Intelligent detection and control for environmental noise pollution

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Abstract. Noise pollution is a common environmental problem that directly or indirectly affects people health, productivity, behavior, and sometimes leading to death. Harmful noises are extensively found within specific environments such as airports, power stations, railway lines, road works, factories, construction, demolition sites, etc. Countries around the world initiated regulations in terms of monitoring as well as controlling and treating such pollution. These regulations raised the issue of finding a suitable, cost-effective, and reliable technology to encounter the noise pollution effects. Traditional manual noise detection and treatment solutions are not scalable to the high demand in time and space. So, Wireless Sensor Networks (WSNs) can provide an effective, inexpensive, and flexible real-time acquisition platform to support the detection and control process of noise pollution sources. This paper brings the concept of noise pollution to the light. Also, a model is proposed for automatically monitoring, detecting, and controlling abnormal sound pressure levels representing noise pollution in the ambient environments. The proposed approach utilizes the integration of wireless sensing and Smartphone technologies for dealing with that type of pollution.

Keywords: Wireless Sensor Network (WSN), Noise pollution, Smartphones, Sound Pressure Level.

1 INTRODUCTION

Noise pollution is a big challenge in today's daily life as it affects the health of people and the quality of their life. This type of pollution become a common environmental problem that affects people health by increasing the risk of hypertension, heart diseases, hearing losses, and sleep disorder, which also influences human productivity and behavior. There are many effects of noise on humans as well as animals. It affects the human health and behavioral nature. Sometimes unwanted sound damage physiological and psychological health. It causes annoyance, aggression, hypertension, hearing loss, self-disturbance etc. There is a demand for measuring the noise level everyday via collecting the data from the surrounding environment in order for the user to easily trace the noise level of noisy places such as airports, road works, factories, construction sites, and other environments producing loud noises.

Noise level monitoring grows and gains greater interest in many countries. In recent years, there has been a vast literature on techniques for achieving reliable noise monitoring systems. For raising the public's awareness of this problem, the European community requests the European Union members to provide the current level of nosiness in map formats. These maps are publicly available through adequate web interfaces (European Commission, 2002). The information of these maps was questionable that its data are estimated on the basis of mathematical model of rough data set over years. The spread of Smartphones has raised the concept of *Public Sensing*, a new standard for data acquisition systems utilizing Smartphones carried by users. The work carried out in (Maisonneuve, Stevens, Niessen, Hanappe, and Steels, 2009) uses the GPS-equipped within Smartphones for turning them into noise sensors. Their approach enables citizens to daily measure the noise in their ambient environment. The

Geo-localized data and user-monitored nosiness levels are shared directly on a public domain ("NoiseTube," 2013) to also contribute to the collective noise mapping of cities. Noise maps facilitate monitoring environmental noise pollution. That raised citizen awareness of noise pollution levels, and aids in the development of reduction strategies.

Nowadays, many developing countries pay attention to noise issues as an environmental pollution not less than air and water pollutions. Thus, some of them initiated projects to indicate noise sources and to measure their levels. These monitoring activities are the first step toward implementing policies for fighting noise pollution. Recently, noise monitoring serves as a base for a number of applications; such as aircraft classification framework that categorize aircrafts according to the level of noise they produce when taking-off (Fernández, Pérez, Hernández, and Ruiz, 2012). Also, the profoundly deaf people vehicle detection system proposed in (Rahim, Paulraj, Adom, and Sundararaj, 2010) is another example where the noise originated from the incoming vehicles was detected using sensor samples microphone. The sampled collected data is being analyzed using a back-propagation neural network model to identify the distance between the approaching vehicle and deaf people.

This paper presents a detailed discussion for the concept of noise pollution in addition to suggesting future research directions. Also, the paper proposes a model for automatically monitoring, detecting, and controlling abnormal sound pressure levels, representing noise pollution, in the ambient environments. The proposed approach utilizes the integration of wireless sensing and smart mobile devices technologies for dealing with that type of pollution.

