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A virtual perception method for urban noise: The calculation of noise annoyance threshold and facial emotion expression in the virtual noise scene

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ABSTRACT

With the development of immersive virtual technology and GIS, the virtual perception for noise annoyance will lead into new research issues. The aim of this study is to construct a methodology to realize virtual noise perception. There are three aspects: calculating method for annoyance thresholds in different noise control zones, facial emotion expression generating method, and linking method between subjective response and emotion.

A face-to-face social survey has been carried out among 7483 participants in three different noise control zones. The noise annoyance is assessed by five-graded scale. With stratified random sampling results of survey as input data, the analysis hierarchy process is adopted to calculate noise annoyance threshold. Then the emotion is determined by excessive level and linkage between five-graded semantic scale and emotion. Finally, the facial emotion expression is used to realize the visualized expression and virtual perception of noise annoyance. The key technologies are the emotion determination method and the facial expression generating with free-form deformation technique.

To illustrate the application of the proposed methodology, the method has been applied to a local district in Qingdao, China. Comparing the regulatory standards, results of calculated threshold value for noise control zones are more closely aligned with the people's real subjective responses. At the same time, the facial emotion expression provides a visualization display to achieve people's emotional reactions under noise pollution. Consequently, the proposed method can provide a reference to the competent authorities to make better action plans to prevent or reduce annoyance.

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1. Introduction

The relationship between environment noise and public health is perhaps the most significant reason why environment noise emerges as a major issue in scientific community [1,2]. Moreover, many studies have been done on the relationship between noise pollution and detrimental health impacts [3–5]. One of the most important is noise annoyance [6].

In China, with the rapid urbanization and development of transport system, approximately 30% of the population in China is exposed to a sound level above 55 dB [7,8]. In order to guarantee the quality of sound environment for the daily life of urban residents, the Standard of Environment Noise of Urban Area (GB3096-93) was formulated in 1993. The regulatory standards for noise control are based mainly on noise control zoning. Noise control zones are delineated by conditions within their areas of jurisdiction. The noise control zones in China are classified into five categories [9]. It is estimated that 3–6% of the China population experiences severe noise annoyance based on the analysis of daytime and nighttime qualification rates of different noise control zones [10,11]. Consequently, the quantification and control of urban noise have become a critical issue, and the thresholds of noise control zones are important to achieve acoustic quality. However, few researches have been done on the determination method for thresholds of different urban noise control zones.

Annoyance is one of the most widespread and well-documented subjectively reported effects of environment noise [12,13]. It can be viewed as an indicator of negative reactions to noise and can be affected by psychological or non-acoustical characteristics [14,15]. The previous studies on noise annoyance mainly focused on the annoyance evaluation of human reactions [16,17], the relationship with specific noise source [18,19], survey method [20] and so on. Noise annoyance assessment and its relationship with urban noise control zone limited value are essential

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when trying to achieve acoustic quality objectives. However, there is a paucity of study on these issues.

On the other hand, within application conducted in immersive virtual environments, the facial emotion expression is an important parameter [21,22]. Moreover, the virtual reality technology can be combined with acoustic simulation [23,24]. In addition, the European Directive requires performing noise maps to help locate which urban areas are exposed to unacceptable noise levels, and to determine the percentage of the population who is affected by excessive noise levels. Together with noise maps, the Directive requires performing a psychosocial report on noise annoyance [25–27]. However, little attention has been paid to the noise perception with facial emotion expression in the virtual noise scene.

The purpose of this paper is to construct a methodology to realize noise perception visualization with facial emotion expression. With sampling results from original psychosocial survey as research object, this paper outlines the method through annoyance threshold calculating model and virtual perception development. The proposed method further reflects on the multidisciplinary approach to study the subjective response to environmental pollution, and also provides good practice guidelines for future research.

2. Materials

2.1. The study area and noise control zones

The cross-sectional study was performed in Shinan District of Qingdao city in China. It has an area of 30.01 square kilometers and approximately 547,400 residents in 2014. Shinan, as the center of capital, economy, travel and education of Qingdao, is located 120°19′E and 36°04′N with a temperate monsoon climate. Common features include moderate temperatures, moist air, abundant rainfall, and four distinct seasons. Fig. 1(a) shows the geographic location of the study area.

