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PRELIMINARY CLUSTERING ANALYSIS OF NOISE IN A HOSPITAL ROOM

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ABSTRACT

In recent years, noise levels in hospitals and healthcare facilities have been on the rise. This becomes a significant concern as high levels of noise can negatively affect patients' recovery and interfere with communication between healthcare providers and patients. Furthermore, hospital noise can also have a negative impact on staff, leading to increased stress, fatigue and decreased job satisfaction. The present paper investigates environmental noise in a hospital setting by analyzing the sound pressure levels and comparing it with the WHO guidelines' limitations. Moreover, this work tries to overcome the classical analysis by exploiting the Gaussian Mixture Model (GMM) clustering algorithm to separate the noise sources during the morning round into two different clusters: mechanical and human noise. The mechanical noise cluster is further analyzed by comparing it with the sound pressure level collected in another room where only the mechanical sources were on. The results show that the GMM can provide important details of noise sources even in occupied conditions and that the proposed approach can effectively identify different noise sources in a hospital environment, which can potentially help in the development of noise control strategies and improve the overall acoustic environment for patients and staff.

Keywords: *Hospital, Environmental Noise, Machine Learning*

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1. INTRODUCTION

Hospital noise is a pervasive problem that affects both patients and staff [1]. Despite the importance of quiet in the healing process, many hospitals are excessively noisy environments [2,3]. The sources of noise are numerous and include equipment alarms, overhead paging, ventilation systems, staff conversations, and even the movement of carts and equipment. Excessive noise can have a range of negative effects on patients, including increased stress levels, sleep disturbance, and difficulty communicating with healthcare providers [4]. Additionally, high levels of noise can lead to decreased job satisfaction and increased stress among hospital staff [5]. As such, reducing hospital noise has become an important focus in healthcare in recent years, with many hospitals implementing noise reduction strategies and guidelines to promote healing environments.
The World Health Organization (WHO) recommends that hospital noise levels should not exceed 35 decibels (dB) during the day and 30 dB at night in patient areas [6]. Moreover, sound-absorbing materials should be used in hospital design and construction to reduce the reverberation time and to create a more soothing acoustic environment [7]. Previous studies generally investigated the environmental noise inside hospitals through the classical metric of sound pressure levels or used supervised analysis of the hospital noise. Machine learning has already been used in acoustics to analyze environmental noise in classrooms and offices [8,9] and demonstrated to be a solid tool to separate noise sources in hospital facilities [10].
In this study, a phonometric campaign has been carried out in a fully occupied room and in fully unoccupied room of a university hospital in Italy. A comparison with the WHO guidelines' limitation has been reported. This study also provides the results of an experimental campaign of reverberation time (T_{20}) inside the unoccupied room where only the ventilation systems were on. Then, the Gaussian Mixture Model (GMM) algorithm has been used to

investigate deeply the acoustical context of the data collected during the most disturbing period of the day for patients, the morning round. Clustering helped to separate and classify the noise sources into two different groups: the "mechanical noise", which includes HVAC system, air exchanger and life-saving equipment, and "human noise", which includes speech and human activities. Finally, a comparison between the mechanical noise coming from the algorithm and the results of the experimental campaign of the unoccupied room has been provided. The results showed a good agreement validating the method and demonstrating the goodness of machine learning as a solid tool to deeply analyze the acoustical context, even in complex situations. Moreover, understanding the noise sources may allow to develop targeted strategies to reduce environmental noise inside hospitals.

2. METHOD

2.1 SPL monitoring

A 48 hours phonometric campaign has been carried out in a fully occupied four bed bay and in a fully unoccupied four-bed bay. Both have similar shape and building design and they were placed in different portion of the same geriatric ward of the hospital. SPLs have been monitored for two consecutive days (from Thursday to Saturday) using calibrated 01dB DUO sound level meters with a data acquisition of 100 ms. The time histories of both rooms are reported in Figure 1.

2.2 Reverberation time

The reverberation time (T_{20}) of the unoccupied room was investigated to better analyze the response of such an environment. There are no Italian or European regulations for reverberation time in hospitals wards and facilities at the moment this paper is written. The Swedish Standard 25268:2007 [11] and the Danish Regulation for BR 18:2019 [12] have been taken as references for reverberation time limitations inside the hospitals. It was not possible to make the reverberation time measurements in the occupied room because of the proximity of sensitive receivers. The reverberation time has been measured according to ISO 3382-2:2008 [13]. Two source locations and six different receiver locations have been used.

