ANALYTICAL STUDY AND SIMULATION FOR PROPAGATION OF ALERTS, CASE OF EMERGENCY VEHICLES IN SMART CITIES

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ABSTRACT

This paper proposes methods and tools to support analysis and simulation of propagation of alerts in a city. Environmental modeling and monitoring is now a major framework for application of wireless sensor networks. Sound and visual alerts remain a major way to warn and prevent accidents in social life. This work combines a cellular segmentation of the city, representation of buildings and roads, representation of vehicle paths, and cell behaviour that compute sound wave propagation with respect to space and time. As a first result, there is the possibility to evaluate nuisance from vehicles repetitively travelling their sirens along avenues. Coupling to smart cities sensing systems will allow a better control on traffic lights and management of autonomous intersections. This can help to prevent and reduce noise and accidents. In the context of smarts cities, cooperative sound detection can be associated to the development of new smart cars, and better rescue or police vehicles. High speed simulations with real time opportunities are obtained thanks to code generation for graphic accelerators.

KEYWORDS

Wireless sensor networks, cellular automata, siren alert, sound propagation simulation, parallel computing.

1. INTRODUCTION

Monitoring our environment allows us to understand, control and anticipate its evolution. This is one of current expectations in the society. Radio communications, micro-systems, networked sensors are the system interface for this task. By analyzing and simulating physical phenomena, we will be able to build better systems that adapt gradually to evolutions. Indeed, modelling provides a simple and abstract representation on which reasoning and decisions can take place. This proceeds by constructing formal, textual, graphic, and abstract models of reality. These models are of critical importance for analysis of real world dependencies, saving risks, energy, and improving social life, and simulation is a key activity to predict consequences. This paper considers the propagation of sound alerts in the city, as produced by rescue or security vehicles.

Understanding noise sources and propagation involves a complex analysis of situations with mathematical representation of activities around us, remarkable objects, persons, air status, transportation, and of course, noise estimation and nuisance. This modelling can be considered from several angles. Indeed, many disciplines, such as chemistry, physics, biology, biochemistry, geology and others contribute to the understanding and refinement of these models.

Dealing with this complexity can be managed using geographic data extracted from information system, mobile activities including alert production and automatic or natural perception. The discrete framework of cellular automata was chosen to handle physical relations this context and to produce measures about these phenomena.

Figure 1. Simulation of siren alert along an emergency vehicle path. The left figure is part of a city map, with a trip path used by many health transport vehicles having sirens. The right part displays a sample of sound pressure estimation in part of this path. Red pixels represent expected sound on city locations.

The paper will also discuss high-performance simulations, for the propagation of alerts, focusing on the specific case of vehicles and complex topology of the city. The solution is generic, easy to handle thanks to the tools. It can be reused for other problems such as noise nuisance estimation, noise diagnostic, railway or mechanics security.

The explanations start with discrete modelling of sound propagation.

2. Modeling alert sirens as cellular automata

2.1. Background

2.1.1. The Characteristics of Sound Waves

Following Stanley A Gelfand [1], sound is defined as a wave that travels through the air in the form of a pressure variation, without material displacement. Sound wave also propagates through solids in the form of tiny vibrations of atoms. There are several types of sounds: we are interested in sounds heard by the human ear that range from 20 Hz to 20 kHz in the context of sirens alert.

2.1.2. Definition of the Physics of Sound

Sound can be decomposed into elementary sounds that give off wave “noises”, that are perfectly periodic, and sinusoidal. The equation for the elongation of the sound wave as a function of time is $x = A\sin(\omega t + \phi)$, where A is the maximum elongation, ω is the pulsation, ($\omega = 2\pi/T = 2\pi f$) in radian per second and wher ϕ is the phase shift (in radian) at the initial time t0. The partial differential wave equation (Alembert equation) useful for sound propagation modelling is given by the equation:

$$\frac{\partial^2 u}{\partial^2 x} - \frac{1}{v^2}\frac{\partial^2 u}{\partial t^2} = 0 \quad (1)$$

