RF Sounding: A System for Generating Sounds from Spectral Analysis

Fabio Graziosi, Claudia Rinaldi, and Francesco Tarquini

Center of Excellence DEWS,
Faculty of Engineering,University of L'Aquila, 67040 Monteluco di Roio, L'Aquila, IT
{fabio.graziosi,claudia.rinaldi,francesco.tarquini}@univaq.it

Abstract. In this paper we present *RF Sounding*, an open space installation which comprises both artistic and technological innovations. The aim of this project is to provide the user entering a specifically defined area, with awareness of radio frequency signals characterizing the cellular networks band. Indeed, radio signals are shifted, with proper elaboration, to the audible band and the result is spread all over the specific area through a certain number of loudspeakers. The system produces different reactions depending on the communication phase (e.g. initial handshake procedure, reception or initiation of a call, etc.). Moreover, the sound produced after translation of signals to the audible band, is assumed to be spatialized as a function of user movement; localization is indeed achieved through a wireless sensor network that is installed in the defined area.

Keywords: Radio-frequency propagation, audio signal processing, wireless sensor network, localization, sound spatialization.

1 Introduction and Motivations

The opportunity to integrate technology and arts represents one of the most stimulating and creative research areas. The contamination between scientifical knowledge and artistical components is too often limited to casuality, mainly stemming from the convergence on the same researcher of technical and artistic interests. In this scenario we are mainly interested on the integration of wireless communications and audio wave propagation, being both characterized by the same propagation medium, even if with substantially different propagation modes. More in particular, in this paper we want to highlight the limitations of our senses which are capable of feeling audio waves (sounds) but are not capable of directly feeling radio frequency (RF) waves. We propose to overcome this limitation by translating RF waves to the audible band. This translation can be exploited as an interesting opportunity for modern music composers which will be called to introduce a proper signal processing on revealed RF signals. Some features of RF sensed signals will be kept unchanged in order to give to the listener the clear feeling of the amount (power) of RF signals present in the monitored area. The IT technology has evolved in furnishing the most advanced services in terms of communication [1,2,3], monitoring [4,5,6], and security [7].

F. Huang and R.-C. Wang (Eds.): ArtsIT 2009, LNICST 30, pp. 128–135, 2010.

Our project aims in particular to investigate the possibility to exploit wireless sensor networks (WSNs) in artistic applications, with particular efforts on electronic music. In order to properly design the RF sounding the main topics to be investigated are: WSNs with main attention on localization, spatialization and sound elaboration, cellular networks communication.

Localization in the context of WSNs is a well known topic in the IT research sphere, [4,5,11,12,13,14], but the problem of localizing a passive target through small sensors is still a very open research area and it appear of fundamental importance for our project since it is thought for end users that can use the installation with their cellular phones only.

On the other hand a lot of possibilities have been proposed since the birth of the computer music for sound spatialization and elaboration, [15,16,17,18] and it appears that most of them are suitable to be realized and improved in our proposed prototype.

The aim of this project is twofold. Indeed, from one side we want to increase end users knowledge of the strength of the power emitted by their cellular phones with respect to the electromagnetic fields produced in the environment, on the other hand we want to provide for an artistic and interactive installation that can also be remotely joined through a web interface.

The paper is organized as follows: the system architecture together with its general components is presented in section 2, section 3 is concerned with the specific functioning of RF Sounding, while the localization aspect is detailed in section 4; techniques for sound processing and spatializations are presented in section 5; finally conclusions and future works are drawn in section 7.

