Noise Mapping through Mobile Crowdsourcing for Enhanced Living Environments

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Abstract. Environmental noise pollution has a significant impact on health. The noise effects on health are related to annoyance, sleep and cognitive performance for both adults and children are reported in the literature. The smart city concept can be assumed as a strategy to mitigate the problems generated by the urban population growth and rapid urbanisation. Noise mapping is an important step for noise pollution reduction. Although, noise maps are particularly time-consuming and costly to create as they are produced with standard methodologies and are based on specific sources such as road traffic, railway traffic, aircraft and industrial. Therefore, the actual noise maps are significantly imperfect because the noise emission models and sources are extremely limited. Smartphones have incredible processing capabilities as well as several powerful sensors such as microphone and GPS. Using the resources present in a smartphone as long with participatory sensing, a crowdsourcing noise mobile application can be used to provide environmental noise supervision for enhanced living environments. Crowdsourcing techniques applied to environmental noise monitoring allow creating reliable noise maps at low-cost. This paper presents a mobile crowdsourcing solution for environmental noise monitoring named ***iNoise-Mapping***. The environmental noise data is collected through participatory sensing and stored for further analysis. The results obtained can ensure that mobile crowdsourcing offers several enhanced features for environmental noise supervision and analytics. Consequently, this mobile application is a significant decision-making tool to plan interventions for noise pollution reduction.

Keywords: Enhanced Living Environments; Environmental Monitoring; Mobile Crowdsourcing; Participatory Sensing; Smart City; Smartphones

1 Introduction

The ‘environmental noise’ can be seen as an unwanted sound produced by human activities that are considered harmful or detrimental to human health and quality of life, while ‘noise’ was identified as being sound that is ‘out of place’ or as a form of acoustic pollution as much as carbon oxide (CO) is for air pollution [1].

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The concept of the "smart city" has recently been introduced as a strategic device to encompass modern urban production factors in a common framework and, in particular, to highlight the importance of Information and Communication Technologies (ICTs) in the last 20 years for enhancing the competitive profile of a city as proposed by the authors of [2]. Nowadays cities face interesting challenges and problems to meet socio-economic development and quality of life objectives and the concept of "smart cities" corresponds to answer to these challenges [3]. The smart city is directly related to an emerging strategy to mitigate the problems generated by the urban population growth and rapid urbanisation [4]. The smart city implementation will cause impacts at distinct levels such as impacts on science, technology , competitiveness and on society but also will cause ethical issues as the smart city need to provide correct information access as it becomes crucial when such information is available at a fine spatial scale where individuals can be identified [5].

Noise maps are created with standard methodologies and are based on specific sources such as road traffic, railway traffic, aircraft and industrial. The CNOSSOS-EU was created by European Commission for noise mapping and is a common framework for noise evaluation not only to provide reliable and comparable data on the noise levels personal exposure and the related health implications but also to plan interventions to reduce the exposure to unhealthy noise levels [6]. However, this approach is not reliable because the noise emission models and sources are extremely limited [7].

Several countries such as Germany and the United Kingdom have produced noise maps in the recent past based on statistics. Truth be told, noise evaluation is not an easy task. Environmental noise can be extremely dissimilar on the same location at different hours of the day, but also can vary relatively over small distances at the same space of time. Therefore, noise mapping is a difficult and time-consuming task.

The name crowdsourcing is formed from two words: crowd, referring to the people who participate in the initiatives; and sourcing, which refers to some procurement practices aimed at finding, evaluating and engaging suppliers of goods and services [8]. Crowdsourcing is a concept where the information is collected by a large group of people who submit their data via the Internet, social media and mobile applications. These people can be paid or be done as voluntary work. Crowdsourcing allows not only to avoid costs but also speed and provide the ability to work with people with different skills. On the one hand, this methodology enables building a database of data where people can add new information that in another way was impossible. On the other hand, crowdsourcing uses mobile applications to provide rapid and flexible data collection to everyone as anyone who has the smartphone application can contribute.

