Practical experience in noise mapping with a MEMS microphone based distributed noise measurement system

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Abstract

The first round of noise mapping exercises, required by the European Noise Directive, are now complete. A criticism of the mandated software modeling approach expressed by some researchers across Europe, is the absence of a role for measurement in the process, which is often neglected because of its high intrinsic costs. DREAMSys is a MEMS microphone based measurement system that has been developed by an industrial consortium led by NPL, to address this problem. The paper briefly describes the rationale for developing the system, and then focuses on experiences gained in deploying it at a number of test sites where long-term outdoor measurement trials are in progress. Until now, distributed measurement systems employing large numbers of sensors (5-100 or more), have been restricted to specialised applications having large financial resources available to them. DREAMSys has been designed to make wide-scale distributed measurement readily accessible to the general noise measurement practitioner. Initial results are discussed that show (a) the added value of including experimental measurements in the noise mapping process, and (b) the potential of MEMS microphones in measurement applications.

Keywords: DREAMSys distributed measurement noise-mapping MEMS.

1 Introduction

MEMS technology now yields a multitude of devices that have found their way into everyday products and high-tech applications alike (for example in Apple's *iPhone* and Sony's *Playstation*, and in medical robotics and energy harvesting). M-E-M-S is an acronym for

micro-electro-mechanical systems; techniques originating in the micro-electronics industry are used to fabricate devices in materials such as silicon. It was recognised early on that the technology lends itself well to the production of microphones [1], [2], and the potential for miniaturisation led hearing aid manufacturers to pioneer the development of MEMS microphones. However opportunities to supply microphones for consumer products, especially mobile telephones, saw manufacturers addressing these high volume markets [3]. Consequently, and amidst a strongly competitive environment, MEMS microphones developed rapidly, leading to a selection of commercial products being available today. MEMS microphone have two significant features; they are very low cost, and they have a very small form factor. The technology is also in its infancy, so further improvements in performance and miniaturisation are to be expected in the course of time. Amidst these developments, the National Physical Laboratory (NPL) saw a role for such devices in *measurement*, an area that no manufacturer appeared to be considering.

Meanwhile, a completely separate and unrelated initative was underway in Europe. EU Directive (2002/49/EC) [4] requires that noise maps be produced for major urban areas, roads, railways and civil airports, across Europe, to inform strategic planning for noise control. The approach mandated in the directive makes exclusive use of modelling to predict noise levels. However, due to issues of complexity, it is necessary to make some over-simplified assumptions and exclude vital features such as temporal variation in the predictive process. This has led to data that is at best, indicative. The first round of implementing the Directive saw noise maps published in 2007, initiating the action planning phase. However many authorities across Europe are finding it difficult or impossible to use noise maps for this action planning or as part of a noise reduction strategy. The problems include lack of confidence in the output data reflecting reality and lack of any temporal variation. Such issues could be resolved by including a role for measurement in the process, but it is prohibitively expensive with instrumentation currently available to achieve the spatial coverage requrired.

NPL was therefore well positioned to recognise that MEMS could have a significant part to play in improving noise mapping exercises and enhancing the impact and effectiveness of this socially important process. This application was therefore chosen to drive the development of a new MEMS microphone-based measurement system, but with expectations that such a system could be readily deployed in a much wider range of noise measurement situations.

2   Development of the system

In response to this prospect, a collaborative research project was proposed to develop a measurement system with appropriate level of performance for noise mapping applications. The system was required to be of sufficiently low cost to enable large numbers of units to be deployed over the area to be studied. A second objective was to demonstrate the effectiveness of the system by carrying out noise measurement trials at a range of outdoor sites to illustrate the benefits of including measurements in noise mapping.

The project started in October 2007 and, at the time of writing is in its final stages. The project partners are NPL, Castle Group, QinetiQ and Hoare Lea Acoustics (HLA).

The measurement system has now been developed and is known as DREAMSys (**D**istributed **R**emote **E**nvironmental **A**rray **M**onitoring System). The development of

DREAMSys, and the validation of it performance in the laboratory, has already been described [5].

