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NOISE CONTROL FOR QUALITY OF LIFE

Real-time source-selective noise monitoring (ReSoNo)

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ABSTRACT

Unattended noise monitoring technique has spread widely in the last decade as a solution for noise measurement in 24/7. However, the lack of human operator on site results uncertainty in the determination of the measured noise immission's sources. Therefore, we initiated the research and development of an automated system that can substitute the human operator during the measurement. We analyzed the way how the human operator is able to determine the sources of noise on site and we modeled the necessary perception and cognition processes with electronic sensors, signal processing and artificial intelligence. We designed a system with audio and video sensors, real-time signal procession, measurement database and an evaluation algorithm able to learn. The resulted system prototype has a built-in certified sound level meter, cardioid microphones and video cameras covering 360°, all connected to a signal processing FPGA; the processed data is collected together with the measured noise level on a site-PC, which runs an evaluating software able to learn. Results are forwarded to an online server for examination. Source-selective noise monitoring can be a large step forward in environmental noise control, but the perspectives opened by an intelligent environmental monitoring system are even greater. (Keywords: Noise, Source, Measurement)

1. INTRODUCTION

Every noise measurement has to be source-selective. Since noise control engineering aims to analyze and mitigate the environmental noise, it is an essential need to know its source. However, source-selectivity can be ensured in many ways. First of all by the positioning and timing of the measurement: in many situations it is enough to find a place and time, when and where the analyzed noise source is dominant, while other sources are silent so the measurement will be representative to the analyzed source. Although there are many noise sources that aren't that predictable, while irrelevant noise events can always disturb the measurement, therefore the operating staff has to supervise the measurement and ensure that it stays representative by pausing the recording during interruptions or keeping a log on noise events so it can be matched with the noise level log later. Although, this activity needs some intelligence to perceive noise events and recognize their sources, but especially in case of a longer measurement of multiple hours it soon becomes the waste of a skilled labor's time. However, human intelligence can be modeled by computer algorithms, and just as a human operator an artificial observer can recognize noise sources relying on audio-visual information using previously learned patterns. ReSoNo (patented [1]) is an automated system that completes noise measurement with artificial perception to provide real-time information about environmental noise and its sources.

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2. CONCEPT

2.1 Source selective noise level

The cumulative noise immission level in a certain point of a multi-source environment is the logarithmic sum of consecutive and overlapping noise events' momentary level originating from various sources. Sound level meters are able to precisely determine the level of the cumulative noise, but unable to decompose it to source components. For this decomposition we need information about the activity of sources so we can determine their contribution to the cumulative noise level. This problem is like observing waves aroused by multiple ships on a water surface: one cannot tell about the impact of a single ship by just watching a swinging buoy, for this he needs to look up and watch the movement of the ships.

Every noise event has a time characteristic, and in most cases it is quite typical to the source: noise of a moving source rises and then fades away, while fixed machinery makes constant or periodic noise. For this reason cumulative noise level is easier to decompose to source components along noise events than by periodic samples. Noise events can be delimited in time by finding local minima in the time function of the cumulative noise level, but sudden changes in spectra or a significant percept can also be determined as an event boarder. Once an event is delimited the noise event level can be calculated by summing the covered noise level samples.

Although, the event delimitation highlights a time period during which a certain source is dominant, it is unavoidable that other sources contribute to the noise event level by their overlapping events. Therefore it is not enough to recognize the main source of the event, but all other significant sources have to be recognized and their contribution to the noise event level has to be determined (see Fig. 1). The equivalent noise level of each source in that certain time period can be calculated then from the cumulative noise event samples as Eq. (1) shows.

$$L_{s,j} = 10 \cdot \log_{10}\left(\sum_t e_{j,t} \cdot d_{s,j} \cdot 10^{L_{\Sigma,t}/10}\right) - 10 \cdot \log_{10}\left(\sum_t e_{j,t}\right) \quad (1)$$

Where $L_{s,j}$ *[dB]* is the equivalent noise immission level of *s[index]* source during *j [index]* noise event, $e_{j,t}$ *[0,1]* is the time filter function of *j [index]* noise event in *t [s]* time, *ds,j [%]* is the contribution of *s[index]* source to the noise event level of *j [index]* noise event and $L_{\Sigma,t}$ *[dB]* is the momentary cumulative noise level.

