Analysis of leisure noise levels and assessment of policies impact in San Salvario district, Torino (Italy), by low-cost IoT noise monitoring network

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Summary
Nightlife activities in open-air create increasing challenges for vibrant cities, in terms of noise pollution and annoyance. City of Torino decided to face strategically this problem by an integrated approach and put in place a low-cost IoT noise monitoring network using several Android smartphones in San Salvario District, where a large number of restaurants, bars, pubs, and clubs attracts each weekend thousands of people spending all evening and night on terraces and streets, enjoying the amenity of this residential historical district. An app for signal processing and data transmission was developed by the Regional Environmental Agency (ARPA Piemonte) and, after a comprehensive set of lab tests for uncertainty evaluations and the definition of a calibration procedure, an on-site deployment started in summer 2016. Hourly data were analyzed after been collected for months in real time by the IoT Open Data platform, leading to a first exposure map for leisure noise and a yearly detailed spectrum of hourly noise levels. This data-driven approach has been chosen to impact on political agenda, on a stronger positive involvement of citizens in focus groups, on local entrepreneurs' engagement, and on patrons' awareness, to start a better adaptation of open-air events to city living. The noise monitoring network allowed measuring the effects of new regulations in summer 2017 and will support the evaluation of the overall effect of new actions for noise reduction planned for 2018, in the framework of the Monica Horizon 2020 Project (http://www.monica-project.eu/).

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1. Introduction

In the last two decades changes in individuals' behaviors, modifications of cities rhythms and investments of Municipalities to revitalize historical city centers led to increasing open-air nightlife activities [1][2][3].
This is true especially in Italy (like others Mediterranean and university cities), where a large number of young people usually meet in residential historic districts, attracted by a high density of restaurants, bars, pubs, and clubs, and spent all night for several days each week chatting and drinking. Often the center of nightlife changes in a few years, following new trends and new commercial initiatives, renewing the need for both citizens and the public administration to find a good balance between amusement, security, and quality of public spaces.
Municipalities are called to face this dynamic phenomenon and its negative externalities, firstly leisure noise, where sources are mostly people with their behaviors in an urban open space [4][5][6][7].
In this paper, the approach of the City of Torino to this complex challenge in the San Salvario district is described, from the deployment of an *ad hoc* sound monitoring network, the collection, and analysis of data, the evaluation of indicators for communication activities to the implementation and monitoring of reduction actions.

2. San Salvario District area

The area of interest is part of the historic district of San Salvario, located near the central railway station and bounded by Vittorio Emanuele II (North), Nizza (West), Madama Cristina (East) and Marconi (South) boulevards.
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 .
The district hosts a daily big open market and offers various commercial activities. Home to an increasing immigrants' community, the district is an example of cultural integration.

2.1 Nightlife "*Movida*" and noise issues

Starting from the 90s, the nightlife grew in this city district thanks to a lot of pubs, low-cost bars, restaurants, liquor stores and wine cellars, boutiques and multi-ethnic shops that have been opened. These activities stay open until late and have completely reshaped the map of city entertainment, known as "*Movida*" [from Spanish: movement, happening].
The nightlife hot spots in San Salvario are in Largo Saluzzo and Via Baretti, where crowds gradually increase, from the areas in front of bars until occupying all public spaces, thus causing huge side effects: noise (chatting, shouting, quarrels), traffic blockages, irregular parking, obstruction of driveways, rubbish on the ground, etc.
The City Administration conducted some spot monitoring campaigns on noise levels in summer time; those measurements revealed that the legal zonal limits (50 dB(A) $L_{eq\ night\ (22\text{-}06)}$ and 55 dB(A) $L_{eq\ 1hour}$ on the façades) where overpassed during the weekend nights, with $L_{eq\ night}$ form 58 dB(A) up to 72 dB(A) and $L_{eq\ 1hour}$ from 64 dB(A) up to 75 dB(A) between 11 PM and 3 AM.
These campaigns pointed a high variability of noise levels in the area when a lot of people meet in narrow streets; they also showed how difficult could be controlling noise levels in open urban spaces.
At the same time, citizens asked for more information and actions to face the noise problems caused by "*Movida*" and they conducted by themselves extra surveys on noise levels and noise effects [8].
To promote an integrated approach to the management of "*Movida*", the Municipality decided to strengthen its knowledge of noise levels in San Salvario district and started the design and implementation of an *ad hoc* noise monitoring network.

