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Distributed noise monitoring in intensive care units

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Intensive Care Units (ICUs) can be extremely noisy places, where staff conversation and equipment alarms are often cited as extremely disturbing. These noises are frequently implicated in causing sleep disturbance and may have deleterious effects on patient recovery and staff wellbeing alike. This study presents the first results of research aimed at assessing the acoustical environment in the General Intensive Care Unit (ICU) at St. George's Hospital in London (UK), and produces a longitudinal noise map. As a first step towards the deployment in-situ of a distributed monitoring system, this work reports some initial acoustic data gathered from the ICU and a laboratory characterisation of the instrumentation, with particular interest in the measurement microphone at its installed location. The impact of the microphone performance on the accuracy of gathered data and the measurement parameter requirements for the distributed system will also be discussed.

1 Introduction

Noise is unwanted or unpleasant sound and is generated in an intensive care unit (ICU) by a variety of sources. These include care and housekeeping related activities; staff, visitor and patient conversation and the multiplicity of supportive equipment necessary for patient care including mechanical ventilators, oxygen therapy and equipment alarms. Of these, staff conversation and equipment alarms are cited as the most disturbing [1].

The noise levels generated in an ICU and perceived by patients are commonly implicated in causing sleep disruption in ICU patients [1-9]; this noise may also have deleterious effects on patient recovery [10-12] and staff wellbeing [13]. The World Health Organisation (WHO) [14] has recommend a maximum noise limit in a room where a patient is being observed or treated of 35dB (L_{Aeq}) during the day and 30dB (L_{Aeq}) at night. Furthermore, European Directive (2003/10/EC) [15] requires ear protection for employees at continuous noise levels of 87dB (L_{Aeq}) with action to be taken with levels above 80dB (L_{Apk}). Recent studies have demonstrated that noise levels in ICUs commonly exceed the WHO guidelines and occasionally also those of the European Directive [2,3,10,16-22].

There is some considerable variation in the methods described to measure sound in these published studies: variability occurs in the recording of sound pressure levels, the time period for continuous recording, the reported energy levels – including maximum and/or mean continuous and/or max peak levels – and the positioning of the microphone. The majority of these studies have only recorded noise for short periods up to 24 hours, with the longest reported continuous recording being three days [18] thus risking to record during a period of atypical noise. Additionally, the studies reported have been unable to simultaneously acquire acoustical data in multiple areas of intensive care units, failing to provide a picture of the acoustic environment precise enough for investigating correlations between the different sources. Moreover, the use of visible sound equipment may itself be a limitation, in that staff are aware of the purpose of the equipment and may therefore change their behaviour accordingly (Hawthorne effect) [23].

To overcome the problems encountered in previous studies, the ideal sound monitoring system would not require regular intrusive calibration and could be maintained in position, gathering continuous data at different locations and for a sufficient period of time. To reduce the Hawthorne effect, microphones should be installed in a less visible position, and a period of acclimatisation [18] should be allowed for – i.e. a period when the sound recording equipment is installed, but not recording data. The acquiring system should give enough information to establish how the sounds associated with the different activities are perceived by the patients, who are often incapacitated to react to them, and by the staff.

Ideally, the monitoring system should produce a visual representation of the acoustic environment – for example a "noise map" of the ICU – providing sufficient and detailed information to facilitate investigation of the causes of undesired sounds (i.e. noise) and their management.

This paper presents the results of a preliminary study, conducted jointly by St. George's Hospital (SGH) and the National Physical Laboratory (NPL) in London (UK), aimed at investigating the soundscape in their General Intensive Care Unit (GICU).

1.1 Long term goals

Figure 1 presents a layout of the General ICU selected for this study. The unit consists of two larger rooms (bays), containing respectively 6 beds (the lower acuity area of the unit) and 9 beds (the main unit), and of two single isolation rooms, attached to the larger 9 beds room (red circles). Each bed has around it various monitoring and supportive equipment and can be (visually) isolated from the others by drawing a paper curtain. Each of the larger rooms hosts a staff base in its centre (also reported as red circles in Figure 1): an area with computing and desk-space, where staff communicates, review investigations and document care.

