MADRID
inter.noise 2019
June 16 - 19
NOISE CONTROL FOR A BETTER ENVIRONMENT

Application of Internet of Things technology for sound monitoring during large scale outdoor events

Haddad, Karim[1]
Brüel & Kjaer
Skodsborgvej 307, 2850 Naerum, Denmark

Munoz, Patricio[2]
Acoucité
24 rue Saint-Michel, 69007 Lyon, France

Gallo, Enrico[3]
Comune di Torino
via Padova 29, 10152 Torino, Italy

Vincent, Bruno[4]
Acoucité

Song, Min-Ho[5]
Acoustic Technology Group, Department of Electrical Engineering
Technical University of Denmark
Ørsteds Plads, Bygning 352, 2800 Kgs. Lyngby, Denmark

ABSTRACT

The European project MONICA aims at using IoT technology to help monitoring large outdoor events. The monitoring concerns the security using different types of sensors on one hand, and the sound impact to neighborhood on the other hand, using sound level meters. For this paper, we focus on the acoustic part. MONICA has started beginning of 2017. At Internoise 2018, we presented the concept of the project. During the year 2018, the project has been tested during different outdoor events in Europe. In this paper, we present the outcomes of some of these tests: during Kappa FuturFestival, during Movida, both in Torino, Italy and during Fêtes des Lumières in Lyon, France. During these events, the IoT sound level meters were tested at different locations: close to the sources, and in the neighborhood to estimate the sound impact. In order to reduce noise to surroundings, the Adaptive Sound Field Controller (ASFC) has been also tested during the year. The implementation and the setup of the system is presented.

Keywords: Environment, Sound Monitoring, Internet of Things (IoT)
I-INCE Classification of Subject Number: 52

[1] karim.haddad@bksv.com
[2] patricio.munoz@acoucite.org
[3] enrico.gallo@comune.torino.it
[4] bruno.vincent@acoucite.org
[5] minson@elektro.dtu.dk

1. INTRODUCTION

Monitoring large outdoor events represents a challenge, in terms of security but also for the environment. The purpose of the MONICA (Management Of Networked IoT Wearables – Very Large Scale Demonstration of Cultural Societal Applications) project is to help organisers and city authorities to monitor such events for security and environmental purposes. More specifically the project aims at promoting the use of the Internet of Things (IoT) related technologies to improve the monitoring of such large events. In this paper, we focus only on the sound monitoring aspect. Different types of sensors are used within the project, but for sound monitoring and possibly sound control, we are considering Sound Level Meters (SLMs) transmitting in real time different types of levels and sound metrics using the telecommunication network. More information on the MONICA project is provided in [1].

After one year of the project (end of 2017), cloud and network infrastructure, as well as the different types of sensors, were ready to be tested during pilot tests. The systems have been tried out during five different types of outdoor events in Europe (concerning only the sound monitoring). Here we present the outcomes of these tests for three pilots: Kappa FuturFestival in July 2018, MOVIDA in October 2018, both at Torino, Italy, and the last one: Fête des Lumières at Lyon, France. These tests helped to look at the strong and week points of the systems, for improving the systems before future pilot tests during the last year of the project in 2019.

Additionally, to sound monitoring based on SLMs, we present the Adaptive Sound Field Controller (ASFC) implementation, aiming a reducing the noise impact at a selected zone. This system has been tested in Copenhagen and evaluated during the Kappa FuturFestival.

In the next section, we describe the acoustic systems: the SLMs and the ASFC. This is followed by the description of the different pilot tests, as well as the outcomes. Finally, in conclusion we will mention the perspectives for the last year of the project.

2. ACOUSTIC SYSTEMS

2.1 The sound Level Meters

A sound measuring unit is made of a sound level meter, a device to connect to a communication network (either WIFI or 3G/4G) and a powerbank to charge these devices. All these elements are within a casing to withstand rain. The microphone emerges from the casing and is protected by a windscreen. In this paper, we call this unit a Sound Level Meter (or SLM). Figure 1 shows a Sound Level Meter.

Figure 1: A Sound Level Meter

The SLM contains a GPS receiver as well, which provides the current location of the device, but also which enables the possibility to perform synchronous measurements with other SLMs.

The Sound Level Meter data are transmitted to the SLM gateway, which takes care of local buffering, data analysis/reduction and communication with the MONICA Cloud (see [1]). From the cloud, levels and specific noise metrics can be visualized and analyzed through a web-based interface called the Common Operational Picture (COP), see Figure 2.