Right now, smartphones have incredible processing capabilities as well as a set of very interesting sensors for the study of assisted living, such as GPS, accelerometer, gyroscope, proximity sensor, camera, microphone, NFC and BLE. Smartphones have mobile sensors that turn possible to make activity recognition and detect physical activities such as walking, running, climbing stairs, descending stairs, driving, cycling and being inactive with no additional sensing hardware [9], [10]. The smartphone has a key role in building smart communications architectures for ambient assisted living to know what is happening in the network and detect if older adults need assistance as proposed by the authors of [11]. Therefore, smartphones not only are directly involved

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in several important applications as they incorporate large potential particularly about sensors, communication technologies and processing power but also face an important adoption for crowdsourcing applications for noise supervision [12].

Due to the well-studied health effects of environmental noise and combining the resources present in a smartphone as long with participatory sensing, a noise mobile application is proposed to provide environmental noise supervision for enhanced living environments. The main objective of the presented application is applying crowdsourcing techniques to environmental monitoring in order to encourage users to contribute to the data collection process by using their personal smartphone.

In this document, ***iNoiseMapping***, a mobile crowdsourcing application for noise pollution is presented. The collected data is stored in a structured database. The solution is composed of an iOS mobile application for environmental noise data collection and data consulting and MySQL database for data storage.

The rest of this paper is structured as follows: Section 2 presents the environmental noise health impacts related work; Section 3 is concerned to the methods and materials used in the implementation of the ***iNoiseMapping*** solution; Section 4 demonstrates the system operation and experimental results, and the conclusion is presented in Section 5.

2 Environmental Noise and Health

The noise effects on health are not only related to annoyance, sleep and cognitive performance for both adults and children but can also be associated with raised blood pressure [13].

Environmental noise pollution may be a novel risk factor for pregnancy-related hypertension, particularly more severe variants of preeclampsia [14]. Long-term exposure to railway and road noise, especially at night, may affect arterial stiffness, a major determinant of cardiovascular disease. Therefore the noise monitoring can be significant to the enhanced understanding of noise-related health symptoms and effects [15]. Poor sleep causes endocrine and metabolic disturbances, several cardio-metabolic and psychiatric problems and anti-social behaviour, both in children and adults. The duration and quality of sleep are risk factors significantly affected by the environment but amenable to modification through awareness, counselling and measures of public health [16].

Pregnancy and childhood exposure to road traffic noise can be associated with a higher risk for childhood overweight has been concluded by the authors of [17]. The World Health Organization (WHO) has recently acknowledged that contrary to the trend for other environmental stressors, noise exposure is increasing in Europe [18]. Therefore, the majority of the developed countries support laws noise regulation at specific hours [19]. Environmental noise must be assumed as a serious public health issue throughout the world. Overall, the evidence suggests that environmental noise should be placed at the forefront of national and international health policies to prevent unnecessary adverse health impacts on the general population [20]. Environmental

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planning and policy should take both exposures into account when assessing environmental impacts [21]. The variation in noise levels in cities is determined by the cumulative effect of unfavourable or thoughtful city design elements at several scales of a city's general and neighbourhood layout. This is related with the transportation system, the buildings structures, population density, the design of street and building facades, the amount of green space, and the quality of the dwellings concerning sound and vibration features inherent to each city [22]. In the same city, we can find high sound levels at some locations when compared with other places of the same town that are quieter. This is many times related to the city design, especially in cities created a long time ago, not planned and even entirely away from the current mobility needs of the citizens. Currently, environmental noise pollution in cities is based on random sampling. However, these procedures are providing only information relating to a specific sampling and being devoid of details of spatial-temporal variations.

NoiseTube is a participatory sensing solution for noise pollution data collection via mobile crowdsourcing proposed by the authors of [23]. Another approach for noise pollution supervision that implements a crowdsourcing noise pollution monitoring application based on gamification techniques was proposed by [24]. A participatory urban noise mapping system called Ear-Phone that aims to recover the noise map from incomplete and random samples obtained by crowdsourcing data collection has been proposed by the authors of [25]. A middleware solution dedicated to noise monitoring that builds on a refined version of Urban Civics, a platform for urban pollution monitoring currently under development and is focused on the integration of domain-specific sensing applications while applying data assimilation techniques to noise with mobile unplanned was presented by [26]. A ubiquitous crowdsourcing concept where the contributed information is not limited to passively-generated sensor-readings from the device but also includes proactively-generated user's opinions and perspectives, that are processed to offer real-time services to participants was studied by the authors of [27]. A crowdsourcing systems survey which not only provides a better understanding of crowdsourcing systems but also facilitates future research activities and application developments in the field of crowdsourcing was presented by [28].