2 System Architecture

The general project for RF Sounding, fig. 1, assumes a scenario comprising a circular area with a 10m diameter. The area is accessible through at least 2 entrances equipped with gating sensors. Within the area an hexagon will be defined on whose vertex six speakers will be placed. Along with the speakers there will be six or more wireless sensor nodes that will feed a positioning algorithm allowing to evaluate the user position and movement in the equipped area. The positioning algorithm will be based on [23] where the body of a person in the monitored area is reviewed as on obstacle to the radio transmissions among sensors. There will be one node sending a low power radio signal and all other nodes will evaluate the strength of the received signal. A signal processing will follow to determine the user position. These sensors will allow the installation to interact with user's movements by changing lights and sounds conditions. The system interaction with the user will be set according to suitable psychoacoustics evaluations. In the center of the hexagon, at a level of 2.5-3m from the ground, a receiving antenna is placed in order to gather all signals in the band of interest and to send them to a spectrum analyzer. The analyzer will be linked to an elaboration unit, equipped with an audio processing board, that will implement sound's elaboration and spatialization algorithms. This unit will also handle the

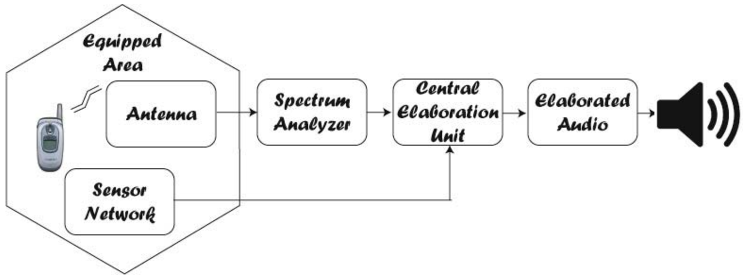

Fig. 1. RF Sounding: general functioning

processing of the localization data obtained from sensors in order to produce a suitable sound spatialization. In order to obtain a real interaction with the user and the system, we plan to implement a web interface consistent with WEB 2.0 technology. This web interface will allow the user to take control of his/her experience in the equipped area, for example using an handled device on site. The remote interface makes possible to start and stop the experience and also to ask the system for a specific response, such as sounds and lights variations, on the basis of the received signal and user position. Any time and anywhere, through the web interface, it will be possible to hear and visualize the signal received by the spectrum analyzer and the system status and to take control of the system.

The architecture of the system is shown in figures 2, 3. The RF Sounding project is characterized by a double aim. Firstly we want users to become aware of the spectral occupancy of phenomena arising while using the services of a certain cellular network and then we want to exploit an aesthetic elaboration of these spectral phenomena in order to allow the user to listen to a likable final sounding result.

The starting point of this project is given by the design and validation of a prototype exploiting signals coming from the GSM public network, [1], [2]. We

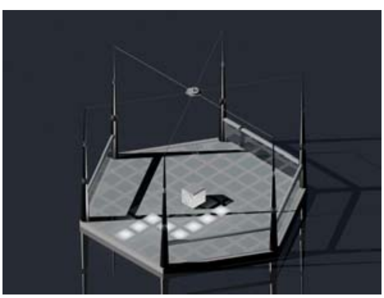

Fig. 2. Axonometric view of the equipped area

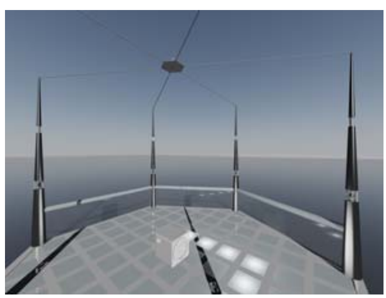

Fig. 3. Subwoofer placed at the center of the hexagon

choose the GSM standard since it is still one of the most diffused all around the world and this represents an advantage in terms of usability of the installation. GSM uses a time-division/frequency-division multiple access technique (TDMA/FDMA). This means that many radio channels are shared by many users. In particular each channel is characterized by a 200Hz bandwidth and is responsible for the transmission of data belonging to 8 users. It has to be noticed that different frequencies are used in different countries, indeed 900 and 1800 MHz are the frequency bands used in Europe, while United States use 850 and 1900 MHz frequency bands. Obviously, we are not going to consider each GSM version, at least in this first phase of RF sounding project. We are indeed mainly interested in exploiting the multiple access technique: the FDMA part involves the division by frequency of the (maximum) 25 MHz bandwidth into 124 carrier frequencies spaced 200 kHz apart. One or more carrier frequencies are assigned to each base station. Each of these carrier frequencies is then divided in time slots, using a TDMA scheme. Eight time slots are grouped into a TDMA frame, which forms the basic unit for the definition of logical channels.