According to Standard GB3096-93 as shown in Table 1, Shinan is divided into three different noise control zones, with which the graphical representation is shown in Fig. 1(b).

2.2. Grid noise survey and noise map

The psychosocial survey should be performed with the corresponding noise map. In this case, Qingdao Environment Protection Bureau has carried out noise survey each year since 1998. In order to select the locations of noise survey stations, Shinan is divided into standard grids with the size of 500 m × 500 m to set up the 100 noise monitoring stations. The noise control zones and the distribution of the stations are shown in Fig. 1(b). At each monitoring stations a weighted continuous equivalent sound level L_{Aeq} and the statistical values L_{max}, L_{min}, L_{10}, L_{50}, and L_{90} are measured for each interval-time.

Grid noise survey data in the study area are collected from each noise monitoring station. Noise maps are then constructed with Virtual Reality Geographical Information System (VRGIS) [28] to integrate the monitoring data with spatial information. Noise level contours are constructed by Kriging method, which is now the most widely used geo-statistical interpolation method. It is noted that we have developed VRGIS platform with truly immersive capability for navigating and understanding a complex city. The virtual urban scene based on VRGIS provides the possibility to simulate a three-dimensional (3D) noise map, which can be generated by the designing plug-in and can dynamically render the spatial and temporal noise distribution data while simulating.

The noise map for Shinan District has already been approved by Qingdao Environment Protection Bureau. The results from the grid noise survey have been correlated to the corresponding noise levels for a better knowledge of average annual noise levels.

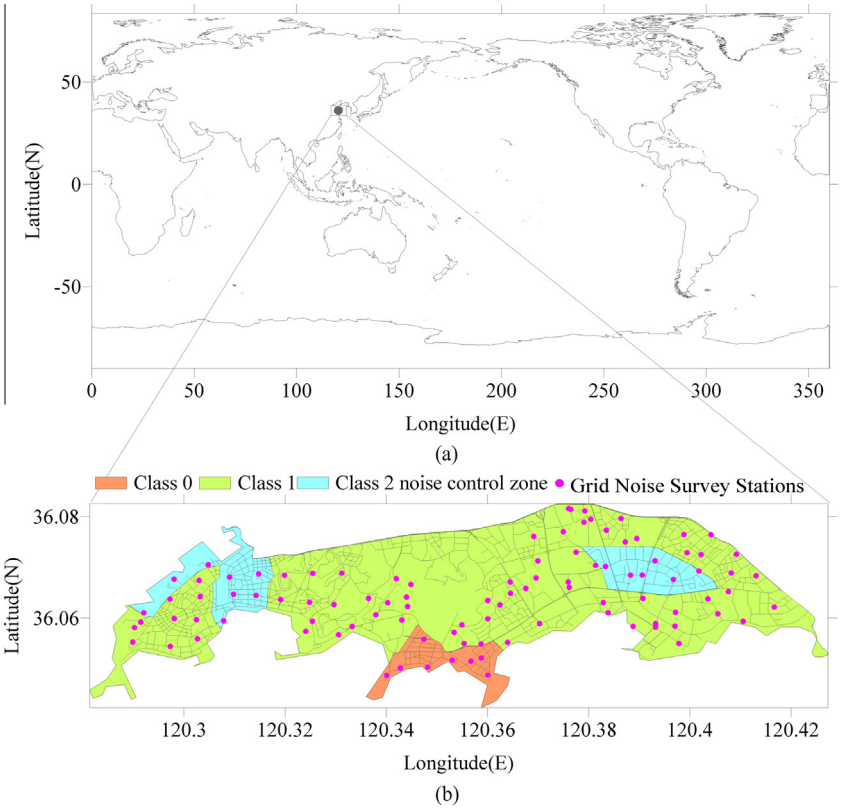

Fig. 1. (a) Geographical location of the study area analyzed in this paper, (b) noise control zones and spatial distribution of grid noise monitoring stations in study area.

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