For all “f” and “g” functions (assumed regular) there is a solution (with a speed v, but without amortizing or mitigation) which is a function of 2 unknowns, “x”(spatial) and “t” (temporal):

$$u(x,t) = f(x+vt) + g(xvt) \quad (2)$$

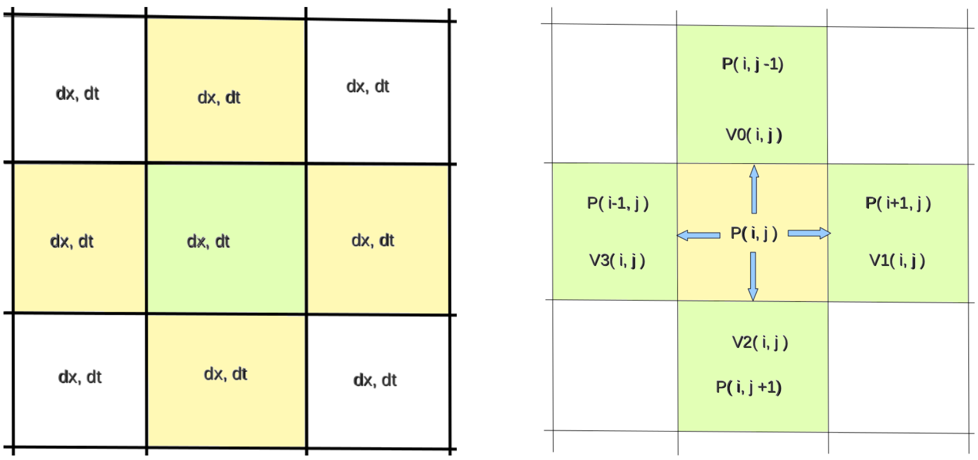
If the sound source vibrates in a sinusoidal manner, on the frequency f, the acoustic pressure, at any point P of the sound field (the space surrounding the source) is a sinusoidal function of the time of the same frequency f.

2.2. Cellular Automata Formalism

Cellular Automata (CA) [3] constitute a dynamic, discrete space, discrete time formalism. Space in Cellular Automata is partitioned into discrete volume elements called cells and time progresses in discrete steps. Each cell can be in one of a finite number of states at any given time. The "physics" of this logical universe is in general local, and deterministic. Deterministic means that once a local physics and an initial state of a cellular automaton has been chosen, its future evolution is uniquely determined. Local means that the state of a cell at time t+1 is determined only by its own state and the states of neighbour cells at the previous time t. The operational semantics of a CA as prescribed in a simulation procedure called the transition rule. Implementing a CA solver dictates that values are updated synchronously: all new values are calculated simultaneously with possible effective concurrency. Examples are gas simulation as described by the HPP model [9]. This work is based on [10].

2.2.1. Transition Function: neighbourhood, pressure and speed

Each cell has a transition function that determines its internal state at each computation step from its previous state and the state of the cells of its neighborhood (four cells located north, south, east, west).



(a) Cell neighborhood matrix (b) Pressure and speed in each cell

Figure 2. Discrete representation of certain characteristics of sound in a cell.

Neighborhood in the 2-D acoustic model. Two state variables: the sound pressure P and the velocity V are present in each cell.

2.2.2. State of a Cell and Transition Function

Each cell is updated at each discrete time step according to a rule of local interaction. First, the particle velocities in the four directions are updated as a function of time, in accordance with the pressure difference between neighbouring cells. The rule for updating is given by: V'a(x, t + 1) = Va(x, t) P(x + dxa, t) P (x, t) [9], is going to represent the particle velocity and P the sound pressure. The position of the cells is expressed as a vector (x) in steps of discrete time (t). The suffix (a) in dxa represents the index of the four neighbours. The particle velocity obeys also:

$$Va(x,t+1)=(1\mathrm{d})Va(x,t+1)$$

This formula expresses the linear energy dissipation mechanism [9]. This state integrates the sound pressure P. The update of this pressure during the cellular automaton stages is written:

$$P(x,t+1)=P(x,t)-C_a^2\sum_a Va(x,t+1)$$

With Ca is the speed of waves traveling in the CA area, Va represents the particle velocity and P is the sound pressure. The absorption coefficient (or constant amortizing of the sound in the obstacle) is another parameter of the cell. In the case of air, one uses: d = 0.0001. This coefficient can reach up to 0.8 for current urban obstacles.