3. Deployment of a low-cost IoT noise monitoring network

Considering the high variability of leisure noise of "*Movida*", and the difficulty to model its local effects in a deterministic way, due to the joint presence of people and bars with music and plants, a low-cost sound level meter monitoring network was preferred, to potentially achieve a good spatial noise distribution based on a high number of sensors despite a limited detrimental of level precision, like in other European cities [9][10].
Smartphones where investigated as IoT sensors, because different studies demonstrate that, under specific conditions, their use, if equipped with adequate microphones and specific mobile applications, is suitable for environmental noise measurements [11].

3.1 Network development and installation

The Regional Environmental Agency of Piedmont (ARPA Piemonte), in order to assess the accuracy of environmental noise measurements using entry-level smartphones, carried out two different types of tests, comparing output data of smartphones using different external microphones and a Class I sound level meter, in an anechoic room, and carrying out, for more than three months, a long-term environmental noise monitoring [12].

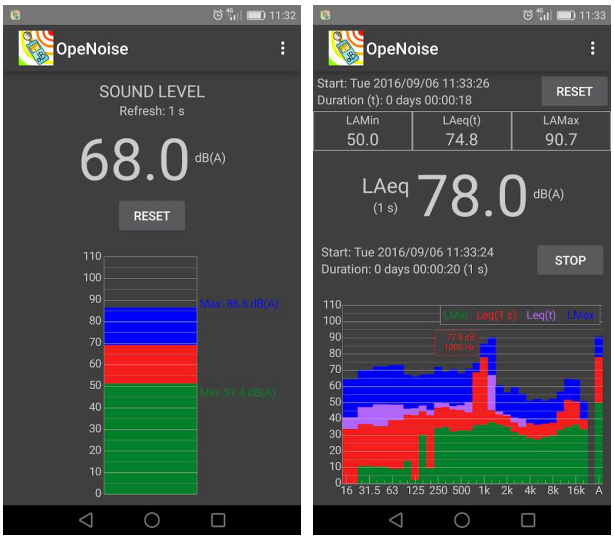


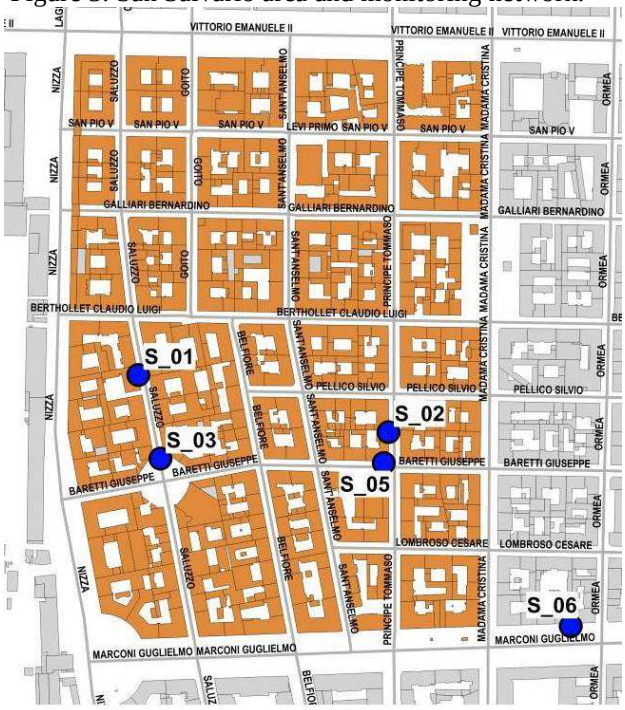
Figure 1. OpeNoise app: standard interface and advanced third-octave analysis

Based on this experience, ARPA Piemonte developed "OpeNoise", a dedicated app (Figure 1) for real-time noise level monitoring. OpeNoise allows Real-time A-weighted sound pressure level measurement, minimum and maximum level, third octave and FFT analysis, data saving in a text file, sampling time setting and calibration [13].
Tests demonstrated that these solutions could be adequate for a long-term environmental characterization of *"Movida"*, with a standard deviation of less than 2 dB(A) between 40 e 80 dB(A) on average levels for L_{night} if compared with class 1 sound level meters. A monthly calibration was planned to verify the quality of measurements (Figure 2); tuning is applied in case of differences higher than 1 dB(A).
Where ready, this new prototypal low - cost noise monitoring system based on smartphone devices, Lavalier external microphones and OpeNoise app (Figure 2) was deployed in San Salvario area, where six measurement points were installed in summer 2016 [14].

Figure 2. Kit for external installation and calibration of Lavalier microphone with a Class 1 source.