3 Materials and Methods

The ***iNoiseMapping*** has been developed by the authors to be a cost-effective solution that can be easily used by everyone. Using crowdsourcing is possible to create effective noise maps in a less time-consuming and expensive way.

PHP is a fast and multifeatured scripting language used for web development. MySQL can be assumed as a relational database management system (RDBMS) database capable of handling a massive number of simultaneous connections. PHP and MySQL technologies offer productivity, scalability, high performance and portability to develop Web applications. The selection of these technologies was first all the fact that are open-source technologies. Furthermore, PHP and MySQL are free development tools with a large community who contribute every day to add new features and avoid licensing costs. In one hand, PHP is cross-platform, PHP applications are supported by

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the majority of operating systems such as Solaris, UNIX, Windows and Linux; PHP is an easy language based on the C programming language and provides significantly reduced database configuration time. On the other hand, PHP has a poor quality of handling errors as PHP has a limited amount of debugging tools when compared to other Web development languages. Therefore, this mobile application use PHP Web Services for data communication and MySQL as a database management system. For security proposes the services are not only authenticated but also use HTTPS protocol. **Fig. 1** shows the ***iNoiseMapping*** architecture.

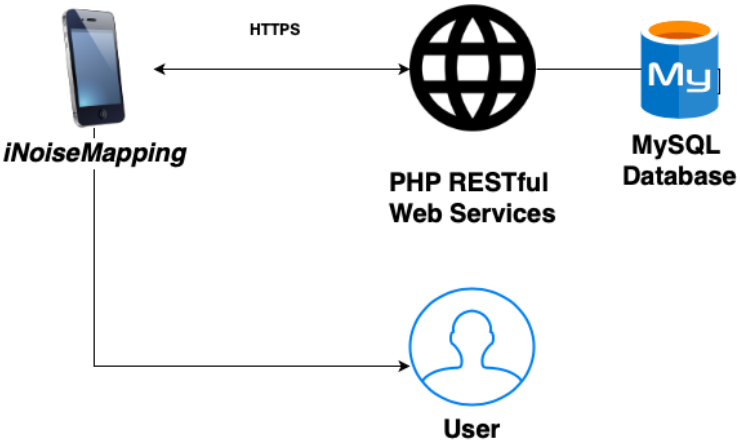

Fig. 1. ***iNoiseMapping*** architecture.

The ***iNoiseMapping*** was developed for the iOS operating system as a study that conducts 1472 tests on 100 phones in a reverberation room shows that iOS applications achieve better accuracy than Android applications [29].

This mobile application uses several native frameworks such as AVFoundation for sound recording, Core Audio for sound analysis and Core Location for GPS access (**Fig. 2**).

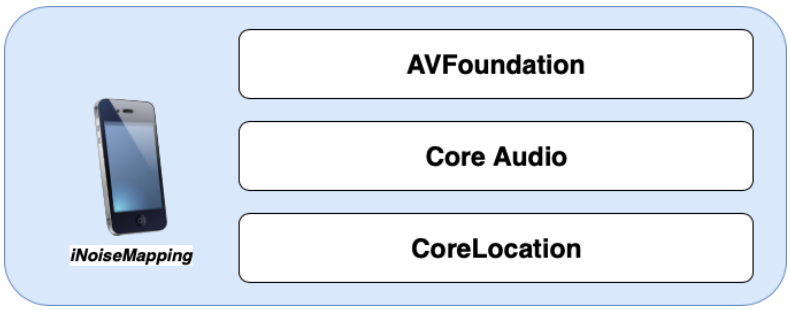

Fig. 2. ***iNoiseMapping*** frameworks.

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AVFoundation is native framework developed by Apple for audiovisual media handling on iOS, macOS, watchOS and tvOS. This framework provides methods for capturing, processing, synthesising, controlling, importing and exporting audiovisual media on Apple platforms. Core Audio is a low-level native Apple framework for sound analysis. Core Location incorporates several methods for device location handling. Using Core Location is possible to get the device's geographic location, altitude, orientation, or position relative to a nearby iBeacon. The framework uses all available onboard hardware, including Wi-Fi, GPS, Bluetooth, magnetometer, barometer, and cellular hardware to gather data.