The rest of this paper is organized as follows. Section 2 reviews the concept of noise pollution. Section 3 presents traditional and intelligent noise pollution detection and control solutions, also this section proposes a WSN based noise awareness framework. Finally, section 4 concludes the paper and discusses future and on-going work for developing the proposed system.

2 NOISE POLLUTION: AN OVERVIEW

2.1 Definition

Noise pollution occurs generally when there is “unwanted or disturbing sound” – that is, when either sound interferes with normal activities or disrupts or diminishes one’s quality of life (Short, and Pearso, 2011). Although the noise is basically a sound and it's considered as unwanted sound, it is unfavorable to normal hearing.

Sound consists of waves of air pressure produced by a vibrating body and can be detected by the human ear over a significant range from 20 HZ to 20,000 HZ (Roads and Traffic Authority of New South Wales, 2001). The sounds with fluctuations higher than 20,000 HZ (ultrasonic) or lower than 20 HZ (infrasonic) are considered as noises. It is a common misconception that noise pollution occurs only in the air, it also happens in other mediums that the sound waves travel through such as underwater.

2.2 Measures

Prior to the selection and design of noise measurement devices, the unit used to measure sound must be identified. Hearing is directly sensitive to sound pressure, which is related to sound intensity. The intensity of sound is measured in sound pressure level (SPL), which is generally measured in decibels (dB) using the A-weighted sound pressure level, abbreviated dB(A) (Kudesia, and Tiwari, 1994). The SPL is measured on a logarithmic scale resembling the audible sound pressure level that human ear can perceive. Based on that logarithmic scale, any sound higher than the reference sound by 10 dB(A) considered as a community (ambient) noise (Santa Monica Civic Center Specific Plan EIR, 2013). In the real world, sound pressure levels are in an inverse relationship with the distance (inverse-square law); that doubling the distance from the noise source equal a decrease by 6 dB(A) on the SPL logarithmic scale (Wiley, and Richards, 1978). Furthermore, noise measurement should consider the period of sound long-lasting, since sounds that occur over a long period of time are more likely to be an annoyance. The equivalent noise level metric (Leq) considers the sound waves measured over specific period of time. In order to calculate the sound pressure level, L_2 in dB at r_2 meters, Eq. (1) is being fed by a previous measured sound pressure level; L_1 in dB is measured at r_1 meters (Kudesia, 1994).

$$L_2 = L_1 - 20 \log_{10} (r_2 / r_1). \qquad (1)$$

Equation (1) didn't take in consideration the actual time period in which the noise occurs. It is important since noise that occurs at night usually being more disturbing than that occurs during the daytime. The Day-Night average level (Ldn), shown in Eq. (2), (Kudesia, 1994) identifies two parameters. Firstly the Ld, which represents the Leq(15hr) as a 15 daytime hours started from 7AM to 10PM. The second one is the Ln demonstrating the Leq(9hr) as a 9 nighttime hour from 10PM to 7AM. The Ldn weighted the Leq with extra 10 dB based on the fact that sound is louder at night than during the daytime.

$$\text{Ldn, dB(A)} = 10 \text{ x} \log_{10} [15/24 (10^{Ld/10)} + 9/24 (10^{(Ln + 10)/10)}]. \qquad (2)$$

There are a numerous noise measurements systems. These systems share a common measurement device. These measurement devices include (World Health Organization [WHO], 2013): Sound level meter, Impulse meters, Frequency analyzers, Graphic recorders, Noise dosimeters, and Calibrators.

2.3 Sources

In order to understand noise pollution, the sound sources responsible for the excessive noise must be identified. Noise pollution is resulted from several sources. It may be external noises to the individual environments such as vehicular traffic, aircraft, etc. Other sources of noises may generate by humans themselves; for example those associated with individual's home, school, or workplace. Countless number of people does a lot of activity in their home that could be considered as noisy activities; for example running the T.V. constantly; especially in sports events. They believe that the absence of loud noise may reduce the enjoyment of the event. Fig. 1 depicts the typical noise levels emitted from various noise sources in decibels A-weighted dB(A) (Nagaraj, 1993).