On the basis of this brief information it is easy to believe that a user getting in the equipped area may experiment different reactions of the installation. Actually, the mobile terminal makes operations even without the intervention of its owner. For instance this happens when the mobile terminal (MT) is switched on and it starts scanning all radio channels in the service band in order to find out the beacon frequencies. The term beacon frequencies indicates the carrier frequencies coninuosly emitted by each cell at a constant power. It is worth noting that most control channels are allocated over the beacon frequencies. As a result of the scanning procedure, the terminal creates a list where frequencies are ordered basing on strength and constancy of the received power and it establishes to connect to the cell characterized by the strongest power.

Once the carrier frequency is known, the local oscillator (LO) of the mobile terminal is tuned to this frequency through a phase locked loop operating on a periodically emitted Frequency Burst (FB) [8] carried by the Frequency Correction Channel (FCCH) of the Broadcast Control Channel (BCCH) of the GSM signaling frame structure. The information traveling through the FCCH is transmitted at the maximum power since it has to be received by all terminals. This procedure takes place even in absence of mobile terminals and this aspect can be exploited in the installation, after a proper elaboration, as a persistent basic element. This basilar aspect represents the starting point of the real performance.

Other interesting procedures to be exploited in the installation performance are the reception of a call, the initiation af a call, the switch-off of the terminal and so on.

Moreover, a wireless sensor network is placed around the equipped area in order to follow the movements of the user. The sound will then be "moved" in the area as a function of user movements. The overall result will thus be a function of both user required services or MT procedures and user movements.

3 Localization

The user localization within the system area is carried out in a passive way: the user is not equipped with any active device collaborating with the localizaion system or aware of its location. We approach to the localization problem by the technique known as LBE (learning by example)[11]. Basically we customize and apply the multistatic radar concept,[4], [5] to the wireless sensor networks. Our localization algorithm is made up by two main phases: the first one (calibration), made offline, basically is made up by some measurement of the RSSI without any passive target, while the second one consists in the evaluation of the perturbations in the RSSI values, introduced by the target in the equipped area. In the user localization we introduce spatial operators. Spatial operators are used to capture all the relevant geometric properties of objects embedded in the physical space and the relations between them as well as to perform spatial analysis. More in particular we use topological operators [21]: intersection test and point in polygon test, to perform a qualitative analysis of user position within the area. This is made possible by the partition of the base, or floor, of the equipped area into zones identified by reinforced concrete and glass tiles. Thus, one we get the supposed user position by RSSI measurements, we test the *intersection* of this position with floor tiles identifying the one with non-empty intersection and we can light this tile up. Due to the fact that the presumed user position is a broad boundary region we are forced to use spatial operator defined for Broad Boundaries objects, [22].

4 Spatialization and Sound Processing

Sound spatialization is essentially related to the movement of sound through space. Techniques for sound spatialization are different if the target display is by means of headphones or loudspeakers, [23]. In this context we are mainly concerned with spatialization through loudspeakers in the installation area, while spatialization through headphones is achieved in the web remote application.

The most popular and easy way to spatialize sounds using loudspeakers is amplitude panning. This approach can be expressed in matrix form for an arbitrary number of loudspeakers located at any azimuth though nearly equidistant from the listener. Such formulation is called Vector Base Amplitude Panning (VBAP) [15] and is based on a vector representation of positions in a cartesian plane having its center in the position of the listener. In figure 4 the case for two loudspeakers is represented while the generalization to more than two loudspeakers and to three dimensions can be simply achieved.

A different approach to spatialization using loudspeakers can be taken by controlling the relative time delay between the loudspeaker feeds. The metaphor underlying the Moore model,[17], is that of the Room within a Room, where the inner room has holes in the walls, corresponding to the positions of loudspeakers, and the outer room is the virtual room where sound events have to take place, 5.

