Workshop on Bio-Medical Instrumentation and related Engineering And Physical Sciences
Technological Educational Institute of Athens
Athens 6 July 2012

NOISE MONITORING AND ALARM SYSTEM FOR INFANT INCUBATORS

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Keywords: Incubator noise, infant health, neurological disorders, digital detector, automated control

Abstract. *Clinical studies have demonstrated a correlation between high noise levels in a neonatal intensive care unit (NICU) and health disorders in newborns. This work aimed at: (a) performing a qualitative and quantitative analysis of noise in the interior and exterior of NICU incubators, and (b) developing and evaluating a system to monitor noise and alert the NICU staff. The noise levels inside and outside the incubators of an NICU were recorded for three consecutive days. An automatic control system was also developed and clinically tested to monitor and record noise and generate a visual alarm when levels were above a selected threshold. Noise levels were above recommended standards inside and outside the incubators. The external noise sources were the routine activities of NICU personnel and the operation of other medical systems in the unit. The internal noise sources were the temperature and ventilation systems of the incubators. The proposed noise monitoring and alarm system could improve infant care. The system could raise awareness and improve NICU personnel training thus, effectively addressing one major, external source of noise. The system could also provide valuable data to the manufacturers, who, in the long run, could improve the technical specifications of the incubators.*

1 INTRODUCTION

Several clinical studies have shown that high noise levels in the NICU environment and/or the interior of the incubators could cause health problems on premature infants, namely infants born before the 37^{th} – 38^{th} week of pregnancy[1-13] . Sources of the external incubator noise include the nursing staff and clinical interventions on the newborns. Often, extremely high noise is caused by the alarms of the medical systems commonly used in an NICU including ventilators, monitoring devices, IV pumps, etc. Sources of the internal incubator noise include the thermoregulation and ventilation systems attached to the units.[11,14-16]

In general, noise exposure has adverse effects on the physical and psychological health as well as the cognition of children. The health problems associated with high, discrete or continuous, noise levels in the NICU may be classified in two broad categories: neurological disorders and hearing loss. Discrete, high noise may cause problems in distinguishing various audio frequencies later on, fluctuations in arterial pressure, increased heart and breathing rates, lower blood saturation that can, in turn, affect the development of vital organs, and increased intracranial pressure that could contribute to hypoxic brain damage.[1-4] There is also increased danger of weakening of the blood vessel walls in the neonatal brain and increased likelihood of problematic development of the central neurological system.[13-15] Continuous, annoying noise during sleep may increase heart and breathing rates, cause breathlessness, possibly decrease blood oxygen levels, and obviously cause sleep fragmentation and sleep deprivation with behavioral, cognitive, neurological, biochemical and other consequences.[5-12] Normal emotional development is finally threatened as environmental and mechanical noises in and out of the incubators interfere with the parents' voices particularly for prolonged incubators stays.[17-21]

For all the above reasons, experts and associated Institutions, such as the American Academy of Pediatrics and the British Association of Perinatal Medicine, have established noise limits for the interior of the incubators. These limits are 45 dB during the daytime and 35 dB at night.[2,3,7,12,18] These limits, however, are often exceeded even in the most modern NICUs. The purpose of this study was twofold: (a) evaluate and analyze the noise inside and outside the incubators of an NICU, and (b) develop a monitoring and alarm system that would notify NICU personnel when noise exceeded set thresholds.

2 MATERIALS AND METHODS

Noise was measured for three consecutive days, three times per day, inside and outside the incubators of the NICU of a major, public hospital of Athens, Greece. Measurements were recorded at the same time every day, namely at 06:00, 12:00, and 18:00. Measurements were recorder under three conditions: (i) incubator off, (ii) incubator on, (iii) incubator and oxygen supply on.

A Mastech MS6701 sound meter was used for all recordings. Four types of incubators were studied: the Dräger-Air Shields C-200 (Lubeck, DE), the Dräger-Air Shields C-450, the Dräger-Hill Rom Air Shields C-2000, and the Ohmeda-Giraffe (GE Healthcare). The sound meter was calibrated prior to the measurements and was adjusted to operate in the range of noises audible to the human ear at a "SLOW" rate. The noise outside the incubators was recorded with the meter positioned at a central location in the NICU room. Subsequently, the meter was placed inside an empty incubator at a height corresponding to the level an infant's ears would be, had it been inside the unit. Noise levels were recorded with the incubator off, the incubator on, and the incubator and oxygen supply on (a typical supply of 5 l/min was used for the measurements). A time delay was used for the last two measurements to allow the systems to stabilize.

