TOWARDS AN EXTENSIVE NOISE AND AIR QUALITY MEASUREMENT NETWORK

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Abstract
This paper presents ongoing research of the IDEA (Intelligent, Distributed, Environmental assessment) project. The aim is to build an extensive multi-sensor urban measurement network. The focus is on noise and air pollution caused by road traffic. The use of cheap sensors is an important prerequisite to come to implementation of such a network. The potentially lower data quality resulting from the use of cheaper sensors should then be overcome by adding intelligence to the network at various levels. A flexible network architecture was designed for the specific aims of the IDEA project. Two noise-related aspects are dealt with in more detail in this paper. Firstly, results from indoor and outdoor testing of different types of microphones are shown. Secondly, the estimation of pollutant concentrations based on noise measurements is proposed to help interpolating expensive-to-measure air pollutants.

Keywords: Measurement network, road traffic noise, air pollution, microphones.

1 Introduction

Exposure of people to traffic-induced noise and air pollution in an urban environment is a major health concern. Recent studies showed that there is evidence that the simultaneous exposure to both high noise levels and high air pollutant concentrations aggravate this health impact [1].

In contrast to modeling approaches, measurements are most often perceived as more convincing by the public at large and governments. Furthermore, measurements do not suffer from modeling restrictions or idealized boundary conditions.

In recent years, the so-called Ultra Fine Particles (UFP, which are particles with a diameter of less than 0.1 µm) have attracted increased attention for being potentially more toxic than their larger counterpart [2]. Just like noise, these particles have a very local character. This has important consequences for the measurement network. To sufficiently capture the spatial and temporal variation, a large amount of sensor nodes is needed.

A main goal of the IDEA (Intelligent, Distributed, Environmental Assessment) project is the development of an extensive noise and air pollution measurement network. For such a network to be applicable, low-cost sensors are needed. Therefore, an important focus in IDEA is getting experience with the use of cheaper and thus less accurate sensors. However, by adding intelligence to the network, the use of a large number of cheap sensors should not lead to significant quality loss of the global measured data.

Related and recent environmental measurement networks with interest in noise are e.g. the MESSAGE project [3] and DREAMSys [4].

2 Adding intelligence to the network

In IDEA, intelligence will be added to the network at different levels. In a first stage, it should help keeping the measurement network operational. An important task will be an early and automatic identification of bad sensors. This task is not trivial, since very high or low sensor readings could either indicate periods with strong or no pollution, but also bad sensor behavior. Such analyses could be based on time series at a single sensor, or by cross-checking with nearby sensors. It is expected that good-quality equipment at a few nodes might strongly improve the overall quality of the measurements.

In a second stage, the availability of both noise levels and air pollutant concentrations should help e.g. interpolation of data in between nodes. Although IDEA aims at a dense urban network, such interpolation techniques will still be needed in practice. The noise levels produced by road traffic at street level are strongly emission-driven, while air pollutant dynamics are much more complicated. There, one has to deal with complex meteorological influences, leading to dispersion, accumulation, and chemical conversion. A good starting point for such interpolation could be the use of traffic data as an approach for the underlying structure of the urban road traffic sources network. Various interpolation techniques will be investigated in the IDEA project. Care is however needed that the results that come out of the network will be strongly based on actual measurements.

At a higher level, intelligence opens the way to various applications and helps making decisions. These applications of the IDEA network go beyond simply presenting measured data. Source recognition of strong polluters is one of the interests. Acoustical data is well-suited to do this task. Various artificial intelligence techniques will be evaluated. Furthermore, IDEA could lead to traffic steering applications. In contrast to already implemented systems in cities all over the world, this could be achieved with IDEA based on the actual state of the (very local) environment. Other applications could be related to public safety like quick detection of gas leaks, car accidents, etc.

3 Network aspects

In order to fulfill the goals of IDEA, a flexible network architecture was designed. Distributed computing (load balancing) is an important aspect, since computational power is needed at various locations within the network.

At each sensor node, a Single Board Computer (SBC) is used. These are small CPUs with minimal computing power, though equipped with e.g. a network card and a sound card. The most demanding task at such SBCs are the noise measurements and the processing to 1/3 octave band levels.

At a higher level, more advanced (computational intelligent) CPUs are used to control a number of sensors and perform more demanding computational tasks like e.g. detecting bad sensors. For even more advanced analyses like source recognition, access to computer grids will be facilitated by the network.

4 Testing cheap microphones

In the last two decades, (cheap) microphones appeared massively in consumer electronics. In IDEA, a number of such microphones of different price categories were extensively tested to evaluate whether such devices could be used as a reliable measurement instrument.

Eight on-shelf and off-shelf microphones were tested, including two high-quality (reference) microphones, a type II microphone and a MEMS microphone. An overview is given in Table 1.

A first series of tests were performed in an anechoic chamber. The criteria of interest were the noise floor, saturation at 100 dB, linearity and a flat frequency response. Saturation at 100 dB was not observed at any microphone. The noise floor differs significantly among the tested devices. For a 1 kHz pure tone, the noise floors ranged from 13 dB till 41 dB. The sensitivity of the microphones differs. Therefore, an adequate amplification of the sound card was set.

The two reference microphones had a flat frequency response over the audible region. Some microphones were sufficiently flat up to a few kHz, while others deviated significantly from an equal sensitivity at different frequencies. Linearity is usually observed – the same deviations from the flat response are found at various levels. This means that easy compensation is possible.