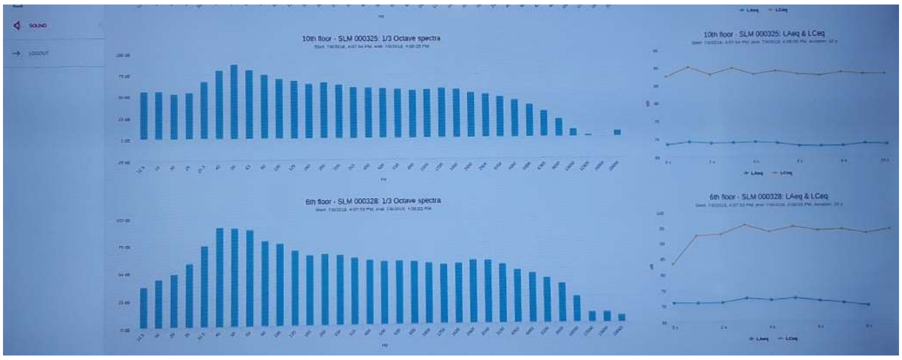

Figure 2: Levels and spectra in the COP

The types of data transmitted to the MONICA cloud depends on the test pilot requirements. In all cases, Laeq (A-weighting Sound Pressure Level), Lceq (C-weighting Sound Pressure Level) and spectrum (without weighting) for every second are sent. Other types of data are also sent, if requested: averaged levels over a pre-defined duration (other than one second), Contribution analysis, Annoyance Likelihood Index, and event detection. These three last quantities are described below.

Contribution analysis

The contribution analysis estimates the level contribution of a source at some remote distance. For our scenarios, we want to calculate the contribution of the concert place to residential area. Using a SLM in a residential area is not enough to get such estimate, since other sources of noise influence the noise level, such as passing cars, human activities... Therefore, the purpose of this analysis is to extract the part of the noise originated from the venue. To do so, we have chosen to estimate the transfer function from the concert place to the residential area. This requires synchronous measurements between the SLMs. Based on the transfer function, we can then estimate the contribution.

Annoyance Likelihood Index

The analysis of acoustic measurements carried on outdoor festivals (Nuits Sonores, Kappa Futur Festival, Festival of Lights and Woodstower) showed that sound emissions at these events have a big amount of energy within the low frequency range (i.e.: from 30 Hz to 250 Hz). In addition to that, results from annoyance survey carried out for the Kappa FuturFestival in July 2018 (number of respondents: 156) and Woodstower 2018 (number of respondents: 338) revealed that:

• Annoyance is associated with noise for more than half of the respondents.
• There is a predominance of low frequencies in the emergence of this discomfort.

Thus, both subjective and physical assessments conclude on the importance of low frequencies in the expressed noise annoyance of outdoor large-scale events. Following these observations, a review of the state-of-the-art was conducted mainly focused on annoyance and low frequency noise [2]. The main findings of this review are:

• Noise annoyance depends on multiple factors. Acoustical dimension being one of them.

• A high inter-individual variability is observed on expressed annoyance of subjects under the same acoustic stimulus.

• Assessment of annoyance based on acoustical measurement can bring to light the main tendencies of community annoyance, but it cannot be used as a reliable predictor of individual annoyance.

• Conventional methods of assessing annoyance, typically based on A-weighted equivalent level, are inadequate for low frequency noise and lead to incorrect decisions by regulatory authorities.

• A-weighted level underestimates the effects of low frequency noises.

• Annoyance of low frequencies increases rapidly with level.

• Loudness, and particularly loudness percentile N5 (loudness which is exceeded the 5% of the time of observation) can be used for describing time varying sounds (take into account of fluctuations).

In order to take into account the aspects previously described, it was decided to investigate loudness (Zwicker method according to [3]) of a set of sound recordings of festivals (recorded in audience and neighbour areas) and its correlation with C-weighted sound pressure levels recorded every second. C-weighted sound pressure levels and loudness showed a good correlation (R2>0.75). Even if loudness can provide a most precise description of the acoustical phenomenon in terms of sensorial response, C-weighted values are less time consuming and can be found on most part of sound level meters.