4 Discussion and Results

The ***iNoiseMapping*** provides two major features. In the map view scene, the user can consult the participatory data collected. The map view is centred based on the user GPS location. At the sound analysis scene, the user can check the dBA level of the environment and press the "share" button to contribute with real-time noise data from their environment. **Fig. 3** shows the ***iNoiseMapping*** features.

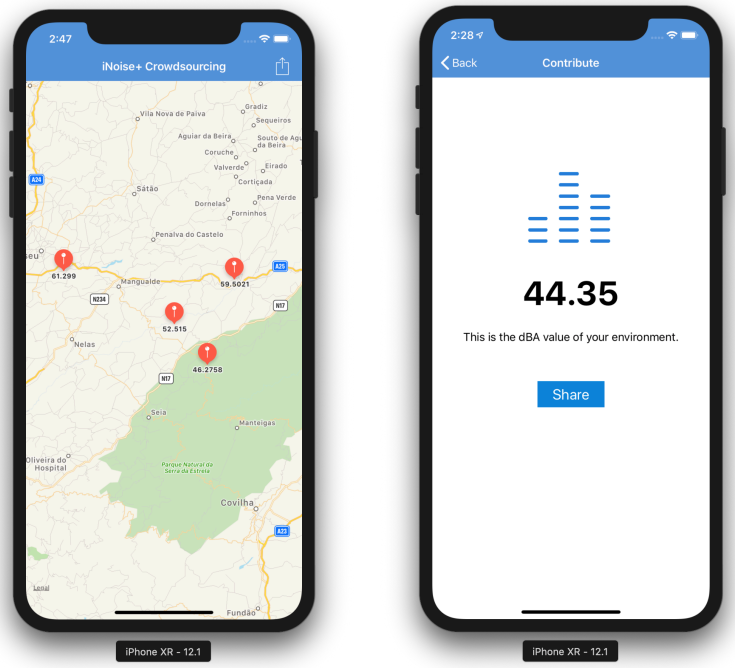

Fig. 3. ***iNoiseMapping*** mobile application developed by the authors.

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In order to access the device's GPS location, GPS access must be requested to the user. The ***iNoiseMapping*** application can access to the device's location data only when the application is used. To enhanced user privacy, the microphone recording feature must be request and the user must accept before audio recording.

The smartphone application allows quick, simple access, intuitive and real-time access to the environmental noise data. Mobile computing in the U.S. has had an exponential growth as adult smartphone device ownership was at 33% in 2011, 56% at the end of 2013 and 64% in early 2015 [30]. In the Netherlands, 70% of global population and 90% of the adolescents own a smartphone [31], in Germany, 40% of the people use a smartphone [32], and 51% of adults owned smartphones in the UK [33]. About 36–40% of smartphone owners use their smartphone 5 minutes before bed and in the next 5 minutes after wake up [32]. Actually, smartphones have excellent processing and storage capabilities, and people carry them in their daily lives. For all these reasons a mobile-based crowdsourcing application which uses the resources present in a smartphone and participatory sensing has been developed. On the one hand, this application enables a crowdsourcing approach for environmental noise supervision considering spatio-temporal data for enhanced living environments. On the other hand, the proposed mobile application provides a quick, easy, and intuitive access of the noise monitoring data to the end user. In this way, the user not only can carry the environmental noise data with him for everyday use, but also can contribute by collecting real-time noise data from their environment to a global network which will be used to create efficient and effective noise maps.

Environmental noise pollution control and monitoring policies should be adopted for enhanced living environments. A people's willingness to pay for noise reduction measures study concludes that 80% of respondents were unwilling to pay anything for a noise-control policy [34]. Therefore, cost-effective solutions for noise mapping should be adopted. Participatory sensing is a low-cost approach and can be used to create an effective database with structured spatio-temporal noise data that can be analysed by the city manager to support decision-making in the planning of interventions for noise reduction. Using ***iNoiseMapping*** is possible to identify specific locations with unhealthy noise conditions and discuss possible interventions for noise reduction. This mobile crowdsourcing approach can provide spatio-temporal sound data which are particularly relevant to plan interventions in order to promote a healthful and productive living environment in smart cities. Consequently, the ***iNoiseMapping*** is important decision-making tool as this system can not only be used by the city manager authorities to detect unhealthy situations in real-time but also to address behavioural changes to enhance productive environments and wellbeing. On one hand, if several users report unhealthy noise levels in the same area, the city manager can plan inspection activities at the industries and regularly check the sound levels in order to improve the quality of city life. On the other hand, if the noise levels are reported during specific hours of the day and are related to the transportation systems the city manager can plan for changes in traffic flow.