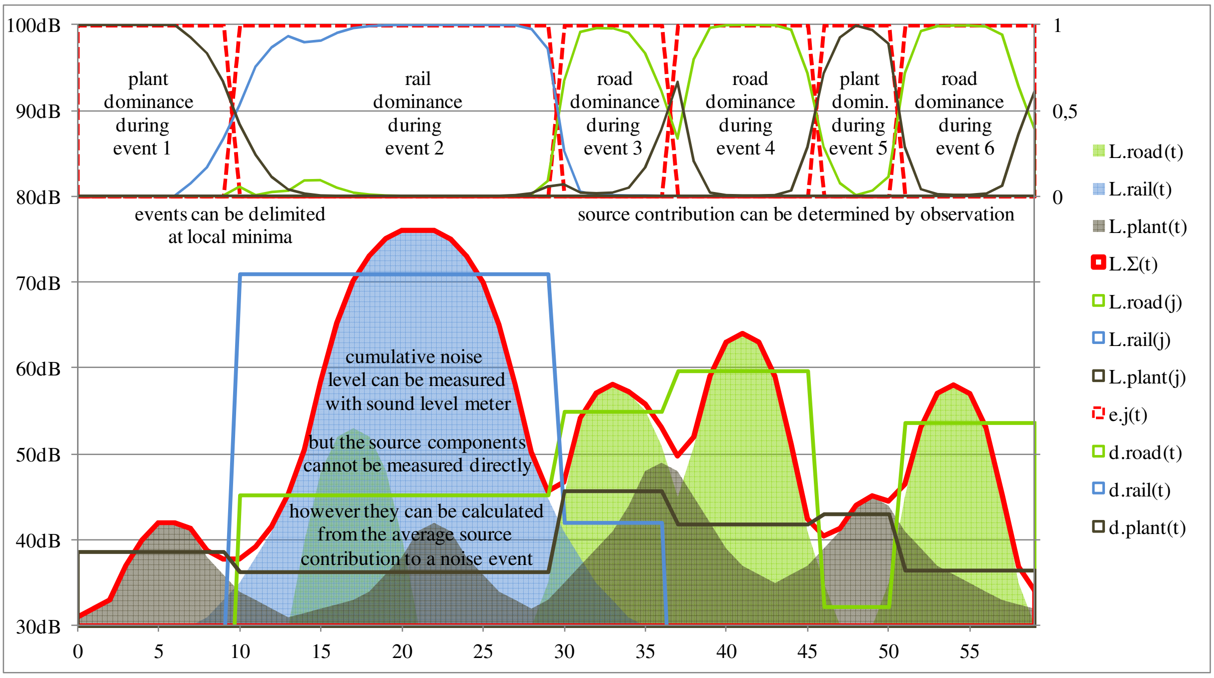

Figure 1 – an example of the source selective noise level calculation process

2.2 Noise source identification

The identification of the source of a noise event is about what we see and what we hear, what we think and what we know. It is a process of perception and cognition involving both our senses and intelligence. The identification of a noise source sometimes can be trivial – like when a giant freight train passes us closely – sometimes it can be difficult – like finding a noisy machine in an industrial hall – and sometime it can be even misleading – like when we are looking for the noise source of a jet, and the plane is far away from what we would expect by hearing. Consequently, if we design an automated noise source identifying system with humanlike senses and humanlike intelligence, the result will be uncertain, just as in the case of a human operation. However, in most cases of environmental noise monitoring this uncertainty can be acceptable.