Three main groups of "users" can therefore be found in St. George's GICU: the patients, their visitors, and the staff (including in the latter both medical and nursing personnel). These have different expectations and are subject to a potentially different impact: a noisy and uniform background affects everyone but, on the long term, mainly the staff (as the patients eventually leave); the intruding presence of alarms over a less noisy background may affect the patients more than the staff, by preventing their sleep or contributing to raise their anxiety.

Such a complex environment needs to be monitored in different locations, simultaneously and continuously, in order to establish correlations between acoustical indicators and the response of the users, later to be assessed also by a questionnaire survey. The lighting posts over each bed (inset in Figure 1) were identified, at start of the project, as the ideal location for mounting a microphone sufficiently close to patients and visitors, but without intruding in the daily duties of the personnel. Two additional measurement locations were planned, in correspondence of the staff bases. NPL has been pioneering the use of MEMS microphones in measurement applications, exploiting their low cost to enable distributed measurement of noise to become feasible.

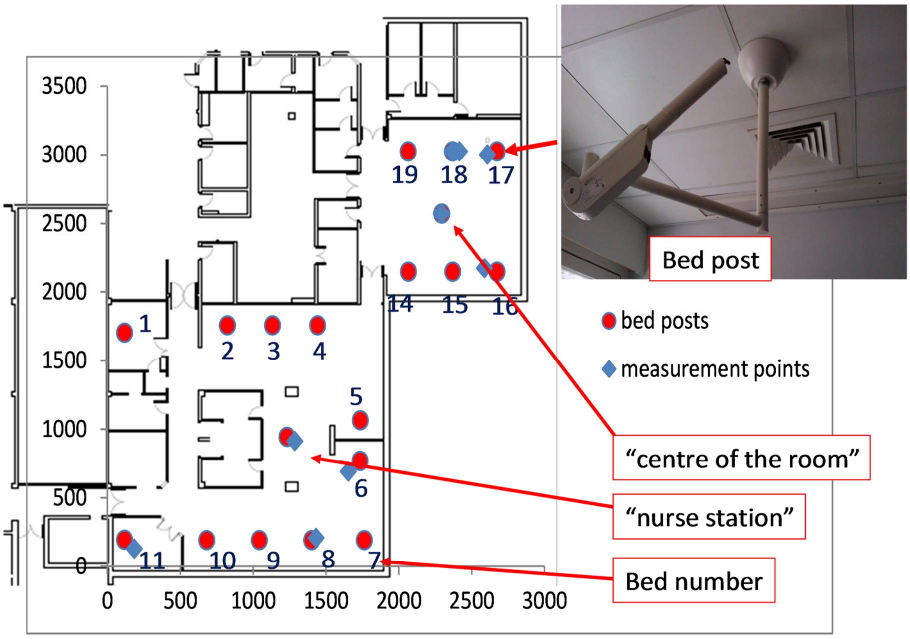

Figure 1: Layout of the area of interest, highlighting the position of the bed spaces by the light fittings above them (red circles) and the measurement points in this preliminary study (blue diamonds).

Until now, the MEMS based distributed noise measurement systems developed at NPL have been deployed only in outdoor studies [24]. At an initial consideration, indoor applications appeared to have a less demanding set of requirements. However, a more detailed evaluation identified new challenges to be solved, e.g. the choice of a minimal – but informative – set of acoustical indicators; the temporal resolution for the acquisition (right compromise between the amount of data to treat and the effects to be monitored); the influence of the room boundaries and microphone mounting configuration; the effect of the room acoustics on the mapping algorithms; the contrasting needs for the system to be unobtrusive and, at the same time, close to the patients' beds.

In order to answer these questions – at least in part – and therefore inform the specifications of the new noise mapping system, a preliminary investigation has been conducted, partly on site and partly at the NPL. The results of this study will be discussed in the following.

2 Preliminary investigations on site

This part of the study was conducted in the general intensive care unit (GICU) of St George's hospital in London, using a Norsonic 121 sound level meter and a ½'' microphone (Norsonic, type 1201/30323). The microphone was mounted on extensible tripod and protected from air conditioning influence using a windscreen (∅ 6cm). Each measurement lasted 30 minutes and the instrument was programmed to acquire FAST-averaged, A weighted levels in 1/3 octaves (35 bands between 8Hz and 20 kHz).