2.2.3. The Cell Modelled in the city environment

A suitable segmentation for our simulation is a grid of 1000 x 1000 cells representing one million elements. Figure 3 shows a city zone chosen for simulation which is divided into an array of such cells. To clarify noise simulation context, we can assume a wave frequency of 10 kHz, corresponding to a period of 100 microseconds. The sound propagation speed is 344 m/s in the air under normal pressure conditions, and temperature to 20 degree Celsius. The space occupied by a sound pulse is the wavelength of the value of 3.44cm. By sequencing a cellular automaton at 10,000 Hz, a grid whose grain is 3.44cm would cross a cell of this size in each period. In Figure 4, the propagation is observed from 3 sound sources composed of interference, diffraction and refraction.

2.2.4. Scale calculations

Thus, in this case, the size of a cell (1 pixel) corresponds to 35.6 meters in the field. The graphics are based on geographic measurements done inside the QuickMap tool shown Figure 3. Quickmap is a tool developed to support geographic navigation and choice of sensor positions [20].

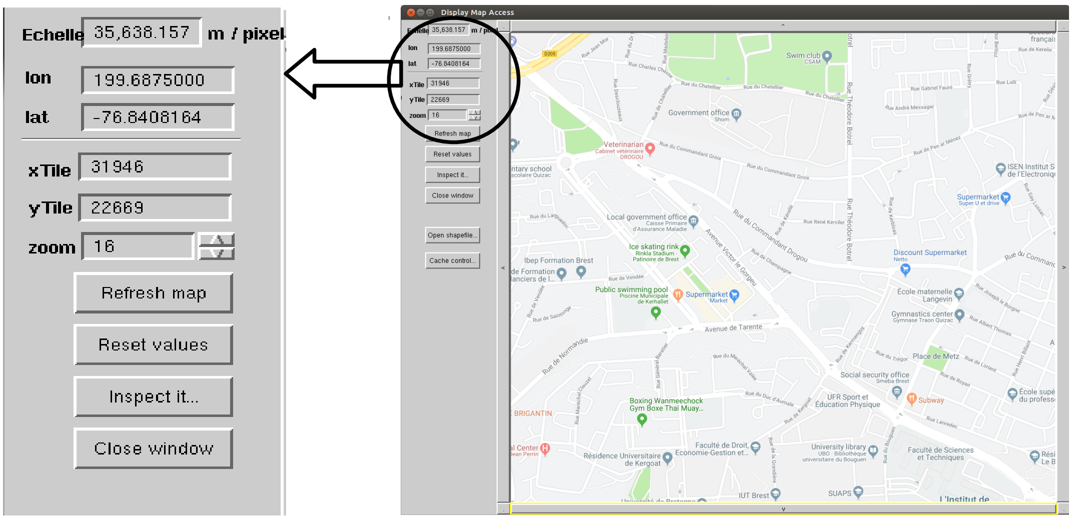


Figure 3: Scale calculations to know the equivalence of the pixels of the cellular automaton in meters on the ground. Map tiles can be extracted from servers following standard such as Open Street Map.

3. Simulation organization

3.1. Execution

As shown Figure 3, QuickMap can also represents the contours of the buildings loaded according to the shapefile format. In Figure 3, buildings are displayed over OpenStreetMap map tiles.

The trajectory of an emergency vehicle can be defined a user over these data. Then the useful context is exported as two files. The first contains the matrix of cells of the automaton. It is an array of integers indicating the type of each cell: empty cell (value 0), cell containing a sound source (value 1) and obstacle cell (value 2). The second contains the positions of the mobile over time: it is a text file with the date of entry of the mobile in a new cell and the position thereof.