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The Internet of Everything (IoE) concept aims to connect people, data, things, and processes in a global network which used intelligently will provide significant enhancements on the daily lives of human beings, particularly in the smart city context [35]. The ***iNoiseMapping*** allows people to take direct action in the smart city context providing a mobile application to collect environmental sound data and contribute in real-time to the noise mapping creation process for enhanced living environments. Therefore, this mobile application is a useful and cost-effective tool to collect real-time environmental sound data.

As future work, the main goal is to make technical improvements, including the development of important alerts and notifications to inform the city authorities when a specific location is reported with high noise levels. The authors also plan to develop an integrated management Web portal for noise pollution analytics. This portal should allow the municipal authorities to enhanced dashboards about the noise pollution map for enhanced smart cities.

5 Conclusions

Several studies present in the literature advice for noise reduction as this can be assumed as a significant problem for global health. The environmental noise pollution can be related to annoyance, sleep and cognitive performance, raised blood pressure and a risk factor for pregnancy-related hypertension.

Noise maps are created with standard methodologies and are based on specific sources such as road traffic, railway traffic, aircraft and industrial significantly imperfect because the noise emission models and sources are extremely limited.

The resources present in a smartphone as long with participatory sensing allow the creation of a noise mobile application that can be used to provide environmental noise supervision for enhanced living environments in smart cities. The main objective of the presented application is applying crowdsourcing techniques to environmental noise monitoring in order to encourage users to contribute in the data collection process using their personal smartphone. Crowdsourcing techniques applied to environmental noise monitoring can be assumed as a low-cost approach for noise mapping.

The authors conclude that mobile crowdsourcing offers several enhanced features for environmental noise analytics and supervision. The ***iNoiseMapping*** can be used not only to create reliable noise maps but also to identify specific locations with unhealthy noise conditions and discuss possible interventions for noise reductions. Consequently**,** the proposed approach provides direct action in the smart city context to people by providing a method to collect environmental sound data in real-time for enhanced living environments. The collected sound data can be analysed to address interventions for enhanced living in smart cities.

The results obtained are encouraging, on behalf of an important contribution to noise mapping methodologies. Nevertheless, the proposed needs further experimental validation and software improvements to adapt the application to specific cases or problems in smart cities such as traffic noise pollution.

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Software improvements are planned in order to provide notifications to alert the city authorities when a specific location is reported with high noise levels. The creation of a Web portal for noise pollution supervision and analytics is also planned.

In spite of the influence of environmental noise pollution in daily human activities, systems like this will be significant for enhanced living environments. The authors believe that the first step is to create reliable noise maps through crowdsourcing in order to detect unhealthy noise pollution levels in real time and plan interventions for enhanced living environments.

References

[1] E. Murphy and E. A. King, "Principles of Environmental Noise," in *Environmental Noise Pollution*, Elsevier, 2014, pp. 9–49.

[2] A. Caragliu, C. Del Bo, and P. Nijkamp, "Smart Cities in Europe," *Journal of Urban Technology*, vol. 18, no. 2, pp. 65–82, Apr. 2011.

[3] H. Schaffers, N. Komninos, M. Pallot, B. Trousse, M. Nilsson, and A. Oliveira, "Smart Cities and the Future Internet: Towards Cooperation Frameworks for Open Innovation," in *The Future Internet*, vol. 6656, J. Domingue, A. Galis, A. Gavras, T. Zahariadis, D. Lambert, F. Cleary, P. Daras, S. Krco, H. Müller, M.-S. Li, H. Schaffers, V. Lotz, F. Alvarez, B. Stiller, S. Karnouskos, S. Avessta, and M. Nilsson, Eds. Berlin, Heidelberg: Springer Berlin Heidelberg, 2011, pp. 431–446.