The aim of the observation is to determine the three 'W'-s of each remarkable event: when, where and what happened. The time stamp ('when') is an essential part of the observation record that allows us to combine the observations with the measured noise level and separate cumulative noise level to sources, once an event is recognized its starting time and duration will be recorded using a clock synchronized over the network. The position ('where') is next information we need, and not only the angle relative to the observer, which can be easily determined with all-round camera and microphone array, but also the absolute position of the source, which necessitates GPS, compass and the estimation of source distance and height by perspective, loudness and frequency analysis; the absolute position tells a lot about the source, whether it is on a road, railway, water surface, inside an industrial area, a garden or up in the air, we can already give a guess about the source without even trying to really recognize it. The description ('what') is the final task of observation, which can contain the most information about the source for the price of a complex analysis, therefore it has to be split to levels of detail, starting with silhouette and spectra analysis and deepening into image and sound matching.

Sources are abstract concepts that we have to define accurately to be able to assign certain observations to them. A road, a railway line or a construction site can be a definite source of environmental noise, which is a simple positional definition and so the observations with the proper position record can be assigned to the certain source. In case of a more detailed source classification – like trucks, buses, cars and trams running on the same road – the description is also needed for the assignment of observations to sources. Therefore, the observation is to serve the source identification and not to serve itself, the sensor arrangement (e.g. as on Fig. 2) and the data procession has to be designed considering the information needs of the source-selective noise level calculation.

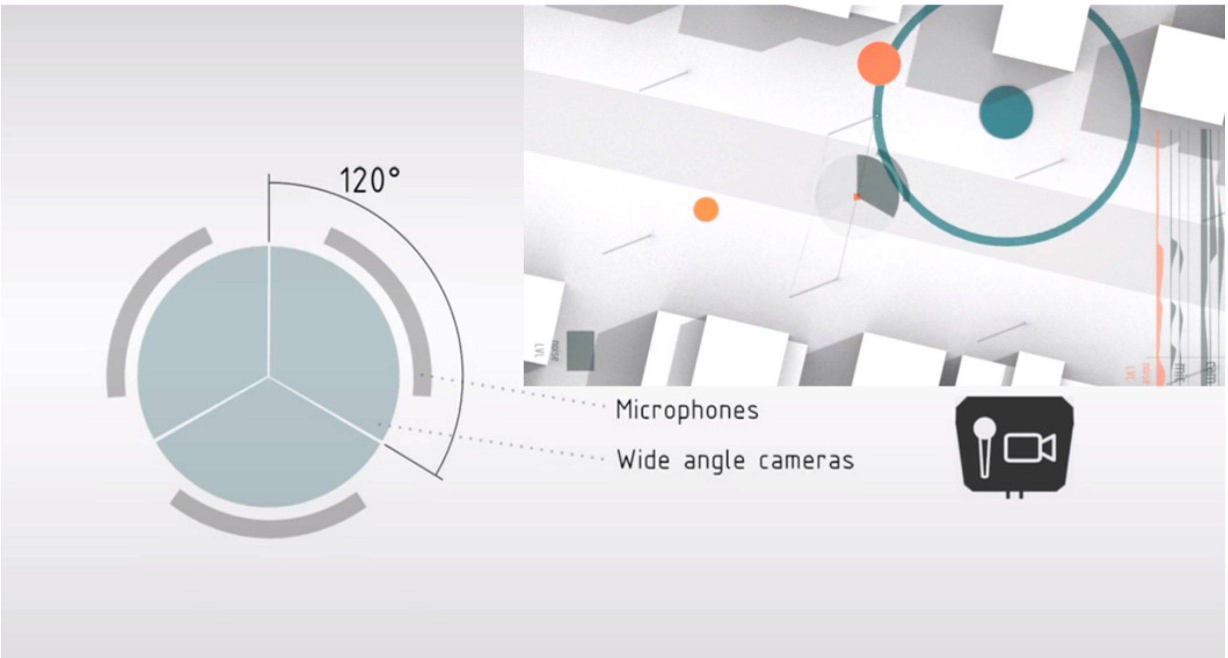

Figure 2 – an example of sensor and site arrangement of noise source observer

2.3 Learning system

Observation records form a multi-dimension parameter space where certain ranges can be delimited for sources considering their unique characteristics. Delimitation of these parameter ranges is however difficult to do analytically – how to define the shape of cars or sound of truck in general – the empirical approach – take samples, interpolate, extrapolate – is more practical in most cases, but with the increase of dimensions it quickly becomes impossible to process manually, so observatory system cannot be pre-programmed efficiently. The solution is humanlike just as the whole system concept: learning. While the system makes observations it gets an external input of abstract concepts that it can assign to physical parameters and create rules, which later can be used for the unattended identification of certain events – just like a child is taught to speak by telling words while showing objects.