An annoyance index was thus proposed, build on three main rules:

• Easy to understand: linear scale from 0 to 10 (where 0 means "no annoyance" and 10 means "maximum annoyance")
• Based on C-weighted sound pressure levels
• Comparison between sound levels during the event (contribution of event at receiver point in terms of L_{Ceq},1 minute) and without the event (L_{C90} hourly from measurements before the event at receiver point during an equivalent time period)

The proposed annoyance index was tested with measurement performed during festivals in 2018 (Nuits Sonores, Kappa Futur Festival and Woodstower) with coherent results. However, as noticed in the state-of-the-art, noise annoyance is highly subject to inter-individual variability, so the annoyance index could preferably be named as "Annoyance Likelihood Index".

Event Detection

As mentioned in the introduction, a large part of the project is dedicated to the security. The analysis of sound recordings could possibly help to detect dangerous situations, such as gunshots. The selected approach is based on machine learning: a large set of gunshot (for example) audio samples is used to train a classifier after features extraction. During operation, the audio samples recorded by the SLMs are used as input to the trained classifier. If a gunshot is detected, an alarm is raised.

The Event detector is currently being implemented, and therefore has not been yet tested in the field.

2.2 The Adaptive Sound Field Control system

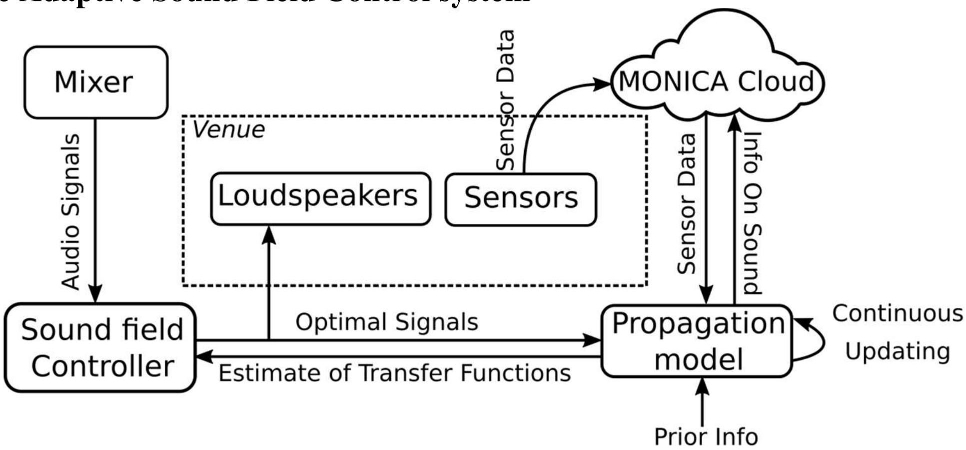

Figure 3: Information flow of MONICA Adaptive Sound Field Controller

General Description of the system

The role of Adaptive Sound Field Controller (ASFC) is to reduce the sound impact to a neighborhood where the sound event is held (we called this region as a dark zone). The ASFC is composed of a physical Sound Field Controller (system) with other modules which enables the adaptive feature to the controller (Figure 3). The physical system is basically a loudspeaker array system that is widely used in a multichannel audio system or concert Public Address (PA) system. It can play many loudspeakers independently with multichannel convolution to make a desired effect or sound. However, there are two main differences with a conventional array system.

First, the loudspeakers of MONICA ASFC are added to the main PA system (Mixer module in Figure 3) that is already installed for the outdoor sound event. It means that the PA system is already optimized by sound engineers of the venue to give the best audience experience thus should remain independent from ASFC control not to affect the sound quality in the audience area. Due to this partial controllability, ASFC requires accurate PA signal monitoring in real time. Also, the control algorithm is modified in order to overcome the partial controllability [4].

Second, the control loudspeakers of ASFC (the secondary array) is placed between the audience area and the dark zone, therefore the distance from the main PA system to the secondary array can be quiet far up to few hundreds of meters requiring massive long-distance audio cables. To overcome this problem, the system is implemented using DANTE (Digital Audio Network Through Ethernet) protocol.