The simplest form of spatialization is obtained by drawing direct sound rays from the virtual sound source to the holes of the inner room. The loudspeakers

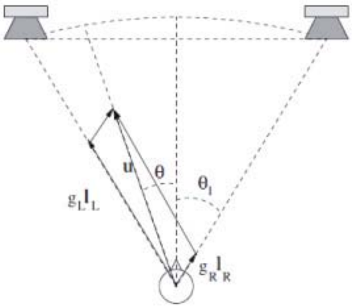

Fig. 4. Stereo panning

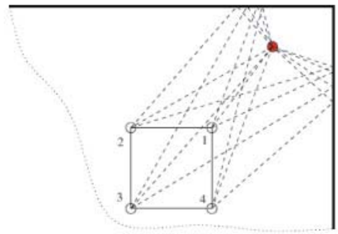

Fig. 5. Moore's room in a room model

will be fed by signals delayed by an amount proportional to the length of these paths, and attenuated according to relationship of inverse proportionality valid for propagation of spherical waves. The two controlled parameters are thus the gain of each loudspeakers and their relative delays.

Actually, while concerning with spatialization more than two parameters can be concurrently varied, [16] and we will control the following parameters: total power of signals emitted, number of loudspeakers emitting sound at the same time for each time interval, envelope characterizing the cross fade from one channel to another or between more than one channel per time, remaining power offset on loudspeakers not directly involved in sound movement.

For what concerns spatialization algorithms it has to be noticed that the proposed configuration allows almost an infinite number of variations. A first characterization could be done as a function of the user's speed; indeed a speed threshold will be established. If the user's speed will be below this threshold the loudspeakers-subwoofer systems will provide for a moving sound that will be characterized by a slow speed and by only circular spatialization, that is, the sound will move only between adjacent loudspeakers. Other mechanisms are instead assumed for the case of a fast user's movement:

- diagonal movement between single loudspeakers,
- sound motion between pairs of loudspeakers,
- varying power offset for loudspeaker not directly involved in the primary spatialization.

All these mechanisms can be properly automatized depending on user position as well as varied in a random fashion in order for the sounding experience to not be predictable.

In terms of sound processing a first distinction has to be done between sound synthesis and sound elaboration techniques. For what concerns sound synthesis techniques, we will base our elaborated sounds on shifts of RF signals to the audio frequency range but we will also process signals through the following type of synthesis: subctrative, additive, granular, wavetable, sample-based, frequency modulation, phase distortion, [18]. On the other hand, for what concerns sound elaboration techniques a first fundamental variation will be given to sound amplitude as a function of antenna's received power. Subsequently a certain number of effects could be applied, depending on e.g. channel carrier frequency, the specific telecommunication operator furnishing a service for a certain user, the number of users inside the equipped area and so on. Some of these techniques are reported in [18], [24].

5 Conclusions and Future Works

In this paper an innovative project integrating technologies and experimental music has been proposed. The project focuses on the creation of an interactive installation with a double aim, to increase users awareness of the spectral occupancy in the cellular networks bands and to provide for a spectral phenomena aesthetic elaboration in order to produce a sounding experience. The very next step of our project will be the system test together with elctronic music composers.