Values of L_{Aeq}, L_{max}, L_{min} were reported at intervals of 15 minutes (2 values/frequency band), 1 minute (30 values/frequency band), and 1 second (1800 values/frequency band). Percentile levels ($L_{0.1}$, L_5, L_{10}, L_{25}, L_{50}, L_{75}, L_{90}, L_{95}) were automatically available for the 15 minutes intervals and calculated in post-processing for the 1 minute intervals. The calibration of the system was checked before and after the measurements using a Norsonic 1251 sound calibrator).

2.1 Measurement locations

A total of eight areas were investigated across the GICU on a typical weekday in November 2011, providing 11 sets of 30 minute recordings. These included three beds in the six bedded bay (beds 16, 17, 18), used as the lower acuity area of the unit, the centre point of this room, a separated room (bed space 11), two bed areas in the main intensive care unit (beds 6 and 8) and the staff base in the larger area (blue diamonds in Figure 1).

These areas were selected with the aim of getting a first assessment of the acoustical climate in different types of locations around the GICU. Measurements were taken at 1.35 m from the floor (the typical height of the head of sitting visitors or personnel, 20 cm above the level of a bed pillow). During the measurements, common sources of noise were noted down (e.g. alarms, staff noise, oxygen, telephones, single loud noise), together with the distances from the positioning of the microphones to the main reflecting boundaries (i.e. the back and side walls closest to each bed space).

Three additional measurements were conducted near bed 18, which was unoccupied at the time. In addition there was no other specific activity going on in nearby bays (e.g. doctors' periodic visit). The measurements were an attempt to determine a correction factor to apply to a measurement taken near the lighting fixture (inset in Figure 1), which was the proposed mounting point for the MEMS microphone. This correction factor would enable measurements near the light fitting to be translated into the more relevant measure of the expected level near the head of a patient. Once a clinically acceptable position was agreed and the method for securing the device decided, a number of recordings were taken to assess the effect of different positions of the microphone on sound pressure level recording.

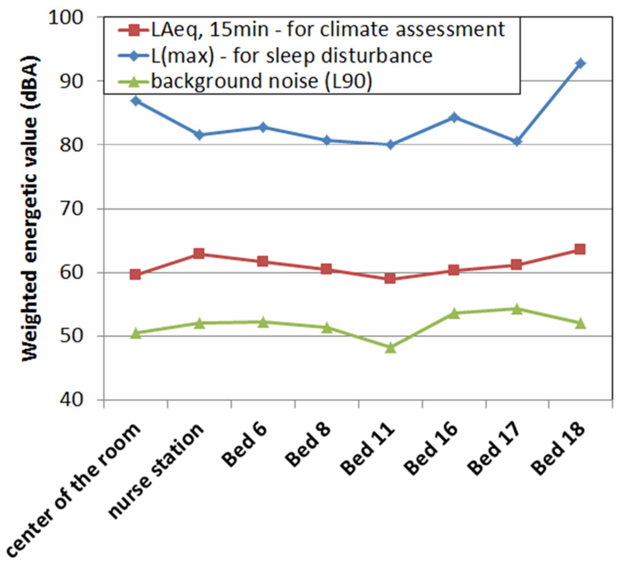

Figure 2: Representation of the on-site acoustical levels data in 15 minutes time intervals.

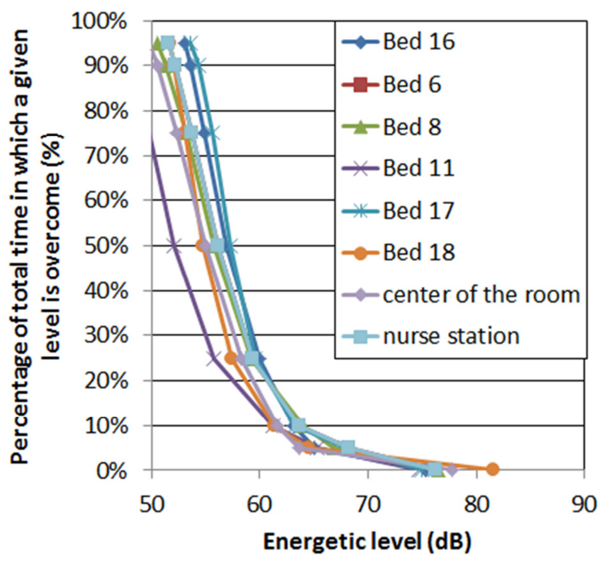

Figure 3: Representation of the on-site measurements in terms of percentage levels (15-minutes intervals).