Monitoring of PA signal

The ASFC requires monitoring the audio signal from the mixer in order to generate the optimal signal. The monitoring of the main PA signal is done in two ways. One is dry-output monitoring, the signal can be monitored from the mixer outputs that fed into amplifiers connected to the loudspeakers of the PA system. It is important to note that the signal output from the PA system can be different from the PA mixing console output. These signals are easy to monitor but do not reflect the signal change occurred in the amplifier stage. Generally, these end-stage amplifiers are equipped with PEQ, crossover, filters, delay and limiter functions which cannot be monitored from the mixer output. To overcome this problem, a device that can monitor the wet-output from the amplifier is used. This device (called Sniffer) is basically a signal splitter with voltage divider that can be fed high-power signal into the analog inputs of the ASFC audio interface. This device can monitor accurate PA signals including the effect from the PA amplifiers. If there is no possibility of change in PA signal chain during the event, the former approach can be practical but if not, the final node after the PA amplifier should be monitored.

Control of secondary array

The DANTE protocol was used for connecting ASFC components because the distances between ASFC components can be very long compared to the standard audio device setup. To ensure the reliable signal transmission over several hundreds of meters, signal routing over Ethernet cable is the most suitable approach. ASFC requires monitoring a high number of PA channels, but this can be easily done when the DANTE protocol is used. Once the signals are on the DANTE network using any DANTE-enabled device, now they are ready to be controlled.

3. PILOT TESTS

3.1 Kappa FuturFestival

Kappa FuturFestival, organized by Movement, is the first dance Italian summer festival and has been selected as large-scale event of the MONICA project for both security and sound issues. Dedicated to electronic and techno music, it takes place every year in Turin with two full days of concerts from midday to midnight in Parco Dora, which has recently completed the overall urban transformation of the area.

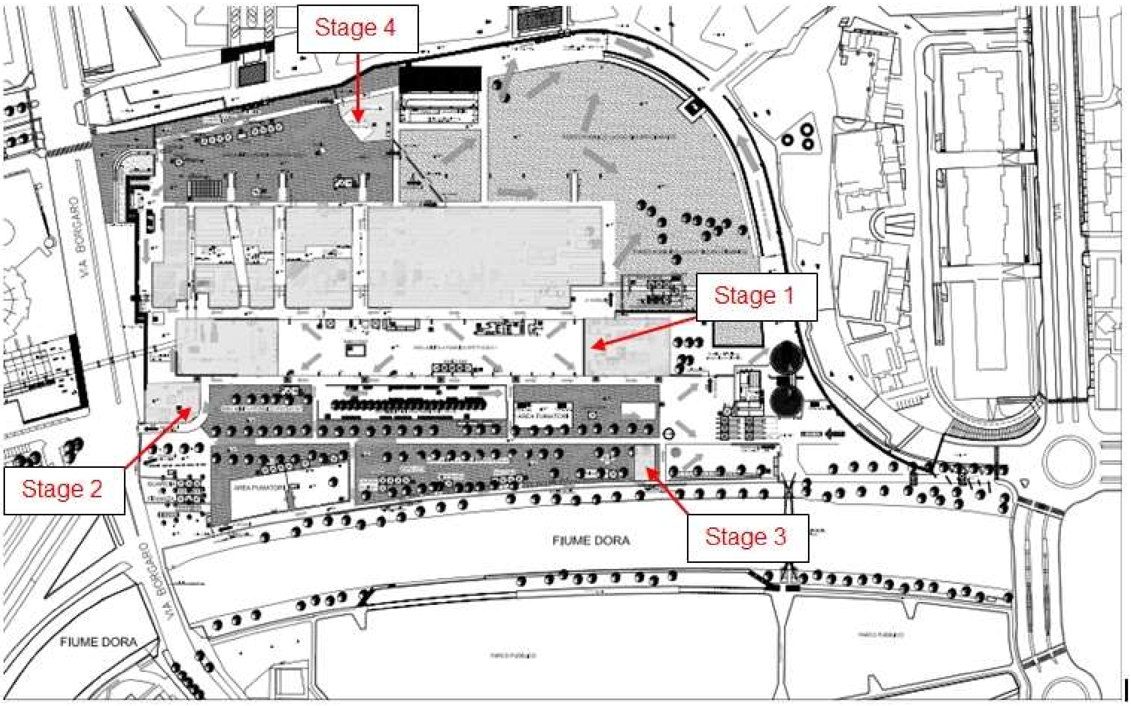

Figure 4: Parco Dora map and stage locations

Focusing on noise impact, low frequencies are pointed out by the neighbourhood as the main reason of annoyance, together with excessive levels during some performances.

The 2018 Kappa FuturFestival, with its 50000 participants and four stages (see Figure 4), held in July 7^{th} and 8^{th} was the first demonstration of the MONICA project providing the Adaptive Sound Field Control and a real time monitoring both at each stage and at dwellings.