DREAMSys was developed from the outset to be a low-cost system and a key part of this is the use of MEMS microphones with a cost (at around €2) that is two orders of magnitude lower than conventional measurement microphones.

With the instrumentation developed and prototypes produced in sufficient number, the next key stage of the project was therefore to carry out noise mapping field trials using this new equipment, in order to demonstrate for the first time, the practical use of a MEMS microphone based noise measurement system.

3   Field trials

As well as demonstrating the effectiveness of the distributed measurement approach, the project also aimed to show the added value of measurements in noise mapping. A number of criteria were therefore identified for selecting sites for the measurement trials. These included;

- Geographical location and communication links
- GSM network coverage for transmission of data
- Land ownership and access restrictions
- Security of equipment while deployed
- Public or site owner's interest in the project, the noise data generated and the wider findings
- Variety and types of noise source present
- Expected spatial and temporal variations in noise level
- Range of noise levels expected (matching system dynamic range)
- Terrain and environmental conditions

Originally the project was to focus on a single test site, but this was re-considered during the project, since a number of smaller studies could provide experience of a wider range of locations. Four test sites, with one principal site amongst them, have therefore been used. These are now described.

3.1   National Physical Laboratory, Teddington, UK

The site at NPL was used to carry out the first outdoor measurements, as part of the process of evaluating the performance of the new equipment. Having deployed seven units for a number of months to conduct these outdoor performance tests, it was decided that these should be left in place for the remainder of the project. These units would therefore be deployed and produce data over the longest possible time frame.

The convenience of the NPL site also offered opportunities to investigate different aspects of deployment, such as mounting configurations, interim calibration and monitoring of reliability. The security of the site also enabled type 1 sound level meter system to be securely deployed to enable a performance comparison to be made between DREAMSys and industry standard equipment.

Figure 1 shows two mounting options (left and centre) and a DREAMSys unit deployed alongside a type 1 sound level meter system at NPL (right).

Figure 1 – DREAMSys deployed at the NPL site

Part of NPL is located close to a busy road, but other parts border onto a royal park and sports fields. It is also in the take-off flight path of Heathrow airport. The site therefore provides a mixed range of noise levels. Other noise sources include movements of utility vehicles on-site, electrical plant houses, and natural noises such as birds and wind in trees.

3.2   Wraysbury Reservoir, Staines, UK

This is another location used by NPL, but owned by Thames Water. It was selected as a trial site because in addition to its noise features, there is a high degree of exposure to weather.

The site also presented a number of challenges for mounting the equipment, and protecting it from wildlife (mostly seagulls). Figure 2 shows some of the installations used, including one unit mounted to a tethered boat. It should be noted that while this was a privately owned site, evidence of unauthorized access prevented the deployment of DREAMSys unit in locations outside a well controlled area.

Figure 2 – A variety of mounting solutions at Wraysbury Reservoir

Also of interest was the site's close proximity to Heathrow airport and a major motorway (M25 London orbital). A well as representing significant noise sources, these factors ensured the availability of published noise maps as required under the EU noise directive, providing a ready means of comparison.

6 units were deployed at Wraysbury for a period of 3 weeks in June 2009.

3.3   Festival Square, Edinburgh, UK

The distributed noise measurements at Festival Square were carried out for a separate study on the relationship between sound perception and the physical level of noise (at the time of writing this work is not yet published). This trial was first deployment of DREAMSys in a public space, and therefore of added interest. The opportunity was taken to deployed units in two ways. Some units were unobtrusively integrated into the surroundings (e.g. mounted in bushes or attached to railings and other fixtures), while a small number of others were mounted on tripods in the open. The reasons for this were partly associated with covering the area of the square, but it also served as a means of gauging public reaction to the equipment, and the type of activities it is designed to carry out.

Altogether, 8 units were deployed in Festival Square; 6 around the boundaries and two in the square itself. Measurements were carried out over 3 consecutive days in October 2009, with the instrumentation being removed from the square overnight.