Systems can learn supervised or unsupervised. Supervised learning means that the system gets external information from a source with more experience in order to transfer the capability of recognizing certain events. One way of supervised learning can be that during the learning period the supervisor is staying with the system on the site and after each remarkable noise event he selects the noise source from a prepared list. The same method can be used off-site as well; in this case the supervisor receives audio-visual input from the observer and replies with the source identification. Also it is possible to do offline supervision; in which case the system tries to classify the observations by their parameter similarities without knowing their names and later asks the supervisor to assign sources to them. Unsupervised learning doesn't need a supervisor, but needs measurement feed-back. The system is programmed with a calculation method with a certain number of unknown parameters, in the same time there is an instrument on the site, which transmits measurement data to the system that has to optimize the unknown parameters in order to get the closest result to the measured value. A way of unsupervised learning can be placing a sound level meter somewhere in the range of the system, which transmits the noise level data of that position, while the system measures the noise level of its own position and tries to determine the source components so the preprogrammed noise propagation calculation will give the same result that the control instrument measures.

Learning methods can be combined freely and should be site specific to get the best result. The previous definition of source names, positions, noise propagation factors can improve the quality of source identification. Also the system should never stop learning and checking the quality of previously learned rules, the regular maintenance can guarantee the proper working and still needs only a fraction of the time a noise measurement operator currently spends on the site.

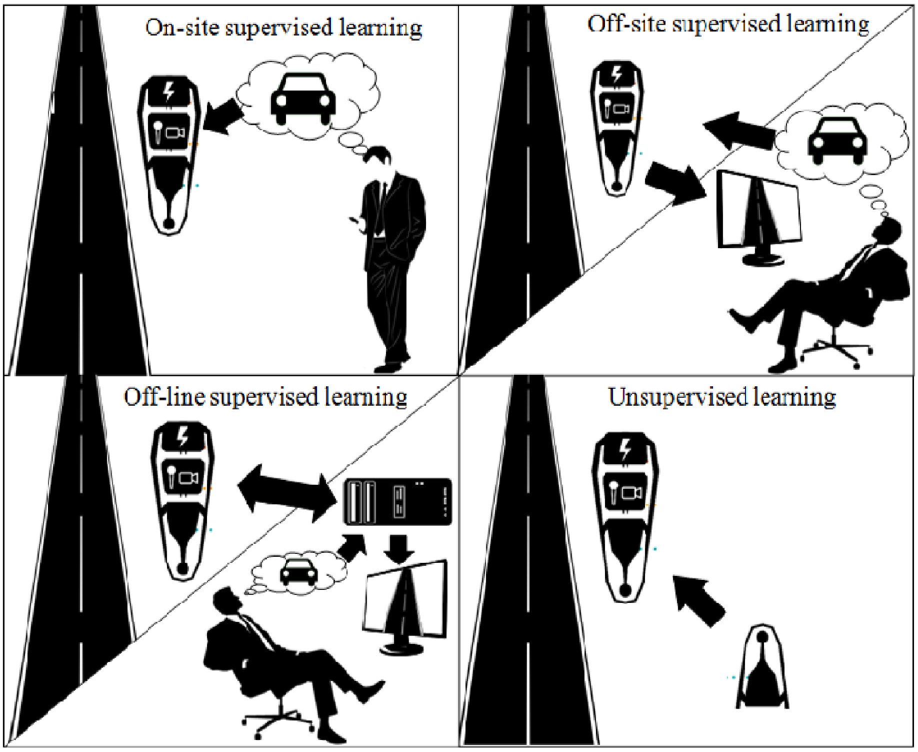

Figure 3 – methods of learning source identification

3. REALIZATION

3.1 Design

No matter how advanced technology we use the main character of every noise control engineering task is the expert, who prepares, coordinates, evaluates and reports the process. We believe that noise control technology has to serve the expert by taking over the simple recurrent tasks and thereby freeing up time for creative activity. Therefore, the design objective was to create a tool for noise experts, which fits into their current workflow and easing their job without forcing them to change their proven practice. Noise analysis methods vary by experts, projects and locations so flexibility and compatibility was the two basic requirements for the design.