The monitoring network deployment during 2018 event was made of nine IoT SLMs. In addition, seven traditional class 1 were installed: one by Movement, two by Acoucité and four by City of Torino (for control of legal limits stated by the sound permit), see Figure 5.

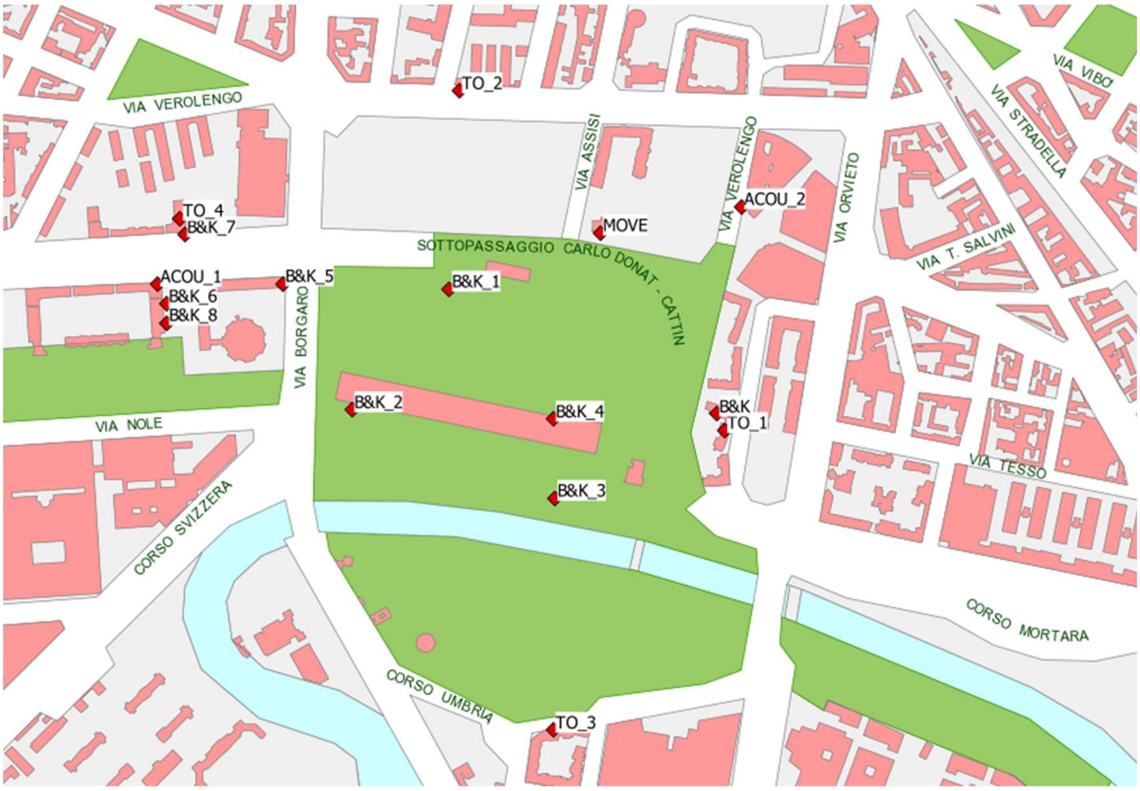

Figure 5: Sound Level Meters deployment during Kappa FuturFestival

Each stage was monitored by an IoT SLM; other four have been used in order to monitor the effectiveness of the Adaptive Sound Field Control.

The last IoT SLM was placed on the façade of the most exposed dwelling, where low frequencies have had the most relevant impact in the previous editions and the effect of an end-fire setup of subwoofers provided by Movement was provided.

This large deployment of SLMs provided a complete noise monitoring in all relevant directions around the four stages.

Considering IoT SLMs, overall SPL values in dBA and dBC plus 1/3 octave band SPL spectra were collected and transmitted each second to the MONICA IoT cloud platform; a certain data loss affected data transmission, using both WiFi and 4G connection during the demonstration.

Real-time monitoring was displayed by the COP, getting data each second. This solution wasn't considered the best option in order to provide effective feedbacks to sound engineers, suggesting that a moving window on 1-5 minutes could be a best option for the following demonstrations.

ASFC setup

Figure 6 gives an overview of the venue, the setup of loudspeakers and the microphone positions in and around a part of the festival area that spans around 300 m.