Given the public access, the site was attended for the duration of the trial. While this afforded some protection of the equipment, it also enabled interaction with the public to explain the purpose of the system and its potential benefits. While there were naturally concerns over privacy, these were quickly allayed, and the exercise received a generally positive response.

Figure 3 – DREAMSys installations in Festival Square

3.4   Silvertown Quays, London dockland, UK

HLA were able to secure access to a disused piece of land (so-called Brownfield land) in the Docklands area of London. The area known as Silvertown Quays, is in the direct take-off path of London City airport, which is just 500 meters away. Despite this, the land is designated for residential development.

The area is also close to the Docklands Light Railway (DLR) and a major road. The addition, of some nearby commercial activities and light industry provides a rich acoustical environment for investigation. Furthermore, there is currently no public access to the site and this is enforces by security patrol.

All these factors coupled with its prominent location made Silvertown Quays an ideal candidate for a test site according to the selection criteria established at the outset. The site was therefore chosen as the primary field trial location, and has seen the largest number of deployed DREAMSys units.

39 units have been deployed at Silvertown Quays, all in the default stand-alone configuration

using the tripod arrangement, with the feet secured with either ground anchors or sand bags depending on the ground hardness. Measurements have been in progress since August 2009.

Figure 4 – Silvertown Quays. The location of the principal DREAMSys trial

4 Preliminary findings

DREAMSys units are capable of measuring both A-weighted and C-weighted equivalent continuous sound pressure levels L_{Aeq} and L_{Ceq}, over a user-defined period from a few seconds upwards (10 minutes being a typical setting), as well as a number of statistical parameters including the maximum A-weighted level, and three percentile levels, which can also be programmed (L_{A10}, L_{A50} and L_{A90} being typical settings). With a typical measurement system consisting of 5 to 100 units, all monitoring continually over periods of several months, it is clear that DREAMSys is capable of generating vast amounts of data. A comprehensive database and a set of visualisation tools are therefore being produced to manage and present this data.

The large volume of data that has be acquired also means that only a small sample can be presented here.

Of the 4 test sites, HLA prepared their own noise predictions for Wraysbury Reservoir and Silvertown Quays, and used these as basis for comparisons with measured data.