2.2 Discussion (15-minutes periods)

The analysis of 15-minutes periods is aimed at determining the acoustical fingerprint of the area investigated and an ordered list of the measurement locations, from the "most disturbed" to the "most tranquil" [26]. Recent studies seem to confirm that the effect of the short-term dynamics of L_{Aeq} on annoyance and the temporal span of interest, the time needed for a "user" to emit a qualitative judgement on the soundscape of a location seems to sit around 15 minutes [27]

Figure 2 demonstrates the consistency of 15-minutes levels across the eight bed spaces surveyed: both the L_{Aeq} and the L_{90} show little variation, even if the measurements were taken at different times of the day and in different locations. These data show a potentially critical situation, as both L_{Aeq} and L_{90} are significantly higher than the values recommended by the World Health Organization in 1999, with L_{Amax} greater than 80 dB in the majority of bed spaces. Only bed 11, which is located in a side room and not in one of the bays, seems to show lower sound pressure levels.

Figure 3 identifies the statistical levels for each bed space, averaged over the two 15 minute recording periods. These levels summarise how much the noise level varied during the period of observation. Figure 3 should be read as follows: once a level is selected (e.g. 60 dB), the curves indicate how long in the 15 minutes of monitoring the level went above the selected value.

Even from this point of view, bed 11 – in a side room – appears to be different: it experienced lower energy levels for the majority of the time period, with the remaining areas and bed spaces demonstrating a similar pattern. However, should a particular level be selected, a simultaneous comparison of Figure 2 and Figure 3 can be used to distinguish two locations with the same L_{Aeq} and to attempt their classification in terms of "tranquillity".

Taking for example 60 dB, this level was overcome approximately 10% of the time at the "centre of the room" location (L_{Aeq} = 59.6 dB), but approximately 25% of the time near "bed 8" (L_{Aeq} = 60.5 dB) or at the "nurses' station (L_{Aeq} = 62.9 dB)", which are both in the higher acuity ICU area. While the staff base has a level which is considerably higher than the other points, and therefore goes towards the "disturbed" area of the scale, the average level measured at the centre of the six bedded bay is similar to the one near bed 8 (which is in centre of the larger bay – see Figure 1). While the overall impact on increased heart rate may be similar (this parameter seems to depend on L_{Aeq} [25]), the patient in bed 8 would potentially be more annoyed by unwanted sounds: at equal energy levels, annoyance has in fact been correlated with the number of noisy events over the background ("emergencies") [27]. Only the monitoring over longer time scales will confirm this preliminary conclusion.

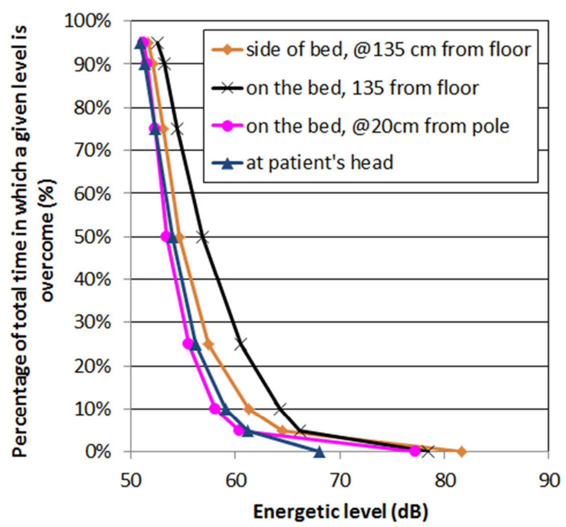

Figure 4: Statistical levels referred to different positions of the microphone near bed 18 (15-minutes intervals).

Figure 4 shows the effect of different positions of the microphone on measured sound pressure level around bed 18. These measurements were made to estimate a correction from the measurement mounted on the lighting fitting (and therefore influenced by the ceiling and the presence of the fitting itself) and the levels actually experienced by the patient (with his/her head on the pillow).