The primary source (the subwoofer system, used in Stage 4, the blue dot in Figure 6) comprised 20 cardioid subwoofers in a digitally curved line array configuration. The secondary source array consisted out of 16 subwoofers of the same type arranged in a single line with 2.55 m spacing (center-center) and facing the negative x-direction.

The dark zone was defined as the area between x = −100 m and x = 0 m. It was sampled at 20 microphone positions in an elevated courtyard and 30 positions on a rooftop. After measurement of the transfer-functions from all sources to all microphone positions, a set of control filters was computed, and the regularization parameter was chosen by hand such that the gain of the control filters was not overly extreme.

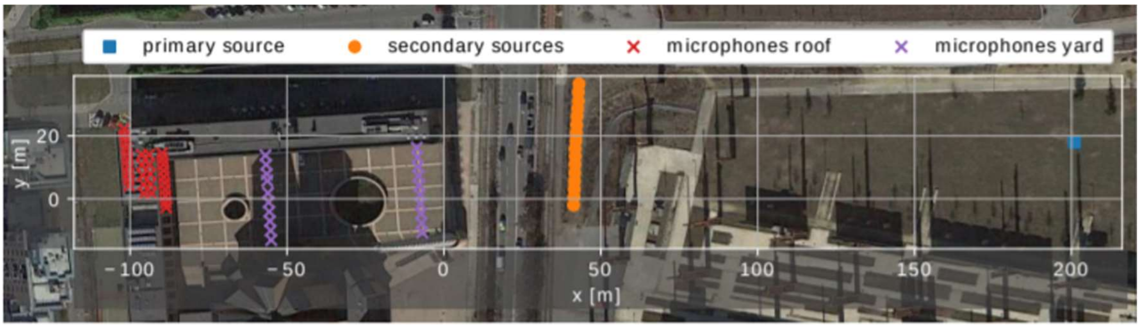

Figure 6: PA loudspeaker and the secondary source location at Kappa FuturFestival

Control results

Figure 7 (bottom) shows the measured magnitude response of the sound system with active and inactive secondary sources at the line of microphone positions around x = −10 m and compares them to the prediction (Fig. 7 (Top)). The result shows the noise reduction up to about 5 dB over 20-100Hz frequency band. For a detailed result, please see [4].

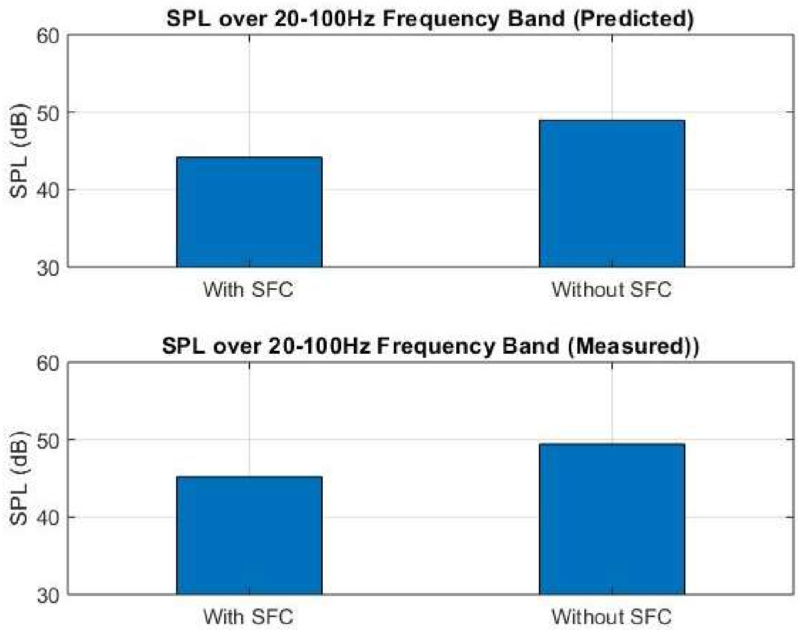

Figure 7: Noise reduction result from Kappa FuturFestival 2018.

.

3.2 MOVIDA

San Salvario district is located in Turin, near the central railway station. This residential area is characterized by the grid plan typical of the old neighborhoods of Torino; with about 470 four/five floors buildings with an internal court; about 7300 people live in the area with a surface of 0,26 km^2.

