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Study of Evaluating Indoor Noisiness in Hospitals under Temporal Varieties using Autocorrelation Analysis

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ABSTRACT

People in the hospital require tranquillity more than others and noise may cause greater damages to the patients. In general hospital buildings, hospitals need to maintain enormous mechanical facilities, which are the main source of noise in hospitals. Noise hazards of 16 general hospitals (single buildings) located in Taiwan were investigated in this study. As the initial stage of the investigation, the heavily trafficked hospital lobbies, including the space of the registration and dispensary counters, were chosen as the investigation objects. A 15-minute equivalent continuous noise level (Leq A) was used to display the possible noise events in the building environment plan of the hospitals. The results indicate that there is a high correlation coefficient ($r = 0.76$, $p < 0.05$) between the noise concentration rate of noise events and the scale values of being agitated by noise in lobbies as shown in the results of the noise psychology questionnaires. It worthily notes that autocorrelation analysis is applied for detecting the preferences stage of sound field as suggested by Yoichi Ando will be effective on noisiness, too.

INTRODUCTION

Ando [1] proposed that fundamental subjective attributes for sound fields are well described by a model of the auditory-brain system. It includes autocorrelation function (ACF) and interaural crosscorrelation function (IACF) mechanisms. Important mechanisms in this model were discovered in relation to the auditory-brain activity [2]. It is discussed that primary sensations loudness, pitch and timbre, in addition duration sensation which is introduced here as a noisy sensor, and noise cumulative sensations are described by temporal factors extracted from the ACF.

People in the hospital require tranquillity more than others and noise may cause greater damages to the patients. In general hospital buildings, noise was caused by enormous mechanical facilities, and daily routine medical treatment activities, such as the noise of carts, furniture, beds, interviews, or even TV. In addition, for the convenience of patients, staff, and visitors of the hospital, more and more convenience stores are opened in the hospital lobby, which in some ways changes the complexity of noise characteristics in the hospital lobbies. These environmental noises have been evaluated according to sound pressure level (SPL) and frequency characteristics [3]. Noise criterion (NC) curves, preferred noise criterion (PNC) curves and balanced noise criterion (NCB) curves were developed to measure the SPL and its frequency characteristics [4-6]. For evaluating fluctuation noise such as traffic noise and industry noise, the equivalent sound level (Leq) has been used widely. It has been reported that aircraft noise evaluated with power spectrum on the subjective sensations of conversation articulation is not quite accurate [7]. In noise measurement, it is important to clarify the relationship between physical properties and psychological affects. In this study, noise hazards of 16 general hospitals (single buildings) located in Taiwan were investigated. A 15-minutes equivalent continuous noise levels (LeqA 15min) measurement from 9:00 am to 5:00 pm as proposed by Yamada [8, 9] was first used to display the possible noise events in the lobby of the hospitals. Moreover, the questionnaire survey was derived from the people who had been at the lobby of 16 hospitals simultaneously, no matter patients, or the companies to the patients. The results indicate that there is a high correlation ($r = 0.76$, R2 = 0.58) between the noise concentration rate (NCR) of noise events and the scale values of noisiness by questionnaire in lobbies. Also, a strong connection ($r = 0.76$, $R^2 = 0.57$) is observed in a temporal factor extracted from the autocorrelation function (ACF) being agitated by LeqA (15min) of noise to the NCR in lobbies [7, 10, 11]. That is, the diversification of lobby functions (namely the diversification of human behaviours) is one of the reasons that make people agitated by noise.

METHOD

Noise Measurement

The measurements were performed by dividing measurement into indoor and outdoor. The actual measurement of indoor/outdoor noise included: (1). Two points in the waiting space that are most frequently used by people coming to the hospital (the two ends of a diagonal line chosen from the side by the counter in the hospital lobby) were selected for indoor measurement (**Figure 1**); (2). One fixed point on the lot line at the front side of the building facing to the main road that does not hinder traffic circulation and is at least 1m away from the outer wall of the building was selected as the outdoor measuring point and the measurement was made simultaneously with these two points in between the lobby (**Figure**

1). When the outer wall is adjacent to the road or when the distance between the wall and the road is within 1m where the microphone cannot be installed, another side of the outer wall shall be chosen and the measurement shall be made 1 m away from the outer wall in principle. If the distance between the main entrance and boundary of the main road is larger than 6 m, the case will be barred from participation. The noise levels shall be measured 8 hours a day (32 recordings); the 15 minutes continuous equivalent continuous noise levels (LeqA: FAST) were obtained by noise meters specified in IEC651 TYPE 1 and the calibration procedures have been done properly. In an initial stage of this research, the noise meter needed to save the instant data and generated a mount of LeqA for 8 hours, two measuring point. It was pity that the frequency responses were not recorded simultaneously.

Measurement objects

The hospitals measured were mostly general hospitals (coded A...P) and they all underwent the screening procedure. Totally 16 hospitals were measured were selected to achieve the statistical reliability. For the sake of fairness of measurement, the buildings of general hospitals chosen wee mostly single buildings (including a small inner court design) and large hospital lots with multiple buildings have been avoided.