In the outdoor test, all microphones were attached next to each other on a horizontal bar on the roof of a building, with direct view to a busy viaduct. If not available by the manufacturer, self-fabricated rain and wind protection was provided. The experiment started at the beginning of winter 2009, and is still active. The past winter period was characterized by long periods of freezing temperatures, high relative humidity, and periods with snow and intense rainfall. The basic logging consisted of 1-s equivalent sound pressure levels, expressed in 1/3 octave bands. An outdoor loudspeaker was placed in front of the microphones to emit test signals to evaluate microphone behavior over the full audible region

Table 1 – Overview of some properties of the tested microphones.

ID	**Type**	**Membrane diameter**	**Cost**	**Indoor test**: Noise floor at 1 kHz	**Outdoor test:** 1-month average deviation from REF1 (February 2010, based on $L_{eq,1h}$)
ELECTRET1	Electret	< 1/8"	3 €	35 dB	0.9 dBA
ELECTRET2	Electret	< 1/8"	3 €	41 dB	*failed*
ELECTRET3	Electret	< 1/8"	30 €	32 dB	*failed*
ELECTRET4	Electret	< 1/8"	50 €	36 dB	0.6 dBA
MEMS1	MEMS	< 1/8"	30 €	23 dB	1.5 dBA
TYPEII	Electret (including preamplifier and outdoor unit)	1/4"	300 €	15 dB	0.7 dBA
REF1	Electret (including preamplifier)	1/2"	2000 €	15 dB	0 dBA
REF2	Electret (including preamplifier)	1/2"	2000 €	13 dB	0.2 dBA

In Table 1, the 1-month average deviations, relative to the reference microphone, for hourly aggregated equivalent levels is given. Two microphones of less than 50 € were identified to give errors of less than 1 dBA. Furthermore, especially the 50 € microphone has a reasonable constant behavior over time. Note that the minimum difference that could be achieved is 0.2 dBA (which is the difference between the two reference microphones on the test bar). As a conclusion, it can be stated that low-cost microphones can accurately measure environmental noise.

5 Correlation between noise and air pollution

Although measuring UFP is of importance, cheap sensors are unlikely to be found in the near future. As a fallback, it is studied to what extent proxies can be used. The basic idea behind the use of proxies is that the same dominant source, namely road traffic, results in high noise levels and air pollutant emissions. The propagation from source to receivers is however different. For air pollutants, one has to deal with complex meteorological influences, having significant effect on dispersion and accumulation, and with chemical conversion.

To gather insight in the correlation between noise and air pollution, simultaneous measurements were performed at various locations along streets in dense urban settings. A few measurement locations were selected and equipped with high-quality noise equipment and a wide range of high-quality air pollutant sensors, including UFP monitors. Measurements were performed during periods of one month, in both winter and summer period, for different traffic situations. These detailed measurements allowed checking correlations between different air pollutant concentrations and between noise levels and air pollutant concentrations.

A number of studies looked at the correlation between noise levels and air pollutants [5][6]. In the current study, not only A-weighted equivalent sound levels are used, but also statistical levels and spectral information. It was further observed that the common A-weighting often leads to smaller correlations compared to non-weighted levels.

In Table 2, the 15-minute averaged correlation coefficients between NO_x (gas pollutant) concentrations or different noise indicators, and UFP counts are presented. Measurements during 4 weeks at a single measurement location (urban street canyon) were considered. Different ranges for UFP sizes were separately considered, together with the total particle number. Meteorological influences have an important influence on UFP dynamics. Therefore, a simple grouping method was considered, by building 4 groups made of low and high wind speed values, and low and high humidity values. Within these groups, more similar dynamics allowed to achieve a better correlation between the particulate pollutants and noise or NO_x. It is observed in Table 2 that noise indicators allow for correlations with UFP that are often comparable to NO_x.

Table 2 – 15-minute average correlation coefficients between NO_x or noise indicators and UFP (number per m^3) in an urban street canyon (based on 4 weeks of measurements).

	UFP [20-30nm]	UFP [30-50nm]	UFP [50-70nm]	UFP [70-100nm]	UFP [100-200nm]	UFP [200-500nm]	Total particle number
NO_x	0.37	0.49	0.50	0.53	0.47	0.25	0.67
L_{Aeq}	0.41	0.38	0.38	0.36	0.36	0.17	0.52
L_{50}	0.42	0.41	0.41	0.41	0.39	0.18	0.56
L_{50} & $L_{2kHz\text{-}125Hz}$	0.43	0.42	0.43	0.41	0.40	0.20	0.57

The correlations presented in Table 2 are often limited. However, in light of the low complexity of the employed linear correlation technique, it is clear that there is potential in using proxies to interpolate air pollutant concentrations in between measurement nodes. Noise data is able to give similar correlation coefficients in some UFP size ranges as NO_x. This is especially interesting, given the fact that very cheap but still accurate microphones were identified. However, using local correlation coefficients might be needed. This topic will be further investigated.

6 Conclusions

In this paper, the basic concepts of the IDEA project are presented. The measurement network must be equipped with cheap sensors. Intelligence is needed at various levels, from making the network operational, to decision making. To fulfill the goals of IDEA, distributed computing is needed. Two noise-related aspects of IDEA were discussed in more detail. The search of low-cost microphones was shown to be successful, based on detailed indoor and outdoor testing. The measurement campaigns indicated that there is potential to approach expensive-to-measure air pollutants with low-cost sensors.

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