To evaluate and analyze noise levels properly, the z-statistic was used to determine the minimum number of measurements required for statistical significance. It was estimated that a minimum of 30 measurements were necessary to yield statistically significant results at the p=0.5 level. Thirty-two measurements were, thus, recorded inside and outside the incubators for each operating condition.

Following the noise measurements, an electronic circuit was designed and developed for monitoring noise levels and alarming NICU personnel when levels exceed a specified value. The system included voltage amplifier, voltage comparator, and voltage divider circuits with an indicative light emitting diode (LED). The circuit is shown in Fig. 1. The reference voltage is set at the output of the voltage divider. A reference voltage of 45 dB was selected for this study. The voltage amplifier circuit includes an LM358, which amplifies the output of the sound meter and sends it to the comparator circuit where the signal from the incubator is compared to the reference voltage from the divider. When the sound meter's output voltage is higher than the reference voltage, the LED is activated notifying NICU personnel that the noise level inside the incubator exceeds the set threshold.

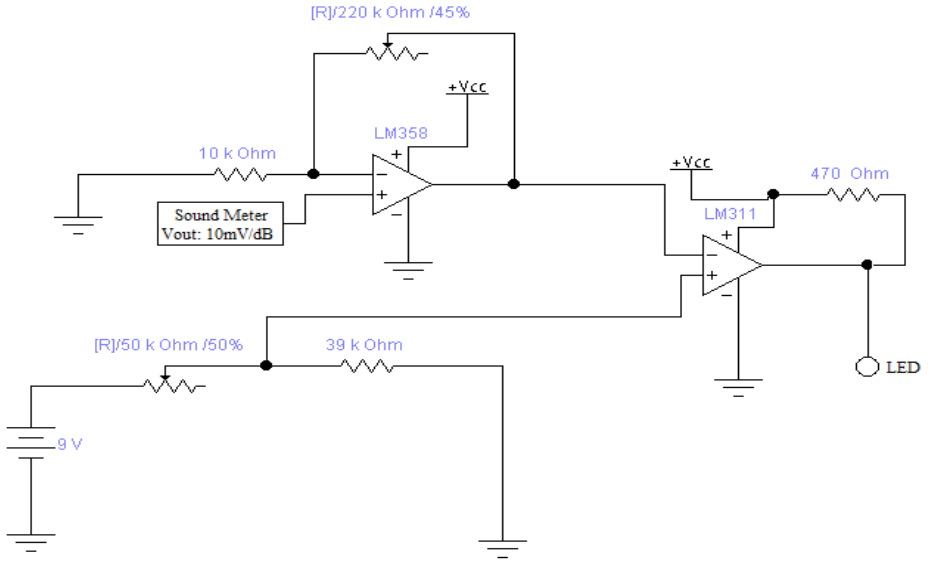

Figure 1. Circuit of the developed incubator noise monitoring and alarm system.

A low cost, compact unit was developed of the circuit in Figure 1 that is shown in Figure 2 along with the meter. The unit was light weight and measured 14cm×11cm×3.5cm.

Figure 2. Complete detector unit and sound meter placed inside an incubator; LED is on indicating that noise levels exceed reference value.

3 RESULTS AND DISCUSSION

Table 1 lists three day averages of the noise levels registered inside the four incubators under the three modes of operation as well as in the NICU environment.

Measurement No		1	2	3
Time of measurement		6:00	12:00	18:00
Noise level (dB)	**NICU**	43.8	51.7	45.5
	Incubator OFF	36.5	40.8	38.3
	Incubator ON	50.6	51.3	50.6
	Incubator ON with 5 l/min O_2 supply	50.8	51.8	50.7

Table 1. Noise levels in the NICU room and inside the incubators (average of four units).

Figure 3 shows the fluctuation of the noise level in the three day period. High noise levels were recorded in the NICU room peaking at noon time primarily due to increased activity of the nursing and medical staff. The noise inside the incubators was below standards when the incubator was OFF but significantly above the recommended daytime levels when the temperature and ventilation systems were ON. Interestingly, the recommended maximum noise of 35 dB at night time was always exceeded. Higher oxygen supplies led to even higher noise levels in the range of 60-65 dB.