[4] H. Chourabi *et al.*, "Understanding Smart Cities: An Integrative Framework," in *2012 45th Hawaii International Conference on System Sciences*, Maui, HI, USA, 2012, pp. 2289–2297.

[5] M. Batty *et al.*, "Smart cities of the future," *The European Physical Journal Special Topics*, vol. 214, no. 1, pp. 481–518, Nov. 2012.

[6] S. Kephalopoulos, M. Paviotti, F. Anfosso-Lédée, D. Van Maercke, S. Shilton, and N. Jones, "Advances in the development of common noise assessment methods in Europe: The CNOSSOS-EU framework for strategic environmental noise mapping," *Science of The Total Environment*, vol. 482–483, pp. 400–410, Jun. 2014.

[7] J. Picaut, N. Fortin, E. Bocher, G. Petit, P. Aumond, and G. Guillaume, "An open-science crowdsourcing approach for producing community noise maps using smartphones," *Building and Environment*, vol. 148, pp. 20–33, Jan. 2019.

[8] E. Estellés-Arolas and F. González-Ladrón-de-Guevara, "Towards an integrated crowdsourcing definition," *Journal of Information Science*, vol. 38, no. 2, pp. 189–200, Apr. 2012.

[9] A. Anjum and M. U. Ilyas, "Activity recognition using smartphone sensors," in *Consumer Communications and Networking Conference (CCNC), 2013 IEEE*, 2013, pp. 914–919.

[10] M. Shoaib, H. Scholten, and P. J. M. Havinga, "Towards Physical Activity Recognition Using Smartphone Sensors," in *Ubiquitous Intelligence and Computing, 2013 IEEE 10th International Conference on and 10th International Conference on Autonomic and Trusted Computing (UIC/ATC)*, 2013, pp. 80–87.

[11] J. Lloret, A. Canovas, S. Sendra, and L. Parra, "A smart communication architecture for ambient assisted living," *Communications Magazine, IEEE*, vol. 53, no. 1, pp. 26–33, Jan. 2015.

ICCS Camera Ready Version 2019
To cite this paper please use the final published version:
DOI: 10.1007/978-3-030-22744-9_52

[12] J. A. Burke *et al.*, "Participatory sensing," presented at the Workshop on World-Sensor-Web (WSW): Mobile Device Centric Sensor Networks and Applications, 2006.

[13] S. A. Stansfeld and M. P. Matheson, "Noise pollution: non-auditory effects on health," *British Medical Bulletin*, vol. 68, no. 1, pp. 243–257, Dec. 2003.

[14] N. Auger, M. Duplaix, M. Bilodeau-Bertrand, E. Lo, and A. Smargiassi, "Environmental noise pollution and risk of preeclampsia," *Environmental Pollution*, vol. 239, pp. 599–606, Aug. 2018.

[15] M. Foraster *et al.*, "Exposure to Road, Railway, and Aircraft Noise and Arterial Stiffness in the SAPALDIA Study: Annual Average Noise Levels and Temporal Noise Characteristics," *Environmental Health Perspectives*, vol. 125, no. 9, p. 097004, Sep. 2017.

[16] A. Gupta, A. Gupta, K. Jain, and S. Gupta, "Noise Pollution and Impact on Children Health," *The Indian Journal of Pediatrics*, vol. 85, no. 4, pp. 300–306, Apr. 2018.

[17] J. S. Christensen, D. Hjortebjerg, O. Raaschou-Nielsen, M. Ketzel, T. I. A. Sørensen, and M. Sørensen, "Pregnancy and childhood exposure to residential traffic noise and overweight at 7 years of age," *Environment International*, vol. 94, pp. 170–176, Sep. 2016.

[18] E. Murphy and E. A. King, "An assessment of residential exposure to environmental noise at a shipping port," *Environment International*, vol. 63, pp. 207–215, Feb. 2014.

[19] A. Zanella, N. Bui, A. Castellani, L. Vangelista, and M. Zorzi, "Internet of Things for Smart Cities," *IEEE Internet of Things Journal*, vol. 1, no. 1, pp. 22–32, Feb. 2014.

[20] E. Murphy and E. A. King, "Environmental Noise and Health," in *Environmental Noise Pollution*, Elsevier, 2014, pp. 51–80.