The system was designed to be suitable for handheld, temporarily placed and permanently installed measurements on sites with rich and poor infrastructure too. The core of the system is the observer unit that contains the audio and video sensors, GPS, compass, data procession and communication electronics and a battery for 8 hours operation. The noise level measurement goes in a separate unit that contains the communication electronics compatible with almost all the recent manufactured sound level meters and also an uninterruptible power supply for 8 hours operation. The third module is the battery pack, which can supply the system with power for a whole week. All three modules have robust weatherproof casing with anti-theft structure, modules can be attached to each other mechanically in every possible combination even with multiple battery packs if longer operation is required without external power. All communications are wireless – however network cable can be plugged to the observer in case of permanent installation – the observer unit communicates with the measurement unit through WiFi and forwards the compressed information towards the server through WiFi or 3G network.

The system was designed for online operation – however there is an offline mode with limited features – therefore the high level data procession and the human interface is independent from the measurement site. The observer unit transmits the collected observation and measured noise level to the server, which evaluates the data and stores the information in a database. The human interface, which can access the database and visualize the information for the user, can be installed on any computer platforms – PC, laptop, tablet, smart phone – and can be used the same way when the user is on the site or at the other end of the world (see Fig. 4). This concept ensures that the collected data is stored in a secure and non-stop accessible storage; the user can smoothly access the information even in case of a large network of observers on any platform from anywhere and there is no limits of the data procession complexity as the intelligent algorithms are run by powerful computers.