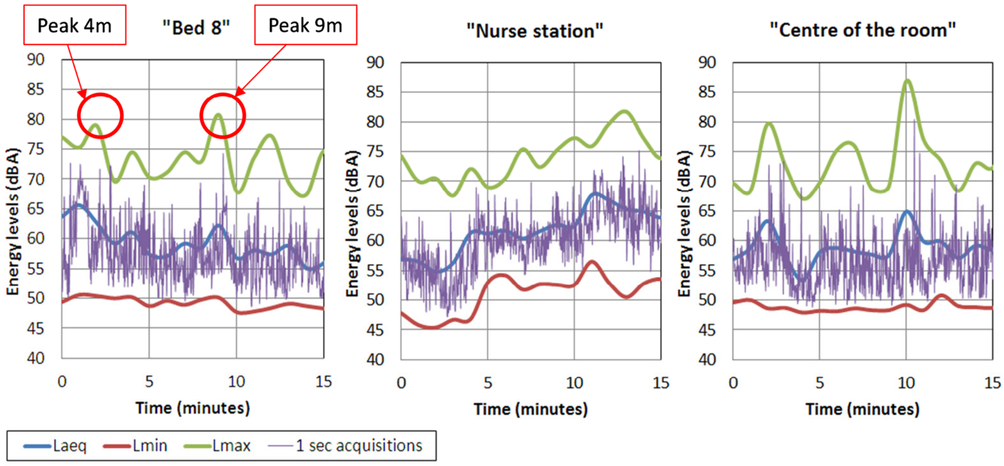

Figure 5: Energetic levels for three locations relative to 1 minute time intervals (initial 15 minutes). The plots also show the relative 1-second L_{Aeq} values, for comparison.

Figure 4 shows that the levels are quite close if the microphone is positioned at 20 cm from the pole. For the measurements closer to the ceiling, levels are about +1.5 dB(A) higher than that actually experienced by the patient. This correction, while requiring a more precise statistical weighting before being applied, gives a sufficient indication that it is possible to measure the local exposure of a patient in bed by taking measurements above the bed itself (see also section 3). The larger values measured near the bed are an indication of the reflections (due to side machinery) that would instead affect a similar measurement position (or a visitor sitting close to the bed).

2.3 Discussion (1-minute periods)

The passage from 15 minutes to shorter time-averages is due to the combined desire of identifying the sources, which often have a shorter life-time, and of capturing indicators more closely related to short-term perception. In this sense, the shorter the averaging time, the better. On the other hand, since large amounts of data require large storage and powerful interpretation algorithms, as the patterns can easily get lost, a compromise is required. With the shorter reported "habituation time" [28] being 3 minutes, the Nyquist theorem indicates 1- minute averages as the first good choice.

Figure 5 shows the 1-minute values of L_{Aeq}, L_{max}, L_{min} for three different locations, during the first 15 minutes of the relative acquisitions. Also shown, in each case, are the corresponding 1-sec values of L_{Aeq}, for comparison. Not surprisingly, being a 60-points moving average, the 1-minute curve is always much smoother than the corresponding 1-sec one: the question is whether the lost information is important or can somewhat be recovered during unassisted monitoring.

As an example, since acquisition was occurring at FAST rate, the extreme values (L_{max}, L_{min}) are preserved when passing from 1-sec to 1-min averages and the effects related to them (e.g. sleep disturbance) can be evaluated correctly using 1-minutes. For the other cases, the analysis of the 1-min statistical levels can help identifying features in the 1-sec dynamics. For instance, the peaks in the "bed 8" time history of $L_{Aeq,\ 1min}$ appearing 4 and 9 minutes from the start of the acquisition ("Peak 4m" and "Peak 9m", in Figure 5), during monitored analysis could respectively be assigned to a number of repeated noises (i.e. a nurse working around the bed side) and to banging occasional event (due to personnel hanging a curtain at the side of the bed). The relative statistical levels can be found in Figure 6 and the following features can be identified:

a) Both peaks last for 4 minutes and have a similar value of $L_{Aeq,\ 4min}$ = 57.8 dB(A);

b) the cumulative curves for the minutes before and after the event show a trend which is typical of the particular measurement location;

c) when the peak (i.e. an external activity) starts, the cumulative curve changes significantly: for peak 4m it gets closer to the average value of the 4 minute period – $L_{Aeq,\ 4min}$ is overcome approximately 60% in the minute of the peak, but the threshold of 70 dB(A) is never passed – while for peak 9m the cumulative curve moves towards the higher noise levels – $L_{Aeq,\ 4min}$ is overcome approximately 45% in the minute of the peak and 70dB(A) 5% of the time.