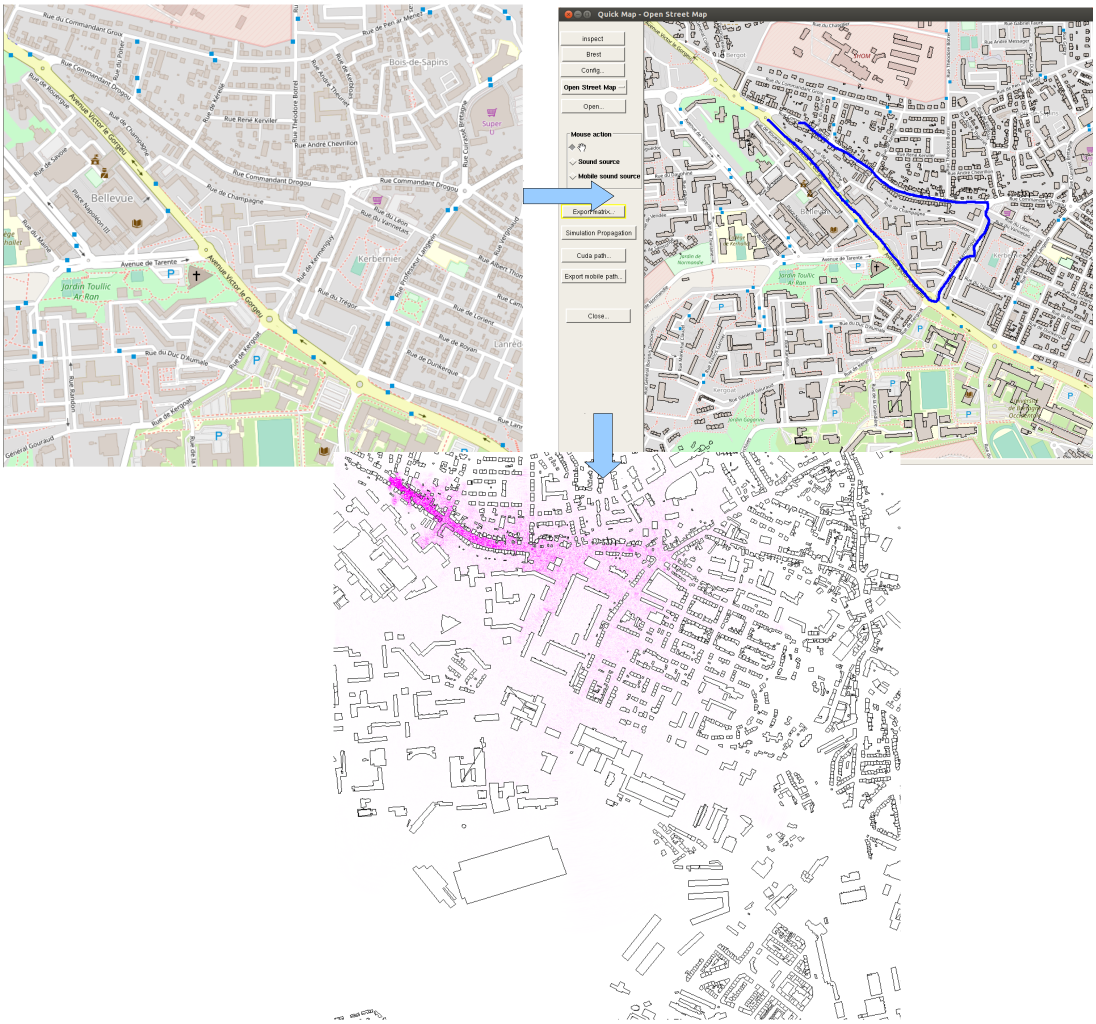


Figure 3: Steps of a simulation processed using QuickMap and CUDA tools

Three views from Figure 3 are: top left, map of the city downloaded from OpenStreetMap, right QuickMap interface [10] with the buildings shape file for Brest, and a vehicle path. A the bottom, a view display the result of a Cellular automata execution on NNN steps, inside a GPU accelerator. The emergency vehicle will follow the route drawn by hand/mouse from cell to cell. In each cell, pressure and velocity are known and correlated to actual velocity and sound power in dB. Therefore, we can know the sound power of the emergency vehicle throughout its journey. This knowledge makes possible to measure the noise nuisance according to the distance to the emergency vehicle.