The noise monitoring and alarm system performed according to specifications. When a 45 dB reference was selected, the visual alarm was continuously OFF when the incubator was OFF since the noise was always below the threshold. The alarm went ON and OFF when it monitored the NICU environment. Specifically, it went ON during noon time when the activities in the unit were increased

and the corresponding levels increased by as much as 20% (Fig. 3). The visual alarm was continuously ON when the incubator temperature and ventilation systems were ON.

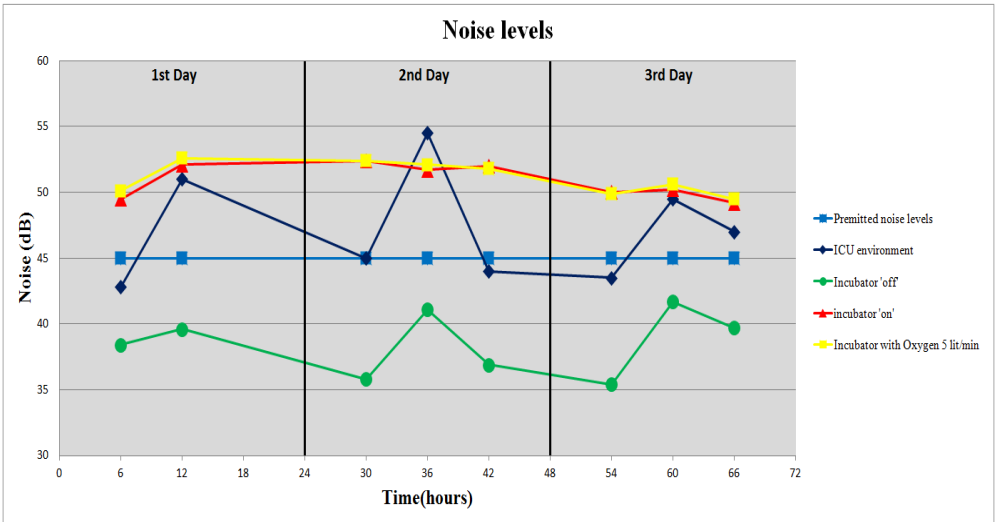

Figure 3. Noise levels recorded inside the incubators under different operating modes. The recommended daytime threshold of 45 dB is also indicated for comparison purposes.

The reliable, reproducible, and efficient performance of the developed system and its successful testing in the clinical environment suggested the following possible uses:

(i) A reliable and "silent" method to raise awareness in the nursing and medical staff regarding noise pollution in the NICU and alert then when recommended thresholds are seriously exceeded so that they can take immediate corrective measures, thus, reducing the likelihood of adverse effects on the newborns.

(ii) A method to accrue statistical data on the performance of the incubators under different operating modes that could be used by the manufacturers of incubators in new and improved designs of their systems that conform with accepted specifications. It is possible that increased incubator chamber wall thickness or different materials would reduce the noise reaching the newborns.

(iii) As a research and educational tool in studies or class work involving noise measurements or experiments since the sound detector may be calibrated to perform in a wide range of noises. The system is currently used in the laboratory of the Automatic Control Systems at the Department of Medical Instruments Technology of the Technological Educational Institute of Athens for the execution of sound detection experiments.

4 CONCLUSIONS

In conclusion, incubator noise is of concern in the NICU since it often significantly exceeds recommended clinical levels. The notification of the NICU personnel for high noise levels can be easily achieved with the proposed low-cost, automatic noise monitoring and visual alarm system so that corrective measures are promptly taken improving infant health care and reducing the likelihood of induced physical, psychological, or cognitive disorders later on.

REFERENCES

[1] Wachaman, E. M., Lahav, A. (2010). "The Effects of Noise on Preterm Infants in the NICU." Arch Dis Child Fetal Neonatal Ed. doi:10.1136/adc.2009.182014.

[2] Abramovich, S. J., Gregory, S., Slemick, M., and Stewart, A. (1979). "Hearing Loss in Very

Low Birthweight Infants Treated With Neonatal Intensive Care." Archives of Diseases in Childhood, 54:421-426.

[3] Abril, A. A., Terron, A., Boschi, C. and Gomez, M. (2007). "Review of noise in neonatal intensive care." Journal of Physics, Conference Series, 90: 012038.