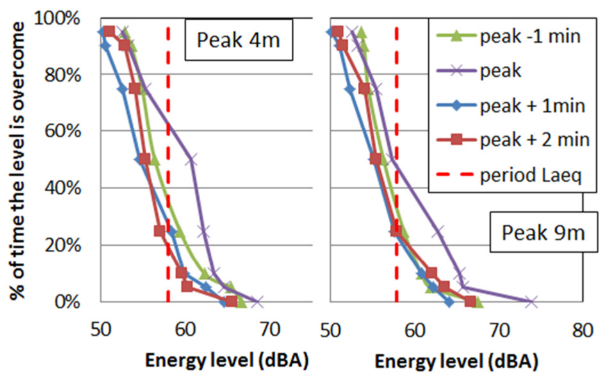

Figure 6: One-minute statistical levels, calculated from sixty $L_{Aeq,\ 1s}$ averages, for two peaks from Figure 5.

In unassisted measurements, these observations lead to assigning peak 4m to a lower noise, possibly repeated, and peak 9m to a higher energy single event. They would not tell anything more about the source of the noise, though. The presence of multiple microphones, acquiring simultaneously, will help in this direction.

3 Laboratory measurements at NPL

One of the constraints in locating the microphones in a busy hospital ward is that they do not obstruct medical activity in any way. As mentioned before, the layout of equipment around each bed space is common to most beds in the intensive care ward, and includes a structure fixed to the ceiling directly above the bed. This structure was identified as a suitable location for the microphone, mainly for pragmatic reasons, but one concern was the influence it may have on the measurements.

Figure 7 shows a mock-up of the mounting structure alongside the actual item (shown inverted). The acoustic influence of the structure was determined using a microphone with a nominally flat free-field frequency response (IEC type WS3F) mounted on a long rod, placed in the far field beneath a downward facing sound source in a hemi-anechoic chamber. The configuration in Figure 7 was then used to establish the free-field frequency response of the microphone, using a time gating technique to remove the influence of reflections from the floor. The microphone was then attached to the proposed mounting structure, and the measurements repeated, but this time without time gating. The influence of the mounting structure was then determined from the ratio of these two responses (or the difference in decibels), showing that there are three main components to this correction that needs to be isolated: reflections from the wall, reflections from the post, and corrections due to distance.

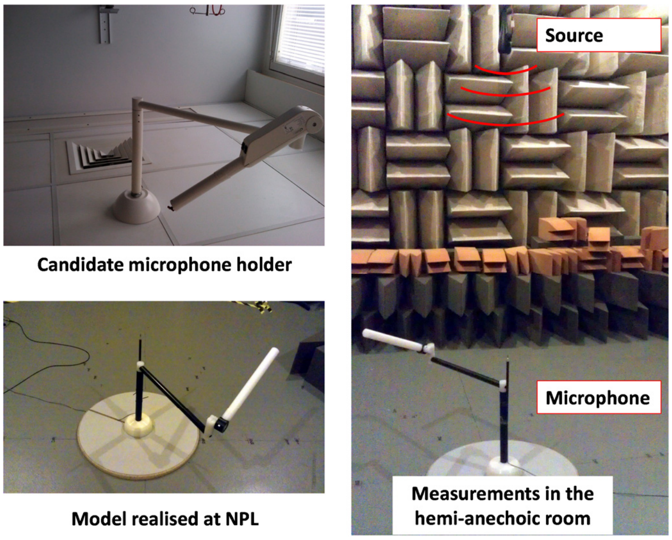

Figure 7: Measurement set-up in the NPL hemi-anechoic room, in order to estimate the effect of the mounting pole on the final measurements.