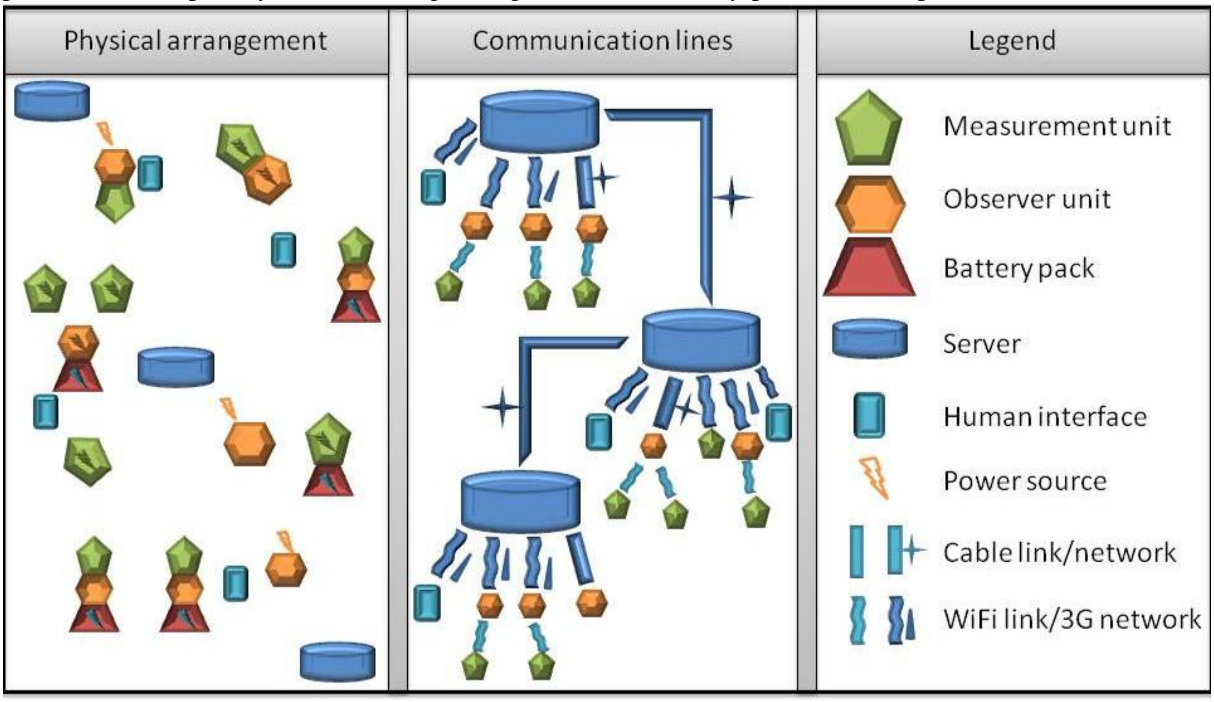

Figure 4 – source selective noise monitoring network arrangement and communications

3.2 Prototypes

Prototypes are milestones of the development process. The development of each prototype enables us to reveal design conflicts and test the design objectives, which leads to continuous improvement of the system design. The project has three stages of prototyping: the first one (ready in March 2013) is for illustration with transparent casing, large spaces and high-quality parts, the second one (ready in July 2013) is for testing with robust structure, compact build-up and economic components, the third one (ready in November 2013) is for production with optimized cost/quality ratio. The first two prototypes intentionally form the two extremes of the design concept to enable a proper optimization in every aspect of the design.

The development objective of the first prototype was to realize a stand-alone model able to measure noise level, record observations and process the collected data for source separation of cumulative noise. The model was equipped with six USB cameras with 60° angle of view each, three studio microphones with cardioid characteristics and a class 1 sound level meter. The data procession was solved with the combination of a custom made printed circuit board designed around an FPGA chip and a tablet computer with dual core Intel Atom processor inside. The system is powered by a pack of 12V VRLA (gel cell) batteries. The housing was made of transparent PMMA (Plexiglas) and black ABS (a common thermoplastic). The data procession software has sound direction analysis, audio time-frequency analysis and video object analysis features.

The development of the second prototype was started after the first prototype was finished and tested; therefore we had a lot of experience that was utilized during the design modifications. The development objective of the second prototype was to realize a compact, economic, power saving and robust model that has the same features as the first one. We also wanted to question every single decision that we made during the development of the first prototype and if there was an alternative then try it too. In contrast to the first prototype's cable connected parts the observer unit of the second prototype was designed to be installed on a single custom made printed circuit board; both the USB cameras and the studio microphones was replaced by miniature circuit parts, the board was equipped with a powerful FPGA able to do all data procession and compression necessary on site and transmit the results to a server with the help of the WiFi/3G communication chips, we also installed GPS, compass and a Li-ion battery on the board. We developed a small circuit for the sound level meter as well, which can receive and forward the measured noise level values to the observer unit. The housing of the model was made of strong PVC for lightness, robustness and cost efficiency. The FPGA was programmed for audio and video analysis and data compression, while the server was equipped with an observation database and artificial intelligence for learning and data analysis.