2.3 Noise sources clustering

A clustering technique has been used in the present study to separate and classify the different sound sources inside the hospital environment. The statistical analysis was conducted using an approach previously employed in offices and schools [8,9] through the Gaussian Mixture Model (GMM) algorithm, processing the occurrences of short-time equivalent levels. The GMM is a clustering method which decomposes the original data into a sum of gaussian curves. First, it is used to perform a preliminary clustering, finding distinct numbers of candidate noise sources; then it selects the best candidate through clustering validation. Finally, it associates each cluster to a noise contribute based on statistical conditions. In particular, the standard deviations of the gaussian curves are used as primary metric to separate noise sources into clusters. In this work, two clusters have been chosen to classify noise sources: mechanical or human. A value of standard deviation below 5 dB defines a mechanical source, whereas a higher value of 5 dB defines a human-related source. To validate this method to investigating the complex context of a hospital room.

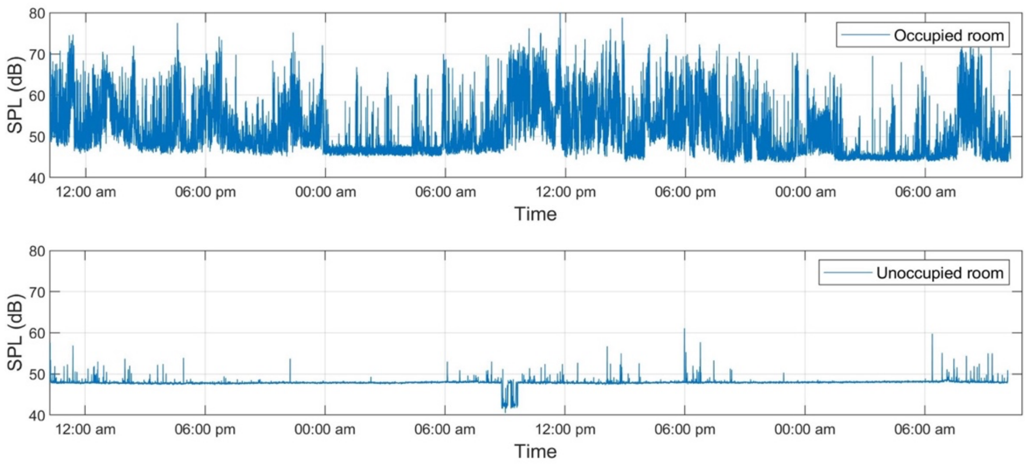

Figure 1. Time histories of the equivalent levels $L_{Z,\,eq}$ collected during the two-days monitoring in the occupied room (Top) and in the unoccupied room (Bottom)

In this work, the GMM algorithm has been used to identify and classify the sound sources inside a fully occupied hospital room. The data collected during the most disturbing period of the day for patients, i.e. the morning round, have been used as input for the algorithm. Specifically, the period between 09:00 a.m. and 11:00 a.m. of the second day of recording has been considered. The aim has been to validate this method also in complex situations, where heterogeneous and intermittent noise sources were of concern.

3. RESULTS AND DISCUSSION

3.1 Noise levels and reverberation time

Two 48-hours SPL monitoring have been carried out in the occupied room and in the unoccupied room. The histogram of Figure 2 shows a comparison between the A-weighted SPL of both rooms and the WHO guidelines' recommendations. Values of $L_{A,eq}$ and $L_{A,\,MAX}$ for daytime and nighttime period have been provided.

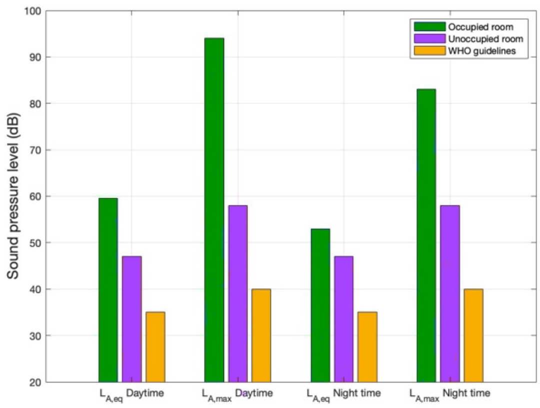

Figure 2. A-weighted SPLs for the occupied and unoccupied rooms compared with the recommended valued of the WHO guidelines.