A series of measurements were made with the microphone mounted at different distances from the structure. After a broadband analysis, the effect of the mounting could be estimated as a correction of $+1.8 \pm 0.2$ dBA (microphone head at 15 cm from the mock-up fitting) and of $+0.65 \pm 0.1$ dBA (microphone at 27.5 cm from the central pole) to the data without it, confirming that the result presented in section 2.2 is mainly due to the fitting.

4 Towards a distributed system

The final system (currently named NPL-*Minim*) uses a specially optimised MEMS microphone with a frequency response conforming to IEC 61672-1 Class 1 [29]. Each unit features a DAQ unit to continuously acquire FAST-averaged A-weighted and C-weighted noise data, from which L_{eq}, L_{max} and six programmable percentile levels can be determined, at pre-determined time intervals. This data is held within the measurement unit, and periodically downloaded to remote storage using Wi-Fi, GPRS or LAN, using mains or battery power. The system is complimented by a comprehensive database with data filtering options and a range of web-based interfaces for analysing and visualising the data.

From the previous analysis, 1 minute intervals seem to be optimal for characterising St George's GICU: with percentage levels (L_5, L_{10}, L_{25}, L_{50}, L_{75}, L_{90}) allowing identification of some quicker dynamics. For maximum reliability, the units will be connected by wire to a local area network (LAN) and take advantage of locally available mains electrical power. The indoor environment therefore enables fully unattended operation over extended time periods. The only necessary intervention is for periodic re-calibration. However, past experience has shown that the MEMS microphones have excellent long-term stability [24]. The studies in the NPL hemi-anechoic room have highlighted the effect of the mounting at different distances from it. If 20 cm seem to be enough to reduce the interference effect of the mounting pole to about 0.5 dB, this distance was eventually shortened to allow the rotation of the horizontal pole. It was therefore decided to grip the microphones on the horizontal pole, as close to the vertical one as possible.

In these conditions, as a first approximation, the levels measured will need to be corrected by a factor of -1.5 dBA to represent the value at the head of a patient and by a further factor of -1.7 dBA (if it is needed to get rid of the reflections effects from the mounting). Once the microphones will be in place, a statistical analysis will allow a more precise identification of the uncertainty on these corrections. Measurements of the corrections in a fully reverberant environment will also help getting closer to the real situation in St George's GICU.

5 Conclusions

This study presented a preliminary analysis of the acoustic climate in the General Intensive Care Unit of St. George's hospital in London. The results indicate a noisier environment than recommended, but are consistent with previous findings. Together with some laboratory studies performed at NPL, these results identified most of the parameters (temporal resolution, indicators to acquire, corrections to apply) needed to configure a MEMS-based distributed noise monitoring system, to be deployed on site in the next months. Future studies will investigate the accuracy of the measurements and, once the system is in place, will pursue the complete soundscape characterization of the area. A dedicated questionnaire survey is anticipated at that stage.

Acknowledgments

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References

[1] H Xie, J Kang, G Mills, "Clinical Review: The impact of noise on patient's sleep and the effectiveness of noise reduction strategies in intensive care units", *Critical Care* 13, 208 (2009).

[2] M Monsén, U Edéll- Gustafsson, "Noise and sleep disturbance factors before and after implementation of a behavioural modification programme", *Intensive and Critical Care Nursing* 21, 208-19 (2005).

[3] N Freedman, J Gazendam, L Levan, A Pack, R Schwab, "Abnormal Sleep/Wake Cycles and the Effect of the Environmental Noise on Sleep Disruption in the Intensive Care Unit", *Am J Respir Crit Care Med* 16,3 451-7 (2001).

[4] I M Hweidi, "Jordanian patients' perceptions of stressors in critical care units: a questionnaire survey", *International Journal of Nursing Studies* 44, 227-235 (2007).

[5] A Richardson, M Allsop, E Coghill, C Turnock, "Earplugs and eye masks: do they improve critical care patients' sleep?", *Nursing in Critical Care* 12(6), 278-286 (2007).

[6] C Jones, D Dawson, Eye masks and ear plugs improve patients perception of sleep, *accepted for publication on to Nursing in Critical Care* (2012).

[7] J Gabor, A Cooper, S Crombach, B Lee, N Kadikar, H Bettger, P Hanley, "Contribution of the Intensive Care Unit Environment to Sleep Disruption in Mechanically Ventilated Patients and Healthy Subjects", *American Journal Respiratory Critical Care Medicine* 167, 708-715 (2003).