Starting from the 90s, the nightlife grew in this city district due to a lot of pubs, low-cost bars, restaurants, liquor stores and wine cellars: these activities stay open until late. The nightlife in San Salvario, known as “Movida”, has its hot spots in Largo Saluzzo and Via Baretti, where crowds gradually increase, from the areas in front of bars until occupying all public spaces, thus causing high levels of noise.

City of Torino, proposed “Movida” as large scale event of the MONICA project and during the 2018 edition a demonstration has been carried out.

In addition to crowd analysis using IoT cameras and WiFi scanners, the City decided to strengthen its knowledge of noise levels in San Salvario district deploying three IoT Sound Level Meters (SLM) class 1 with the low-cost IoT noise monitoring network, see Figure 8.

Figure 8: Sound Level Meters deployment during MOVIDA.

One SLM was deployed in Largo Saluzzo, for long-term monitoring purposes, and the other two on the façades of two dwelling in the noisiest streets.

Overall SPL values in dBA and 1/3 octave band SPL spectra were collected and transmitted each second to the MONICA IoT cloud platform; no relevant data loss was appreciated using 4G connection and during the demonstration, real-time monitoring was displayed by the COP, see Figure 9.

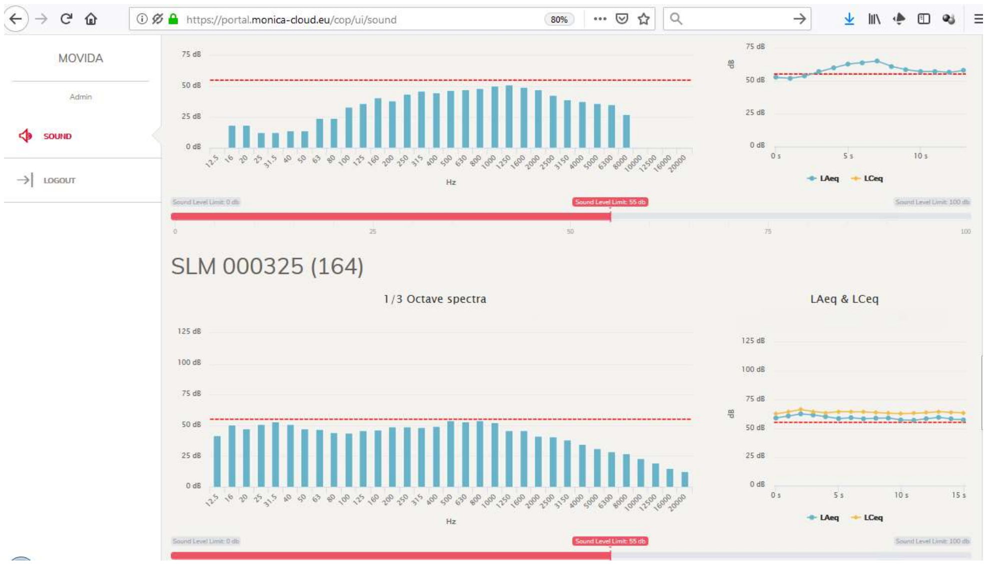

Figure 9: Monitoring of the levels by the COP during MOVIDA

Data collected confirmed the highest noise levels between midnight and 2 AM, and an extra peak due to cleaning service at 3 AM. A great difference could be appreciated comparing levels on Thursday, Friday and Saturday, with Sunday night. This trend is clearly related to the increase of the number of people in the streets and their behavior.

3.3 Fête des Lumières

Every year, during 4 nights near December 8th, the city of Lyon gathers around 1.8 millions of visitors coming from different places in the world to enjoy the beauty of the many lighting installations that cover the city (projections on the facades of emblematic buildings, magical world in the park…).

This large-scale event is one of the pilot events of the MONICA project and during the 2018 edition a demonstration has been carried out. In addition to crowd analysis using IoT cameras, progress in sound monitoring has been tested. For that, 3 IoT Sound Level Meters (SLM) were deployed around Place Saint Jean site in the old town. The first IoT SLM was installed on a building's façade directly exposed to the sound system in Place Saint Jean. This device was transmitting data to the MONICA cloud through a WiFi network. The two remaining devices were installed at receiver points near residential areas (the sound from sound system was diffracted by the first row of buildings before arriving to these 2 devices, see Figure 10). One of those devices was transmitting data to the MONICA cloud through a WiFi network. The second one was using a 4G network.