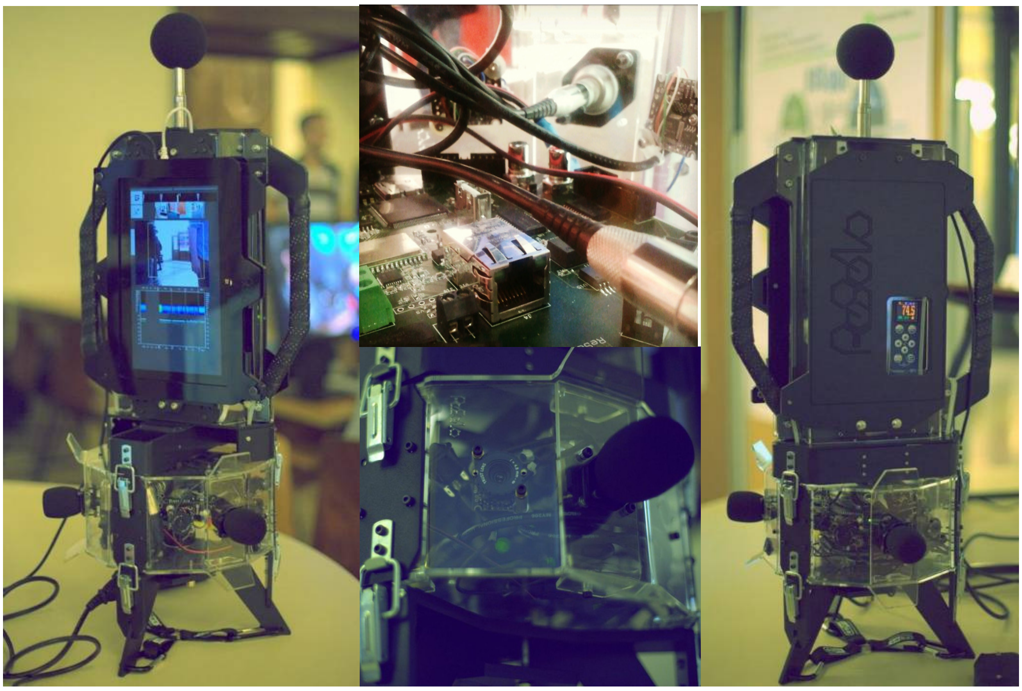

Figure 5 – photos of the first prototype of source selective noise monitoring system

4. EXPERIMENTS

Several experiments have been made throughout the R&D process in order to test the ideas and provide proof of concept. Some of these were done inside the semi-anechoic room of the university's acoustic laboratory and others were done on site in Budapest. In the first time we tested some concepts with laboratory tools, which was followed by testing the features of the first prototype, the long-term durability test are however still to be done.

The first experiments were to prove that the source separation of cumulative noise level is possible. I made some noise level measurements besides a road with 2x2 lanes and tram lines crossed by a railway bridge while I made notes about vehicle movements. Later I analyzed the result logs in the laboratory and concluded that with the vehicle movement information it was possible to sort noise events by sources and determine the equivalent noise level of each source for a period that is significantly longer than an average noise event even if I neglected the fact that the noise events were overlapping each other and I selected only one dominant source for each moment. This was due to the large dynamic range of traffic noise, which resulted that in most of the time there was only one dominant source and the contribution of the other sources to the cumulative noise was negligible.

In the second phase I was experimenting solutions for electronic source observation. I installed two cardioid microphones on the two ends of a horizontal rod held by a tripod and placed it in front of a speaker inside the semi-anechoic room. As I was rotating the rod on the tripod the difference of the microphone signal RMS values showed if the sound source is on the right or left side or in between. Next I connected a USB camera to a computer and made a simple algorithm that can calculate the image different between delimited zones of the view, which worked as a perfect motion detector.

After I had some tools for source observation I went on site to test my source selective measurement concept. I installed the two microphones and the USB camera together with a sound level meter in the crossing of two roads, a railway and a highway plus there was a construction site too. The sensors were connected to a laptop which was recording the whole process while I was making control measurements with another sound level meter around the site and making notes of the noise events. After the measurement was done I returned to the laboratory with all the records and created a simple logic (like sound from the right plus movement on the railway means train pass) that was able to select the noise source by the observations. The results were showing a good start, the decisions of the algorithm was matching my notes in 75%, more importantly I was able to separate the cumulative noise level to source levels and calculate the noise immission map of the area with a propagation model, which resulted an absolute average error of 1dB compared to the control measurements [2].

The latest experiment I carried out was in the semi-anechoic room again, where I was testing the sound direction analysis with three microphones. Although I had some difficulties with reflections on certain frequencies the results showed that the horizontal direction of the sound can be determined in the whole circle with an accuracy of 10°.

Figure 6 – photo and map of the source selective noise measurement experiment on site

5. CONCLUSIONS

Source-selective noise monitoring is an innovative technology that can change the noise control industry by freeing up significant time of noise experts (spent on-site with source observation) without increasing the uncertainty of the measurement results. The concept can be realized by a system that is built from currently available mass produced parts without replacing or modifying the certified sound level meter that continues to be the cumulative noise level measuring instrument. The system design enables the short- and long-term unattended monitoring of in-range sources' noise immission separately while the measurement database can be easily accessed using any kind of PC platform with internet connection even in case of an extensive network of monitoring stations.