3.1.1. Interpretation

This simulation provides a tool for managing intersections, roundabouts and possibly traffic lights. In addition, this can help to advise of the usefulness of using the siren of alert according to the state of the circulation. The graphs shown Figures 5 to 6 illustrate nuisances coming from of the studied cases.

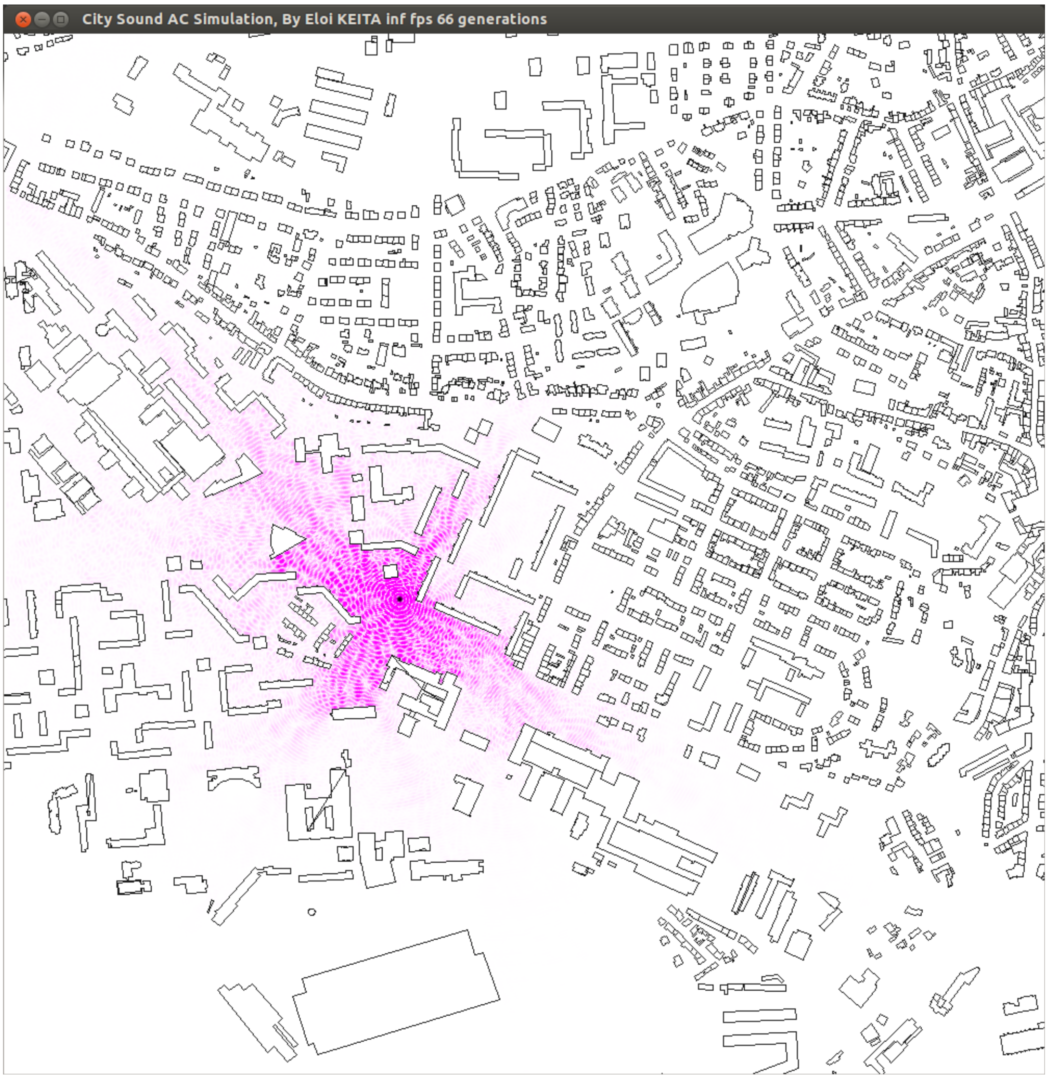


Figure 4: Graphical representation of cellular automata running. The dark lines show the wall of the buildings and other obstacles. This allows us to account for the complexity of buildings topology as encountered in urban areas.