[4] Altuncu, E., Akman, I., Kulekci, S., Akdas, F., Bilgen, H. and Ozek, E. (2009). "Noise Levels in Neonatal Intensive Care Unit and Use of Sound Absorbing Panel in the Isolette." International Journal of Pediatric Otorhinolaryngology, 73: 951–953.

[5] American Academy of Pediatrics (1997). "Noise: A Hazard for the Fetus and Newborn." 100(4): 724-727.

[6] Anagnostakis, D., Petmezakis, J., Messaritakis, J. and Matsaniotis, N. (1980). "Noise Pollution in Neonatal Units: A Potential Health Hazard." Acta Paediatr, Scand 69: 771-773.

[7] Carvalho, A. P. and Pereira, L. F. (1998). "Noise in Infant Incubators and in Neonatal Intensive Care Units." Proceedings of Internoise, New Zealand.

[8] Darcy, A. E., Hancock, L. E. and Ware, E. J. (2008). "A Descriptive Study of Noise in the Neonatal Intensive Care Unit." Advances in Neonatal Care, 8(5S): S16-S26.

[9] Kakehashil, T. Y., Pinheiro, E. M., Pizzarro, G. and Guilherme, A. (2007). "Noise Level in Neonatal Intensive Care Unit." Acta Paul Enfrem, 20(4): 404-409.

[10] Kent, WD, Tan, AK, Clarke, MC and Bardell, T. (2002). "Excessive Noise Levels in the Neonatal ICU: Potential Effects on Auditory System Development." The Journal of Otolaryngology, 31(6): 355-360.

[11] Lasky, R. E. and Williams, A. L. (2009). "Noise and Light Exposures for Extremely Low Birth Weight Newborns During Their Stay in the Neonatal Intensive Care Unit." Pediatrics, 123: 540-546.

[12] Liu, L., Gujjula, S., Thanigai, P. and Kuo, S. M. (2008). "Still in Womb: Intrauterine Acoustic Embedded Active Noise Control for Infant Incubators."Advances in Acoustics and Vibration, Article ID 495317, 9 pages, doi:10.1155/2008/495317.

[13] Liu, L., Kuo, S. M. and Gujjula, S. (2009). " Development and Applications of Active Noise Control System for Infant Incubators." Proceedings of the IEEE International Conference on Systems, Man, and Cybernetics, San Antonio, 2659-2664.

[14] Markou, K. (2010). "Premature newborns: Early battle in life." In Greek, (http://www.healthierworld.gr/portal/cc7146d26842552e/31ab328e47c4ea3f/75181a27e029e8d9/30c54fe92fc8181d/38cf68d1a447b6a0.html), last accessed March 22, 2011.

[15] Robertson, A., Cooper-Peel, C. and Vos, P. (1999). "Sound Transmission Into Incubators in the Neonatal Intensive Care Unit." Journal of Perinatology, 19(7): 494-497.

[16] Thanigai, P., Kuo, S. M. and Yenduri, R. (2007). "Nonlinear Active Noise Control for Infant Incubators in Neo-Natal Intensive Care Units." Acoustics, Speech and Signal Processing, IEEE, 1: I-109-I-112.

[17] Yu, X., Gujjula, S. and Kuo, S. M. (2009). "Active Noise Control for Infant Incubators." Annual International Conference of the IEEE EMBS, Minneapolis, 2531-2534.

[18] Morris, B.H., Philbin, M. K., Bose, C. (2000). "Physiological Effects of Sound on the Newborn." Journal of Perinatology, 20: S54-S59.

[19] Quest Technologies, "Noise in Neonatal Intensive Care Units" (http://www.questtechnologies.com/Assets/ Documents/AppNotes/098-513.pdf), last accessed March 17, 2011.

[20] Surenthiran, S. S., Wilbraham, K., May, J., Chant, T., Emmerson, A. J. B. and Newton, V. E. (2003). "Noise Levels Within the Ear and Post-nasal Space in Neonates in Intensive Care". Arch Dis Child Fetal Neonatal Ed, 88: F315–F318.

[21] Szczepanski, M., Kamianowska, M. (2008). "Evaluation of noise in the neonatal intensive care unit." Archives of Perinatal Medicine, 14(4): 37-40.