[8] A Hilton, "Quantity and quality of patients' sleep and sleep disturbing factors in a respiratory intensive care unit", *Journal of Advanced Nursing* 1, 453-468 (1976).

[9] G Ugras, S Oztekin "Patient perception of environment and nursing factors contributing to sleep disturbances in a neurosurgical intensive care unit", *Tohoku J Exp Med* 212, 299-308 (2007).

[10] N Lawson, K Thompson, G Saunders, J Saiz, J Richardson, D Brown, N Ince, M Caldwell, D Pope, "Sound Intensity and Noise Evaluation in a Critical Care Unit", *American Journal of Critical Care* 19, e88-99 (2010).

[11] Audit Commission, *Critical to success The place of efficient and effective critical care services within the acute hospital.* The Audit Commission, Oxford (1999).

[12] S Parthasarathy, M Tobin "Sleep in the intensive care unit", *Intens Care Med* 30(2), 197-206 (2004).

[13] M Topf, E Dillon, "Noise induced stress as a predictor of burnout in critical care nurses", *Heart Lung* 17, 567-73 (1988).

[14] B Berglund, T Lindvall (eds), *Guidelines for community noise*. World Health Organization, Geneva Switzerland (1999).

[15] European Parliament, D*irective 2003/10/EC on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (noise)* (2003).

[16] R Elliott, S McKinley, D Eager, "A pilot study of sound levels in an Australian adult general intensive care unit", *Noise and Health* 12, 26-36 (2010).

[17] D Kahn, T Cook, C Carlisle, D Nelson, N Kramer, R Millman, "Identification and modification of environmental noise in an ICU setting" *Chest* 114, 535-540 (1998).

[18] M Christensen, "Noise levels in a general intensive care unit: a descriptive study", *Nursing in Critical Care* 12(4), 188-197 (2007).

[19] S Li, T Wang, S Vivienne Wu, H Tung, "Efficiency of controlling night-time noise and activities to improve patients' sleep quality in a surgical intensive care unit", *Journal of Clinical Nursing* 20(3-4), 396-407 (2011).

[20] A McLaughlin, B McLaughlin, J Elliott, G Campalani, "Noise levels in a cardiac surgical intensive care unit: a preliminary study conducted in secret", *Intensive and critical care nursing* 12 (4), 226-30 (1996).

[21] N Akansel, S Kaymakci "Effects of intensive care unit noise on patients: a study on coronary artery bypass graft surgery patients", *Journal of Clinical Nursing* 17(12) 1581-90 (2008).

[22] EE Ryherd, KP Waye, L Ljungkvist, "Characterising noise and perceived work environment in a neurological Intensive Care Unit", *Journal of the Acoustical Society of America* 123(2), 747-56 (2008).

[23] R McCarney, J Warner, S Illiffe, R van Haselen, M Griffin, P Fisher, "The Hawthorne Effect: A randomized, controlled trial", *BMC Medical Research Methodology* 7, 30 (2007).

[24] R Barham, M Chan, M Cand, "Practical experience in noise mapping with a MEMS microphone based distributed noise measurement system", *Proceedings of Internoise 2010*, Lisbon, Portugal (2010).

[25] EEMM VanKempen, H Kruize, HC Boshuizen, CB Ameling, BAM Staatsen, AEM de Hollander "The Association Between Noise Exposure and Blood Pressure and Ischemic Heart Disease: A Meta-Analysis", *Environmental Health Perspectives* 110, 307-317 (2002).

[26] J Kang, *"Urban Sound Environment"*, Taylor and Francis, London (2006) and references therein.

[27] G. Licitra, G. Memoli, D. Botteldooren, B. De Coensel "Traffic noise and perceived soundscapes: a case study", *Proceedings of Forum Acusticum 2005*, Budapest, Hungary (2005).

[28] B De Coensel, D Botteldooren, T De Muer, B Berglund, M E Nilsson, P Lercher, "A model for the perception of environmental sound based on notice-events", *J. Acoust. Soc. Am.* 126(2), 656-665 (2009).

[29] International Electrotechnical Commission. *International Standard IEC 61672-1:2003. Sound level meters. Part 1: Specifications*. Switzerland (2003).