The results are comparable with previous studies and confirm that the WHO recommended values are not satisfied in the occupied room, daytime and nighttime. Moreover, the unoccupied room doesn't satisfy the recommendations, even though only the HVAC systems were switched on. The experimental measurements for the reverberation time have been carried out in the unoccupied room. The results in terms of T_{20} are shown in Table 1. The Danish Building Regulation (BR18) and the Swedish Standard for Sound Classification of spaces in buildings set a maximum value of reverberation time of 0.6 s in the frequency range between 12-4000 Hz with a 20% liberation for the octave-band 125 Hz. Table 1 shows that the recommended values are not satisfied in the unoccupied room.

Table 1. Reverberation time measured in the unoccupied room in the frequency range 125-4000 Hz.

Frequency	125 Hz	250 Hz	500 Hz	1k Hz	2k Hz	4k Hz
T_{20} (s)	1.81	1.35	1.74	1.55	1.68	1.44

3.2 Analysis of the morning round

This section provides the results of the study focused on a specific period of the day: the morning round. During the morning round, human activities are associated with verbal communication between staff and students and between staff and patients. GMM algorithm has been applied to the collected SPLs of the morning round, in order to obtain the sound sources' separation in two clusters, mechanical and

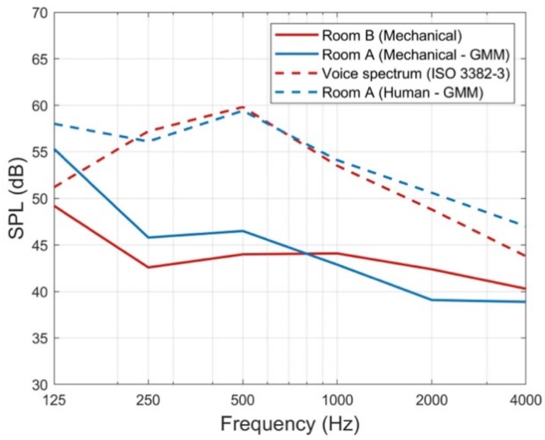

Figure 3. The reconstructed one-octave band spectra of the mechanical and human noise compared, respectively, with the spectra of the unoccupied room and with the directional speech spectrum according to ISO 3382-3

human. Figure 3 shows the results of the clustering. The human-related spectrum obtained via GMM has been compared with the anechoic directional speech spectrum, according to ISO 3382-3 [14], showing a good agreement. Moreover, the mechanical-related spectrum obtained via GMM has been compared with the spectrum coming from the unoccupied room, where only the ventilation systems and alarms were switched on. Differences in low frequencies can be related to the presence of the air exchanger in the occupied room, which was not switched on in the unoccupied room. Differences between 1000 and 2000 Hz may be due to the presence of people inside the room in the occupied room.

4. CONCLUSION

In the present study, two distinct noise monitoring have been made continuously for two days in an occupied four-bed bay and an unoccupied four-bed bay. The monitoring's initial findings support earlier research findings and acknowledge that sound pressure levels consistently surpass the World Health Organization-recommended norms. Additionally, the reverberation time measured in the empty room exceeds the standards established by the Swedish Standard and the Danish Regulation for hospital facilities (> 1.5s). Furthermore, a more in-depth analysis of the results showed that human sources can be responsible for a sizable portion of the total sound pressure level during the routine rounds. These results were obtained using the Gaussian Mixture model, a source-separation machine learning technique, which made it possible to distinguish between human and mechanical sources of noise in the environment.

A comparison between the mechanical component coming from the ML algorithm and the SPL collected in the unoccupied room where only the HVAC system was switched on has been made. The results showed a good agreement, validating the method and confirming the goodness of the GMM algorithm to identify different sound sources, even in complex situations. This study might serve as a springboard to move beyond the conventional analysis in which the sound pressure level is used as the primary metric to assess the ambient noise in hospitals.

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