References

1. ETSI EN 302 403 V8.0.1 (2000-10), Digital cellular telecommunications system (Phase 2+); GSM Cordless Telephony System (CTS), Phase 1; Service description; Stage 1 (GSM 02.56 version 8.0.1 Release 1999)
2. ETSI EN 302 404 V8.0.1 (2000-09), Digital cellular telecommunications system (Phase 2+); GSM Cordless Telephony System (CTS), Phase 1; Lower Layers of the CTS Radio Interface; Stage 2 (GSM 03.52 version 8.0.1 Release 1999)
3. Universal Mobile Telecommunications System (UMTS); Network Functional Model for IMT2000 networks [ITU-T Recommendation Q.1711] (2000)
4. Bistatic: Multistatic Radar H. D. Griffiths University College London Dept. Electronic and Electrical Engineering Torrington Place, London WC1E 7JE, UK
5. Chernyak, V.S.: Fundamentals of Multisite Radar Systems: Multistatic Radars and Multistatic Radar Systems. CRC Press, Boca Raton (1998)
6. Alesii, R., Gargano, G., Graziosi, F., Pomante, L., Rinaldi, C.: WSN-based Audio Surveillance Systems. In: Proc. of WSEAS European Computing Conference 2007 (ECC 2007), Athens, Greece (September 2007)
7. Feller, S.D., Cull, E., Kowalski, D., Farlow, K., Burchett, J., Adelman, J., Lin, C., Brady, D.J.: Tracking and Imaging Humans on Heterogeneus Infrared Sensor Array for Law Enforcement Applications. Department of Electrical and Computer Engineering, Duke University, Durham, NC
8. Acquisition of frequency synchronization for GSM and its evolution systems. In: 2000 IEEE International Conference on Jha, U.S. Personal Wireless Communications, pp. 558–562 (2000)
9. Pahlavan, K., Li, X., Makela, J.P.: Indoor geolocation science and technology. IEEE Communication Magazine (2002)
10. Catovic, A., Sahinoglu, Z.: The Cramer-Rao bounds of hybrid TOA/RSS location estimation schemes. IEEE Communication Letters (2004)

11. Viani, F., Lizzi, L., Rocca, P., Benedetti, M., Donelli, M., Massa, A.: Object tracking through RSSI measurements in wireless sensor networks
12. Tennina, S., Di Renzo, M., Graziosi, F., Santucci, F.: Distributed and Cooperative Localization Algorithms for WSNs in GPS-less Environments. The Italian Institute of Navigation (I.I.N.), No. 188, pp. 70–76 (June/July 2008)
13. Tennina, S., et al.: Locating zigbee nodes using the TI's CC2431 location engine: a testbed platform and new solutions for positioning estimation of WSNs in dynamic indoor environments. In: ACM Int. Workshop on Mobile Entity Localization and Tracking in GPS-less Environments (September 2008)
14. Tennina, S., Di Renzo, M., Santucci, F., Graziosi, F.: On The Positioning Estimation of WSNs in Dynamic Indoor Environments. In: NEWCOM++ Emerging Topic Workshop, Brixen, July 1 (2008)
15. Pulkki, V.: Virtual sound source positioning using vector base amplitude panning. J. Audio Eng. Soc. 45(6), 456–466 (1997)
16. Stockhausen, K.: Musik im Raum, 1958, trad. it. Musica nello spazio, in La Rassegna Musicale 32(4) (1961)
17. Moore, F.R.: A General Model for Spatial Processing of Sounds. Computer Music J. 7(3), 6–15 (1982)
18. Dodge, C., Jerse, T.A.: Computer Music: Synthesis, Composition, and Performance. Schirmer (July 1997)
19. Clementini, E., Di Felice, P.: Spatial Operators. ACM SIGMOD Record 29, 31–38 (2000)
20. Clementini, E., Billen, R.: Modeling and computing ternary projective relations between regions. IEEE Transactions on Knowledge and Data Engineering 18, 799–814 (2006)
21. Clementini, E.: Dimension-Extended Topological Relationships. In: Liu, L., Özsu, M.T. (eds.) Encyclopedia of Database Systems, vol. à Paraître. Springer, Berlin (2009)
22. Clementini, E.: Objects with Broad Boundaries. In: Shekhar, S., Xiong, H. (eds.) Encyclopedia of Geographical Information Science, pp. 793–799. Springer, Heidelberg (2008)
23. Rocchesso, D.: Introduction to Sound Processing, ebook, University of Verona, Departement of Computer Science (2003), http://www.scienze.univr.it/?rocchess
24. Proakis, J.G.: Communication Systems Engineering. Prentice Hall International Editions (1994)
25. Gardner, W.G.: Transaural 3D audio, MIT Media Laboratori Perceptual Computing Section Technical Report No. 342, July 20 (1995)