As well, workplace may be a common noise complaint, specifically when people packed into busy office spaces; that more co-workers talks. This type of community noises can distract and decrease the productivity of those workers.

When human body experiences excessive noise level, the body triggers the “fight” or “flight response” against that noise. This response is a body's primitive, automatic, inborn response that activates the body to "fight" or "escape" from perceived harmful attacks adverse its health. The World Health Organization (WHO) has acknowledged seven categories of adverse health effects of extreme noise level on humans (Berglund, and Lindvall, 1995; Goines, and Hagler, 2007). These categories are: 1) Hearing impairment, 2) Interference with Spoken Communication, 3) Sleep Disturbances, 4) Cardiovascular Disturbances, 5) Disturbances in Mental Health, 6) Impaired Task Performance, and 7) Negative Social Behavior and Annoyance Reactions.

Fig. 1. Different noise sources and their corresponding noise levels.

3 NOISE POLLUTION DETECTION AND CONTROL SOLUTIONS

3.1 Traditional noise detection solution

As previously mentioned, the traditional way to announce the detection of noise is through preparing a noise map. These maps are easily accessible over public and announced websites. Obtaining global assessment of noise levels in a given area is the responsibility of the citizens of that area. Then noise indicators are estimated by numerical models that may be based on synthetic data (European Commission Working Group, 2006; Santini, Ostermaier, and Vitaletti, 2008). Usually, these noise maps don't give a recommendation for action plans.

3.2 WSN based solutions

In recent times, WSNs carried the promise of intensely improving and mounting the quality of care for different segments of inhabitants (i.e. the clinical deterioration through real-time patient monitoring in hospitals, enhance first responders' capability to provide emergency care in large disasters through automatic electronic triage, improve the life quality of the elderly through smart environments, and enable large-scale field studies of human behavior and chronic diseases). Hence, WSNs presented a new paradigm for early system prototypes in order to demonstrate the potential of WSNs for enabling early detection of a number of phenomena. WSNs can provide a cheap and flexible infrastructure to support the detection of noise pollution sources. A specific noise sensor is used to detect sound pressure level form surrounding environments and accordingly taking an action to encounter the harmful effects of noise pollution especially in quiet environments.

3.2.1 The proposed WSN based noise awareness framework

To implement a reliable noise monitoring system using wireless sensor network, it must consider the low-level energy constraints of the sensor nodes. Sensing and data delivery requirements are power consuming operations that leave a clearly defined energy budget for other services. This paper proposes an in-door noise detection and awareness framework. It could be applied in quiet environments, such as libraries and hospitals, to gives awarness of any excessive noise levels. The proposed framework utilizes the event driven approach that allows sensor nodes to translate noise events based on calibration data (threshold). Once the detected noise exceeds that threshold, it is permitted to deliver their detected noise level to the base station. This approach allows the wireless sensor network to monitor and deliver the required noise data while meeting the energy requirements.

The proposed in-door concept diagram, as shown in Fig. 2, illustrates a library noise detection system, which is consisted of two main layers. In the first layer, wireless noise detection sensors, constructing a wireless sensor network, scattered in apecific palces within the library. Once one of these sensors detects high community noise level in specific section of the library, it send this information to the base station. The advantage of that framework is that there is no need for location-providing Global Positioning System (GPS) receivers since the locations of sensor nodes are predefined. Knowing the node ID defines the place at which the noise occurred.

The second layer of the in-door framework gives alerts to mobile carriers. That is, the base station multicasts an IP notification message to the mobile devices of all people currently existing in this geographical section asking them to keep quiet. If the library has silent signs on its tables, the base station may turn their light on to alert noisy people. Also, the base station sends alerts to the librarian of the noisy sections within the library to check them.

Although the library in-door framework increases the concentration of the library's readers, its benefits could be obvious in hospitals. Thus, in order to offer a healing environment for patients, the hospital required to be a quiet environment.