The location of sensors was optimized to cover all significant feature of "*Movida*" area (Figure 3): one in a very crowded square (S_03, not active in daytime), three in narrow streets with pubs and bars (S_01, S_04, S_05), one in a boulevard for traffic noise measurement (S_06) and the last one in a quieter area with no crowd and low traffic (S_02), for global reference. The choice of points of installation was driven also by the power supply, so light poles, public offices and bike sharing station where preferred.
Data collected by OpeNoise app with a sampling time of 1 seconds are continuously sent via Wi-fi or 4G to the regional IoT Open Data Platform and published on institutional websites.

Figure 3. San Salvario area and monitoring network.



Despite general satisfying results, the noise monitoring network suffers from vandalism (one point was decommissioned) and high temperature in summer (damages to batteries of smartphones).

3.2 Analysis and statistical characteristics of leisure noise of *"Movida"*

Data availability allowed a first robust assessment of noise impact of Movida on the residential area on a yearly basis [15].
First analysis led by ARPA focused on long-term L_{night} average levels and on comparisons between levels in different days of the week (Table 1).

Table I. Noise levels of *"Movida"*

Sensor	L_{night} *dB(A)*	L_{night} - $L_{daytime}$ *dB(A)*	$L_{night\ FRI+SAT}$ - $L_{night\ MON}$ *dB(A)*
S_01	62.4	-0.1	8.9
S_02	57.0	-2.6	4.7
S_03	69.4	$L_{daytime}$ *NA*	9.8
S_04	60.9	-1.1	5.2
S_05	60.2	-0.2	5.5

Data collected confirmed that L_{night} levels exceeded the limits stated by local noise zoning; that levels are very close to daytime ones. The

noise levels have a typical distribution during the week, with more than 9 dB(A) of difference between Friday/Saturday nights and Monday ones.

By assigning levels to buildings, a first estimation of the population exposed to leisure noise was completed, showing that almost 50% of inhabitants live in dwellings with more than 60 dB(A) L_{night} on the façade.

A more detailed analysis was performed on an hourly basis, pointing out that weekly, a significant increase of duration and intensity of noise is verifiable each day, with a maximum reached on the night between Saturday and Sunday (more than 72 dB(A) between 2 AM and 3 AM).

4. Initiatives for management of leisure noise in San Salvario

Data availability of noise impacted on the political agenda, and several actions were implemented by the Municipality:

1. EU projects were considered to support special initiatives and experimental solutions;
2. ordinances entered in force in Summer 2017 to reduce noise in the short term;
3. a working group on *"Movida"* was created to outline an Action Plan with detailed reduction policies in the medium and long term.

4.1 H2020 MONICA Project

San Salvario district with its "*Movida*" was proposed as a pilot area for Horizon 2020 MONICA (**M***anagement* **o***f* **N***etworked* **I***oT Wearables – Very Large Scale Demonstration of* **C***ultural Societal* **A***pplications*) project. This project is a large-scale demonstration of new and existing IoT applications, focusing on cultural performances in open-air settings, which create challenges in terms of crowd safety, security and noise pollution [16]. This three years project was financed and started in January 2017.

One of the main challenges of the pilot for *"Movida"* is to achieve noise reduction by engaging the goers, using a mix of IoT technologies and reward systems (set up by the district/sellers' associations) that could foresee special offers, prizes, and other benefits, when users' behaviours minimize annoyance for residents.

Consequently, during the first year of activities, City of Torino activated a focus group to promote proactive involvement of citizens, awareness of local stakeholders, and commitment of patrons, to support more engaging actions in the following two years.

To evaluate acoustic improvements, a monitoring protocol was defined by Acoucité (partner of Monica project for acoustic issues), integrating environmental data from sensors, noise index, surveys, statistical analysis, and audio recordings for soundscape characterization.

In 2017, activities of Acoucité were focused on collecting information on the initial acoustic state of the pilot. For *"Movida"*, a set of audio recordings was performed in May 2017, with a twofold objective: providing other partners with recordings to initialize the development of sound source identification algorithms and developing a prototype of interactive qualitative maps of the sound environments of the sites (Figure 4), with and without the noise sources to be reduced (in our case, nightlife).

Figure 4. San Salvario area and interactive sound recording on web interface.

This activity relied on binaural recordings made with sampling equipment over a full day and 5 points (in the public open space and on the façades of dwellings) and noise measurements made by the low-cost monitoring network.

Data collected of $L_{eq,\ 1sec}$ also allowed the computation of HARMONICA index to *"Movida"*.

The HARMONICA index (developed in a previous European research program [17]) represents in a graphic way the sound contribution of background noise and events in a differentiated way, on a scale from 0 to 10. The use of this index could help

communication initiative, in particular with people not usual with decibel (Figure 5).