Considering Wraysbury Reservoir first, figure 5 shows the predicted noise map for the area. The influence of Heathrow airport and the M25 motorway are clearly evident. The perimeter of the reservoir is also marked. The positions marked refer to the location of DREAMSys nodes where the number alongside denotes the measured parameter, in this case, the long-term average day-evening $L_{Aeq,16hr}$ level or L_{de}.
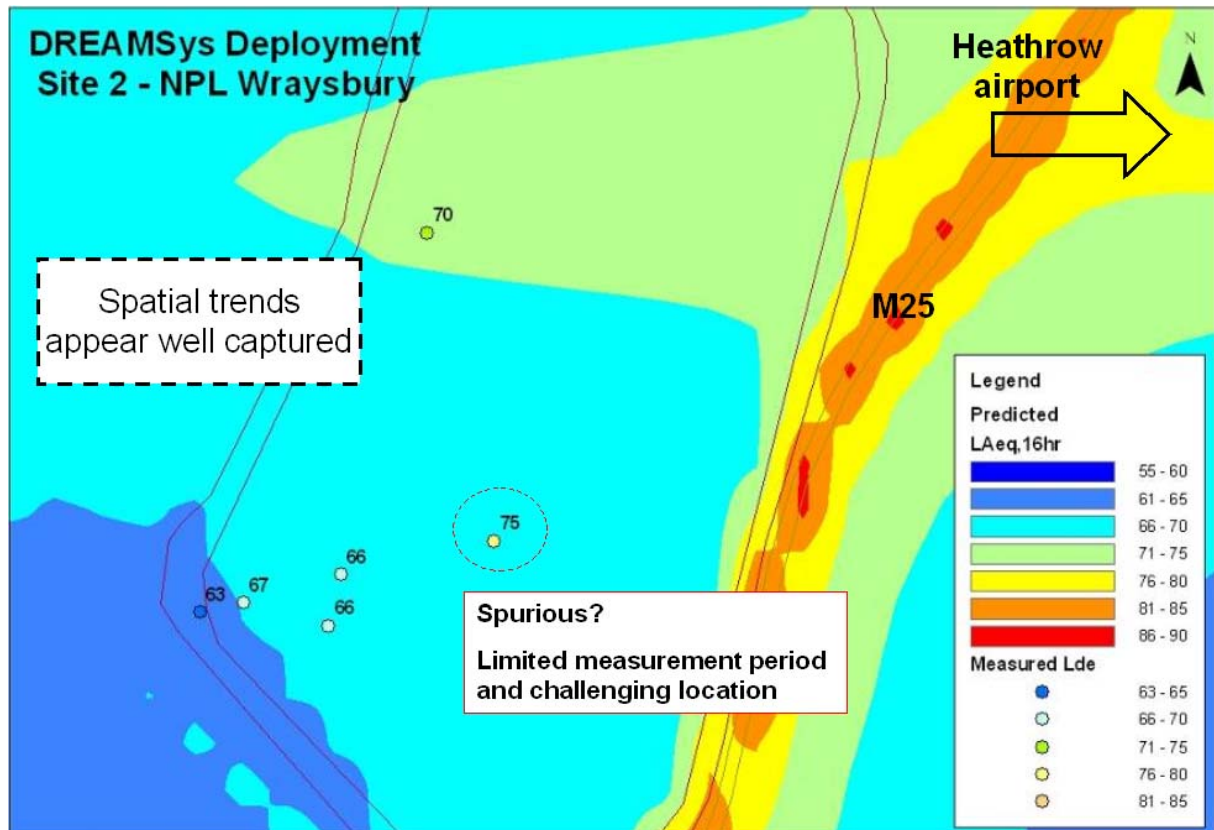
Figure 5 - Predictions of L_{Aeq} 16 hour (c.f, L_{de}) and corresponding DREAMSys measurements at Wraysbury reservoir

Despite limited data filtering (e.g. for the effects of wind or rain), and the relatively sparse deployment due to the limited number of locations available, spatial trends appear to be consistent with the predictions, when a sufficiently long measurement period is taken.

Additional deployment along the shore, particularly along the eastern edge of the reservoir would provide further interesting data, but practical deployment limitations mentioned earlier prohibit this at this time.

In addition to the data shown, DREAMSys can also show temporal trends in the noise. For example, statistics on the distribution of the noisiest events and quietest periods can be derived, and the typical variability of noise levels examined in detail. Such information is not available from the predictions and can provide a very useful context to the model results [6]. Examining differences between the A-weighted and C-weighted data also highlights any significant low frequency component in the noise.