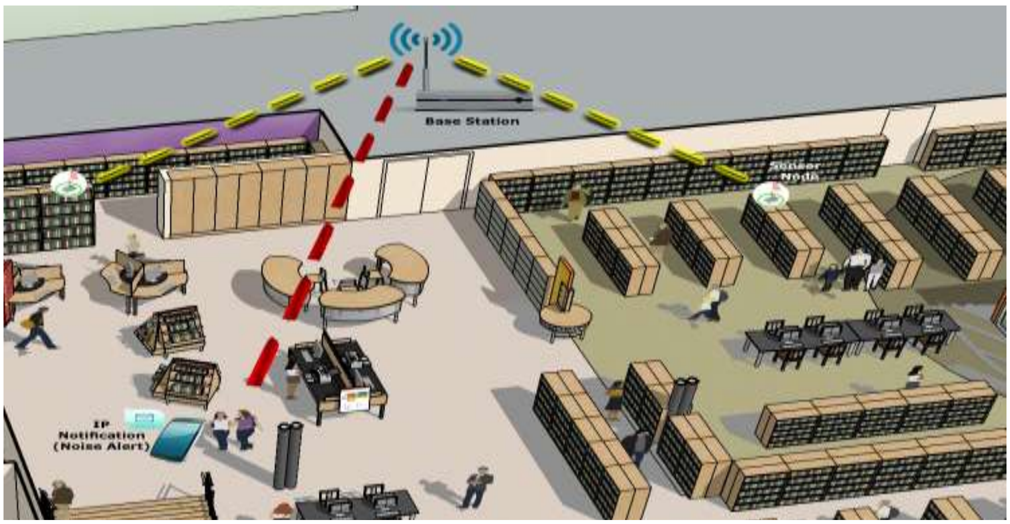

Fig. 2. Concept diagram for an in-door noise detection system in a library.

3.2.2 Noise reduction solutions

The well-known acoustic treatments can reduce the noise and eliminate some problems resulted from ambient noise pollution in a sustainable and in a cost effective manner. However, those solutions lack the properties provided via using WSNs for noise pollution continuous monitoring, detection, and control. Also, traditional noise reduction solutions can only reduce the surrounding noise in a temporary way and not to monitor and predict it in order to accordingly take a prevention action. Basic traditional acoustic treatment methods include: the application of the basic acoustic principles (Absorb, Block, and Cover), individuals' behavior modification, using noise cancellation and masking equipment.

4 CONCLUSIONS AND FUTURE RESEARCH DIRECTIONS

Historically, as a society, it usually fails to recognize the agents that cause disease. Moreover, once the causes have been recognized, the response often comes in a slow and inadequate way. Hence, despite the evidence about the many medical, social, and economic effects of noise, as a society, we continue to suffer from that same slow and indicate responses for that type of environmental pollution.

Wireless sensing technologies represent effective approaches for detecting sound pressure level from the ambient environments, which is accordingly essential for decision makers to initiate strategies for dealing with that type of pollution. Also, these noise detection technologies are useful for the preparation of environmental noise maps that denote the sound level distribution existing in a given region and hence providing several means of controlling the detected noise pollution.

Therefore, as noise represents an important public health problem that can lead to impair the ability to enjoy one's life and increases the frequency of antisocial behavior. This paper highlighted the concept of noise pollution via presenting its different definitions, measures and sources. Furthermore, due to the fact that noise harmfully affects general health and well-being in the same way as does chronic stress, it adversely affects future generations by degrading residential, social, and learning environments with corresponding economic losses. Also, local control of noise has not been successful in most places. Consequently, this paper proposed an approach for in-door noise pollution detection and awareness framework in reading/studying areas designed for noise impact reduction. With the adoption of that approach in different in-door working or reading environments, an additional noise based database server could be used in order to easily integrate collected noise data with data analysis and data mining tools for further illustration or investigation. Accordingly, that enables controlling noise in the surrounding ambient environment.

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