The graph (figure 5) represents the estimation of intensity sound pressure emitted by an emergency vehicle at a distance of ten meters in a roundabout. This allows us to adapt the alert according to the situation (heavy traffic, pedestrian) at the intersection.

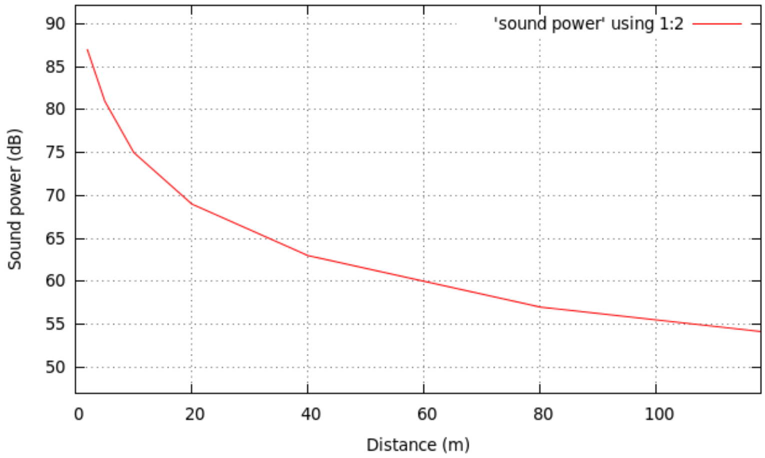


Figure 5a: Sound measure (in dB) showing attenuation over the distance in Figure 4.

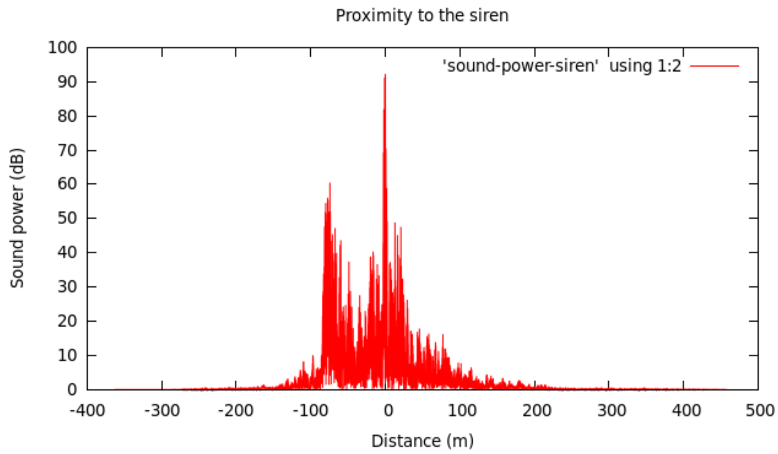


Figure 5b: Sound power showing attenuation with the distance measured in a cell.

At the intersection, the sound power of the alert siren increases by 6dB (A) each time the distance is halved. The measurements give: Lp = 57 dB (A) at 80 m, Lp = 63 dB (A) at 40 m, Lp = 69 dB (A) at 20 m, Lp = 75 dB (A) at 10 m.

These two graphs present the sound power as a function of the distance to the sound source, that is, the siren of the emergency vehicle. Thus, 400 m before the arrival of the vehicle and 400 m after its passage, the sound power is equivalent. Similarly, 5 m from the sound source, we have more than 80 dB, which corresponds to the standard of the sound power of emergency response vehicles in France in the immediate vicinity.