Figure 6 presents a similar analysis of data from the Silvertown Quays site. Here the noise contours have initially been predicted only for the dominant noise source, the aircraft movements. Again, long-term measured and predicted values of L_{de} are shown. These represent preliminary results as a detailed analysis and filtering of the data is to be undertaken.
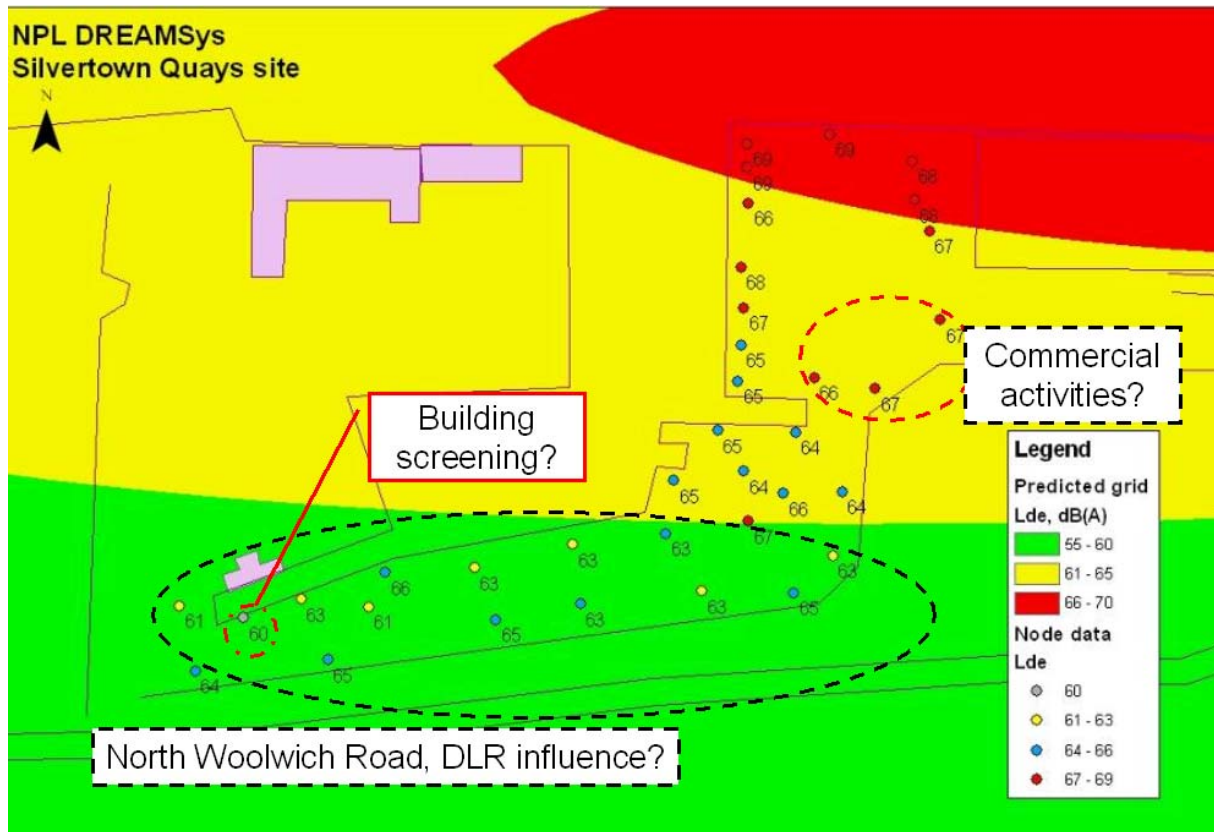
Figure 6 - Predictions of L_{Aeq} 16 hour (c.f, L_{DE}) due to aircraft movements and corresponding DREAMSys measurements at the Silvertown Quays site

Overall, it is apparent that data from measurement locations close to the aircraft flight path are in good agreement with the predictions. However, at a further distances, the influence of other sources such as the road and the DLR train line results in higher noise levels than expected from the prediction based on air traffic only. It is therefore not sufficient in this instance to consider only the dominant noise source. Other discrepancies in the measured data such as the group of results towards the eastern edge of the measurement array appear to come from industrial sources that are also not accounted for in the initial predictions. A building located to the west of the site also appears to be having a screening effect, resulting in lower than predicted noise levels.

The measurement system readily provides information of the combined effect of all significant noise sources. While this can be achieved with predictive noise mapping, it is not a simple process, since each source needs to be modelled at mapped separately and the results combined. Due to the complexities of predictive mapping, it may be difficult to supply input data accounting for this level of detail. As described above, the measurements also provide additional information which is not represented in standard prediction models.

5 Conclusions

Previous reports on the development and laboratory testing of the distributed measurement system known as DREAMSys [5], and the evidence presented here on its successful deployment in a range of noise measurement environments, clearly established proof-of-concept for using MEMS microphones for measurement applications.

Furthermore, the added value that can be obtained from using real measurements to supplement predictions has been clearly illustrated in just two sample data sets from a vast number that can potentially be generated.

The measurement trials at NPL and Silvertown Quays are planned to continue until late-2010. The DREAMSys project is therefore expected to provide further insight into the role of measurement in noise mapping, and stand as a strong example illustrating the potential of MEMS microphones in measurement applications.

Acknowledgments

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