The objectives of sound monitoring demonstration were:

- Transfer overall SPL values in dBA and dBC
- Transfer 1/3 octave band SPL spectra
- Compute source contribution algorithm and transfer results (first event testing this functionality)
- Compute Annoyance index and transfer results (first event testing this functionality)
- Test transfer using 4G connection on a crowded network

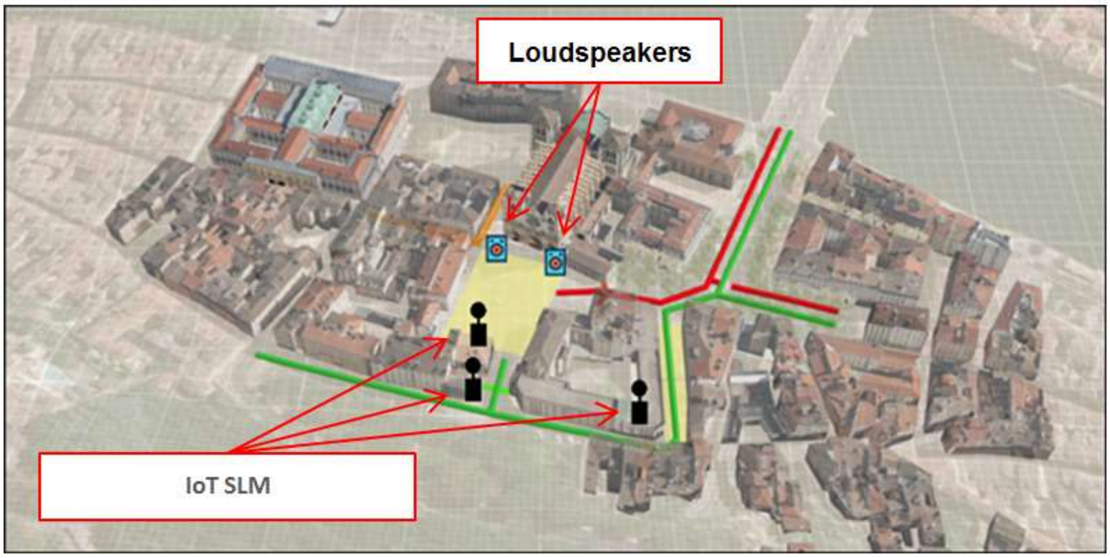

Figure 10: Fête des lumière setup

During this demonstration, the main outcomes were:

- Overall SPL and 1/3 octave band spectra were transmitted to the MONICA cloud. However, periods of missing data were detected. Periods and amount of data loss are different from one IoT SLM to another.
- Source contribution algorithm and Annoyance index (based on results from source contribution) were not transmitted to the MONICA cloud.

Source contribution analysis, tested for the first time, was suspected to create difficulties in terms of data transfer stability on IoT SLM.

4. CONCLUSIONS

During the second year of the MONICA project, the sound monitoring system based on IoT sound level meters, as well as the Adaptive Sound field Control, have been tested during multiple outdoor events. Overall, these tests have proved the feasibility of those systems for realistic scenarios. The transfer of basic data (Laeq, Lceq and spectrum) only from the Sound Level Meters is well handled even in case of large events. But these tests have also shown some issues that need to be reduced for the last year of the project. For the next period, more pilot tests are scheduled. The focus will be on solving these issues and showing the usefulness of such systems to organisers and authorities, for them to monitor and control in real time the sound environment in and around the outdoor event place.

5. ACKNOWLEDGEMENTS

The MONICA project, Management Of Networked IoT Wearables – Very Large Scale Demonstration of Cultural Societal Applications, has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 732350.

6. REFERENCES

1. B. Vincent, K. Haddad, W. Song, E. Gallo, C. Doucet, D. C. Nozal, M. Jahn, *"MONICA, a European project focused on the Internet of Things for the acoustic quality and safety of outdoor large scale events"*, Internoise, Chicago, USA (2018)

2. H.G Leventhall, *"Low Frequency Noise and Annoyance"*, Published in "Noise and Health", Volume 6, April-June 2004

3. International Organization for Standardization (ISO), "*International Standard ISO 532-1, Acoustics-Methods for calculating loudness-Part 1: Zwicker method*", Corrected version, 2017-11.

4. F. M. Heuchel, D. C. Nozal, F. T. Agerkvist, and J. Brunskog. *"Sound field control for reduction of noise from outdoor concerts."* in Proc. 145th Audio Engineering Society Convention, NY, USA. (2018)