3.1.2. Formal description

Sound power (W, in watts)
Sound power level (L_w, in dB)
Acoustic intensity (I, in W / m^2)
Sound intensity level (L_I, in dB)
Sound pressure (P, in pascal)
Sound pressure level (L_p, in dB)

$$Lw = 10\log\frac{W}{W_0}$$

$$L_I = 10\log\frac{I}{I_0}$$

$$L_p = 10\log\frac{P^2}{P_0^2}$$

$$W = I \times S \times \cos\theta$$

$W_0 = 10^{-12}$ W ; $I_0 = 10^{-12}$ W/m^2 ; $P_0 = 20\mu Pa$ or 2.10^{-5} Pa

Equation 1: Sound intensity level calculation equation

The human ear actually hears L_p and so L_p we measure. The sound pressure level is expressed in dB or decibel A [dB (A)] We note that the acoustic problem amounts to connecting L_p (sound pressure level) to the level acoustic power (L_w) using L_I as a calculation intermediate.

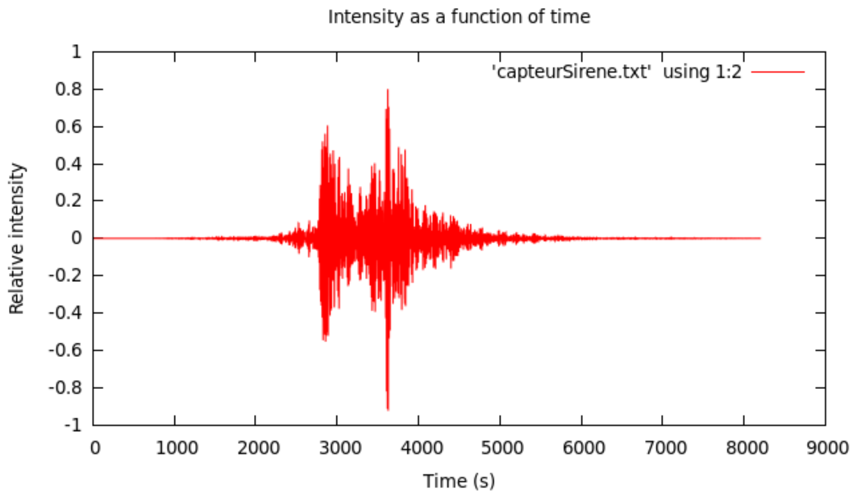


Figure 6: Graph of the measured sound power as a function of time

This diagram shown Figure 6 illustrates the perception of the sound as a function of distance: the closer the vehicle is, the louder the sound and the farther it gets away the weaker the sound. At 1500 seconds from the arrival of the car, the ear perceives a sound power equivalent to that perceived 1500 seconds after the passage of the car.

4. CONCLUSION

Improving the analysis of sound waves in an urban environment rises two major concerns: sound waves blocked by obstacles such as buildings but also the interior of ordinary vehicles and a loss of loudness during propagation as a function of distance and time. The context to be covered can be classified into emergency vehicle (road) routes and surrounding dwellings. As a result, the question of topologies can be almost neglected and calculations can be made in relation to the reduction or increase in sound power along the path of the emergency vehicle. The formula for calculating the sound intensity level is proposed for this purpose to optimize the measurements.

This type of physical simulation is of major interest, which reveals interesting places for detection and causality between events. The software used in this project is yet ready to use for the generation of cellular systems. The present work has added the capability to manage alerts. The implementation of cell transition rules, their adjustment and their verification require in-depth investigations. Other areas have been studied in the same workbench, from the propagation of LoRa radio waves to the behavior of insects. Thus, the methodology seems very general and flexible. Parallel programs very effectively implement the described algorithms. Efficiency is essential to develop space exploration strategies.

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Contributions from students and PhDs have led to the development of high-level tools and code generation targeting GPU accelerators. The combination of several simulations using high-level architectures (HLA) was also demonstrated in this way. High level software layers have been developed on the Visualworks Smalltalk platform, while the described parallel processing has been implemented using NVIDIA CUDA tools for massively parallel programming. Other works have targeted communicating processes and message passing interface.

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