[21] S. Stansfeld, "Noise Effects on Health in the Context of Air Pollution Exposure," *International Journal of Environmental Research and Public Health*, vol. 12, no. 10, pp. 12735–12760, Oct. 2015.

[22] P. Lercher, "Noise in Cities: Urban and Transport Planning Determinants and Health in Cities," in *Integrating Human Health into Urban and Transport Planning*, M. Nieuwenhuijsen and H. Khreis, Eds. Cham: Springer International Publishing, 2019, pp. 443–481.

[23] M. Stevens and E. D'Hondt, "Crowdsourcing of Pollution Data using Smartphones," in *Workshop on Ubiquitous Crowdsourcing, held at Ubicomp '10 (September 26-29, 2010, Copenhagen, Denmark)*, 2010.

[24] I. G. Martí *et al.*, "Mobile Application for Noise Pollution Monitoring through Gamification Techniques," in *Entertainment Computing - ICEC 2012*, vol. 7522, M. Herrlich, R. Malaka, and M. Masuch, Eds. Berlin, Heidelberg: Springer Berlin Heidelberg, 2012, pp. 562–571.

[25] R. K. Rana, C. T. Chou, S. S. Kanhere, N. Bulusu, and W. Hu, "Ear-phone: an end-to-end participatory urban noise mapping system," in *Proceedings of the 9th ACM/IEEE International Conference on Information Processing in Sensor Networks - IPSN '10*, Stockholm, Sweden, 2010, p. 105.

[26] S. Hachem *et al.*, "Monitoring Noise Pollution Using the Urban Civics Middleware," in *2015 IEEE First International Conference on Big Data Computing Service and Applications*, Redwood City, CA, USA, 2015, pp. 52–61.

[27] A. J. Mashhadi and L. Capra, "Quality control for real-time ubiquitous crowdsourcing," in *Proceedings of the 2nd international workshop on Ubiquitous crowdsouring - UbiCrowd '11*, Beijing, China, 2011, p. 5.

ICCS Camera Ready Version 2019
To cite this paper please use the final published version:
DOI: 10.1007/978-3-030-22744-9_52

[28] M.-C. Yuen, I. King, and K.-S. Leung, "A Survey of Crowdsourcing Systems," in *2011 IEEE Third Int'l Conference on Privacy, Security, Risk and Trust and 2011 IEEE Third Int'l Conference on Social Computing*, Boston, MA, USA, 2011, pp. 766–773.

[29] E. Murphy and E. A. King, "Testing the accuracy of smartphones and sound level meter applications for measuring environmental noise," *Applied Acoustics*, vol. 106, pp. 16–22, May 2016.

[30] H. Müller, J. L. Gove, J. S. Webb, and A. Cheang, "Understanding and Comparing Smartphone and Tablet Use: Insights from a Large-Scale Diary Study," in *Proceedings of the Annual Meeting of the Australian Special Interest Group for Computer Human Interaction*, 2015, pp. 427–436.

[31] A. J. A. M. van Deursen, C. L. Bolle, S. M. Hegner, and P. A. M. Kommers, "Modeling habitual and addictive smartphone behavior," *Computers in Human Behavior*, vol. 45, pp. 411–420, Apr. 2015.

[32] C. Montag *et al.*, "Smartphone usage in the 21st century: who is active on WhatsApp?," *BMC Research Notes*, vol. 8, no. 1, Dec. 2015.

[33] C. Pearson and Z. Hussain, "Smartphone Use, Addiction, Narcissism, and Personality:: A Mixed Methods Investigation," *International Journal of Cyber Behavior, Psychology and Learning*, vol. 5, no. 1, pp. 17–32, 2015.

[34] S.-Y. Huh and J. Shin, "Economic valuation of noise pollution control policy: does the type of noise matter?," *Environmental Science and Pollution Research*, Sep. 2018.

[35] G. Marques, "Ambient Assisted Living and Internet of Things," in *Harnessing the Internet of Everything (IoE) for Accelerated Innovation Opportunities*, P. J. S. Cardoso, J. Monteiro, J. Semião, and J. M. F. Rodrigues, Eds. Hershey, PA, USA: IGI Global, 2019, pp. 100–115.

ICCS Camera Ready Version 2019
To cite this paper please use the final published version:
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