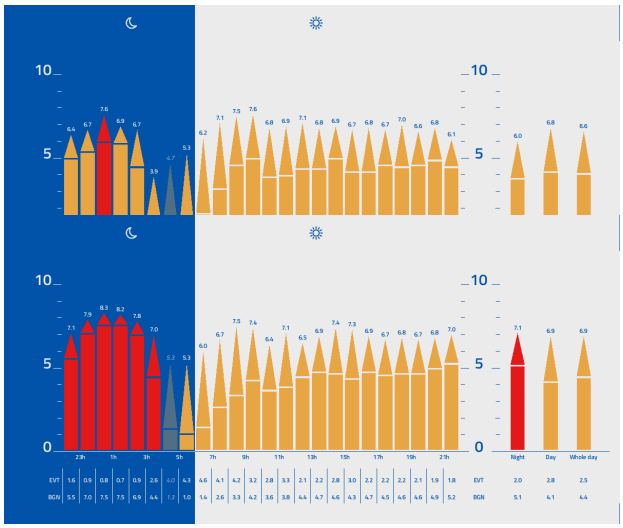


Figure 5. Noise in San Salvario, Thursday 16th and Friday 17th May 2017. The HARMONICA index well highlights higher levels on Friday nights (left down) vs Thursday ones.

4.2 City Ordinances for noise reduction

In Summer 2017, two City Ordinances entered in force, with the aim to limit noise pollution of *"Movida"* in the central area, San Salvario district included.

The first one, Ordinance n. 46, limits alcohol takeaway selling, as many people reach the area of *"Movida"* and buy alcohol in bottles at a low price, spending all night wandering or sitting in the streets, chatting and shouting. So, takeaway selling alcohol in bottles was forbidden after 8 PM and for all night, establishing the same rules for bars, shop, and store. This Ordinance stayed in force from 8th June until 30th September.

The second one, Ordinance n. 60, limits serving food and beverage in terraces or outside bars and shop, as many people stay outside these venues enjoying mild weather, or smoking, or because of overcrowding, disturbing inhabitants with an increasing din. Serving food and beverage was forbidden after 1:30 AM (from Monday to Thursday), after 2 AM (Friday) or after 3 AM (Saturday, Sunday and feast day). Furthermore, a compulsory presence of stewards was introduced, to limit bad behaviours of customers. This Ordinance stayed in force from 8th July until 30th July.

Data collected allowed the assessment of effects induced to the new regulations on L_{nights} levels, proving that both Ordinances led to a noise reduction, with a cumulative benefit of more than 3 dB(A) (Table 2).

Table 2. Leisure noise improvements in summer 2017, S_03 point

L_{night}	*Ordinance n. 42 8th June-30th September*	*Ordinance n.60 8th-30th July*	*1st October-31th December*
2016	69.8	70.4	68.9
2017	67.7	66.9	68.4
Δ	-2.1	-3.5	-0.5

4.3 Action Plan for leisure noise reduction

The availability of acoustic data pointed out that noise in San Salvario should be considered between priorities and a multidisciplinary team (Local Police, Environment, Culture, Economics, Youth, Mobility) started working on an Action Plan.

Four strategies were proposed: integrated monitoring (crowd, noise, traffic, etc.), noise reduction on different sources, long-term urban planning, and improvement of cultural offer. A special focus was given to communication strategies, as awareness appears as a key point for the success of the Plan.

Each strategy considers more actions: some of them are implementations of Monica framework or come from the City Ordinances or, furthermore, introduce best practices validated in Italy and abroad [17].

The effectiveness of Plan will be assessed using noise data and annoyance indexes, taking advantage again of the low-cost monitoring network.

5. Conclusions

Nightlife activities in open-air create increasing challenges for cities, in terms of noise pollution and annoyance.

To devise strategies, a data-driven approach could be chosen, like in Torino, by the deployment of a monitoring network.

This kind of asset widely supports cities in planning, communication, monitoring, and policies assessment process, from short-term and experimental initiatives to long-term urban planning.

The choice of a low-cost solution could help network startup, but the availability of Class 1 reference points will help long-term monitoring, allowing more robust analysis of collected data.

To evaluate benefits of reduction actions, a quantitative and qualitative analysis should be developed, also using surveys and synthetic index, like HARMONICA index based on short $L_{eq\ 1\ sec}$

At present, values on third-octave bands have not been exploited even if collected; further analysis seems possible comparing spectrum in different days to support sources identification.

All these strategies on data will support the evaluation of the overall effect of reduction actions, included ones expected in the framework of the Horizon 2020 “Monica” Project.

Acknowledgment

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