3a, where the waves dispersed by the rain drops are observed.



(a) (b)

Figure 3



(a) (b)

Figure 4

The final distribution of sound pressure, when the simulation finishes, can be seen in figure 3a, where the waves dispersed by the rain drops are observed. Figure 3b shows the signal that the emitter-receiver receive, in which the trigger impulse, echoes coming from drops near the emitter, and the echo produced by the reflection in the object can be observed.
The simulation indicates that a ultrasonic system in air can become useless because of the disturbances in the received signal coming from the rain drops, since they can be erroneously taken as if they were produced by the presence of an object.
For each size of drop (1, 2 and 3 mm. of radius) 50 simulations have been made and the signal received by the emitter-receiver has been recorded in each case, obtaining a total of 151 simulations (including one without rain).
In figure 4a the envelopes of 5 echoes for each size of drop coming from the object, are observed. It is possible to notice that for the drops of 1 mm. of radio (in blue color) the disturbances are despicable, which is explained because these drops are much smaller that the wavelength (16 mm. approximately), making them practically invisible to the ultrasonic system. For the drops of 2 mm. of radio (red color) remarkable differences are observed when the number of present drops in the domain is high. With drops of 3 mm. of radio (green color) it is practically impossible to obtain nonperturbed echoes, even though the amount of drops in the environment is small.
Figure 4b represents the maximum amplitude of the echoes in function of the number of present drops, with different colours for each size of drop. It is possible to observe that in all cases the dispersions of the points increase with the number of drops. For small drops this variation is small, indicating that they hardly affect the ultrasonic propagation. For the big drops this dispersion is maximum, indicating that they are perfectly visible for the ultrasonic system, turning it inoperative for a relatively small amount of drops. For middle sized drops, the system could be operative even with a reasonable density of drops.

5. CONCLUSIONS

In the present paper the effect of rain in the ultrasonic systems in air has been analyzed using simulation. When the size of drops and the intensity of rain increase, the echoes coming from the objects are progressively altered, causing difficulties in measurement or identification systems. The simulations show that the presence of drops of water can turn the system inoperative.

The completion of experimental measures in different conditions of rain will allow to study thoroughly this effects, in order to try to establish statistical relations between the characteristics of the received echoes and atmospherical conditions.

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