The technology has been tested on many of its capabilities; however the long-term reliability tests are still to be done. The tests has proven so far that it is possible to separate the cumulative noise level to source components using observations made on site by a human or automated observer. It has been also proven that it is possible to create a logic - manually or with the help of a learning algorithm - that can assign certain observations to noise source activities. Finally some solutions for automated audio-visual observation were tested successfully including sound direction and video object analyses.

As the utilization project is in start-up phase and the development is over the realization of the second prototype of the technology it is possible that the first commercial model will be out on the market already in 2014. The system design enables the continuous development of the system even if it's already installed on site by remote software update (including the observer, server and human interface units).

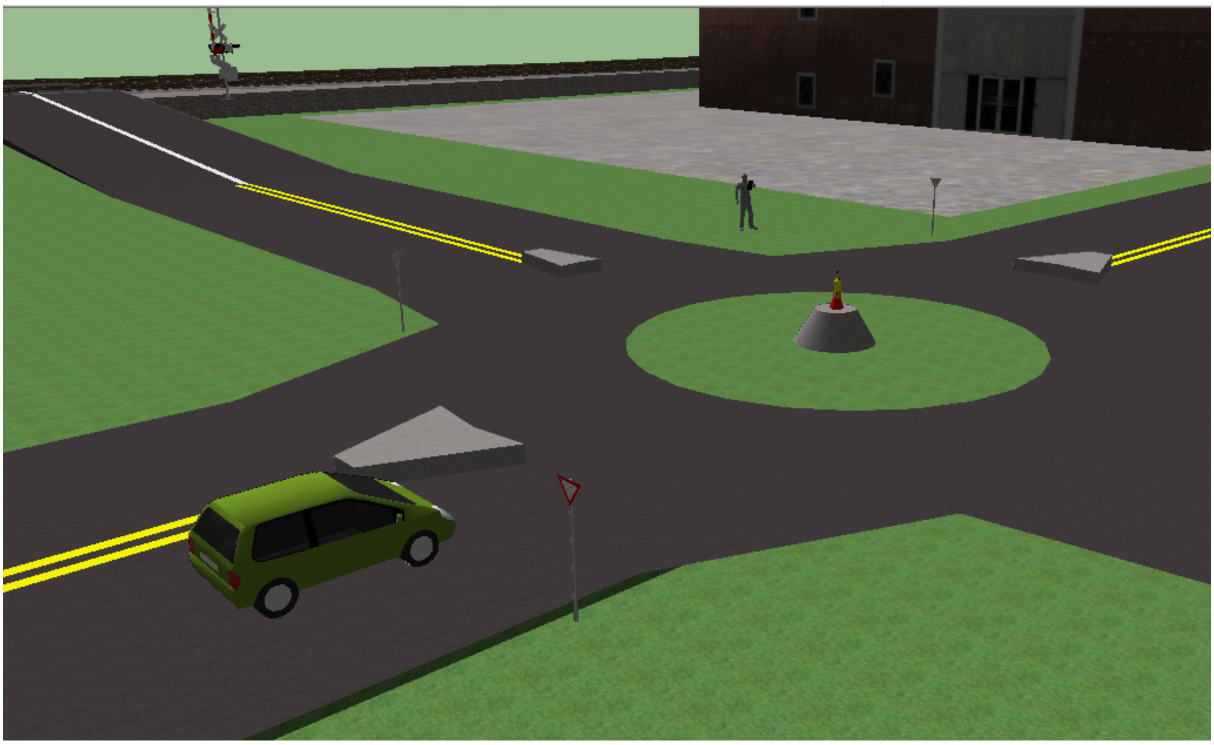

Figure 7 – example of a source selective noise measurement situation

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REFERENCES

[1] Budapest University of Technology and Economics, “A Method and Apparatus for Source Selective Real-Time Monitoring and Mapping of Environmental Noise”, (PCT application, PCT/IB2012/057389)

[2] Gábor Geréb, “Real-time updating of noise maps by source-selective noise monitoring”, Noise Control Engr. J. 61 (2), March-April 2013