Questionnaire surveys of noisy-sensation

This study was intended to investigate the psychological response to noise in the lobby of hospitals. The number of samples required for each hospital should be determined according to the standard deviation of questionnaire replies, thus, more than 60 questionnaires per hospital have been collected. The samples were taken from people aged above 10 in hospital lobbies who were willing to participate in the survey. The total number of participants was 1194. The main contents of the questionnaire included the psychological judgment of the noisiness using Likert 5-point scale [15]. The 5 point scale was deterrmined by 5 grades of conditions: (1). nothing about noise; (2). a little bit noisy; (3) normal degree; (4) quite a little noisy and (5) extremely noisy.

Autocorrelation Function (ACF)

The autocorrelation function (ACF) is defined by

$$\Phi_p(\tau) = \frac{1}{2T}\int_{-T}^{+T} p'(t)p'(t+\tau)dt \cdots\cdots\cdots\cdots (1)$$

Where $p'(t) = p(t)s(t)$, in which $p(t)$ is the sound pressure and $s(t)$ is the ear sensitivity. For convenience, $s(t)$ may be chosen as the impulse response of the A-weighted network. The value τ represents the time delay, and the value of 2T is the integration interval. There are four significant parameters from the ACF [2].

The first factor is a geometrical mean of the sound energies arriving at both ears, $\Phi(0)$, which is expressed by

$$\Phi(0) = [\Phi_{ll}(0)\Phi_{rr}(0)]^{1/2} \cdots\cdots\cdots\cdots (2)$$

where $\Phi_{ll}(0)$ and $\Phi_{rr}(0)$ are the normalized ACFs at delay time $\tau = 0$ for the left and right ears. They correspond to an equivalent sound pressure level. The second factor is the effective duration of the normalized ACF, τe, which is defined by a 10-percentile delay of the normalized ACF, representing repetitive features or reverberation contained within the signal itself. The definition of τe is shown in **Figure 3(a)**. Loudness is related to the effective duration of ACF, τe [12]. The third and fourth factors are the delay time and the amplitude of the first peak of the normalized ACF, τ1 and φ1. The definitions of τ1 and φ1 are shown in **Figure 3(b)**. These two factors are closely related to the pitch sensation. The perceived pitch and its strength of a sound signal are expressed by τ1 and φ1, respectively [13]. Therefore, we employed the effective duration of ACF, τe (2T = 4 hr) to compare with subjective noisy scale since τe of ACF correlates well with loudness of noise [7, 12].

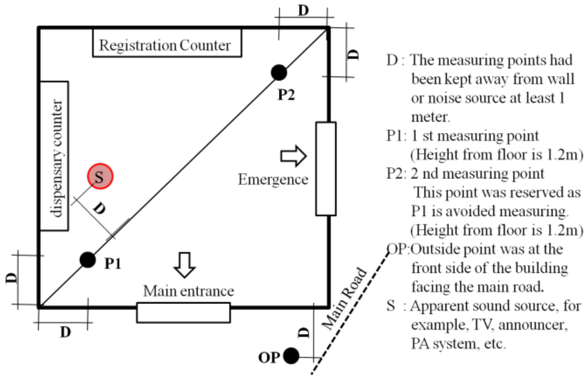

Figure 1. Measuring points in the lobby of hospital building

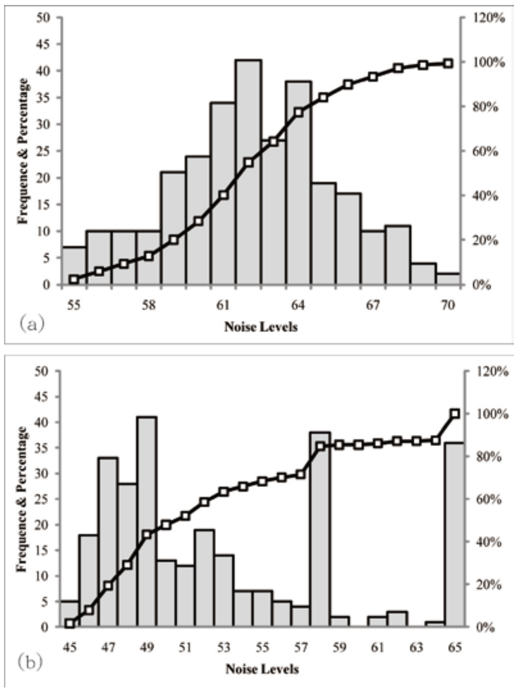

Figure 2. Indoor noise levels in hospitals A to I were analysed by using event frequency distribution and percentage curve in the day time (a) and in the night time (b).

Concentration rate of noise (NCR)

The factor of the normalized ACF, τe, of noise LeqA (15min) was applied in a point of that noisy sensation was considerably agitated by the phenomena of noise signal's repeated similarity. This psychological survey is similar of the noise levels qualification called percentage level ($L_{\%}$) as known. And we applied $L_{\%}$ here because their probabilities' curve of noise events during this period of time tends to be normal distribution in the day time (9:00AM ~ 5:00PM) as shown in **Figure 2**. The results of questionnaire surveys were carried out simultaneously which indicate that the average of the noise value cannot reflect the degree of noisiness interfered in this space (see **Appendix A**). A new method of generating the noise concentration rate (NCR) of two different measuring results derived from two hospitals is shown in **Figure 4**. The average noise difference is 1.43 dB (A), however, their noise concentration rates differ greatly—the noise concentration rate of the former is 1.5 times than that of the latter.

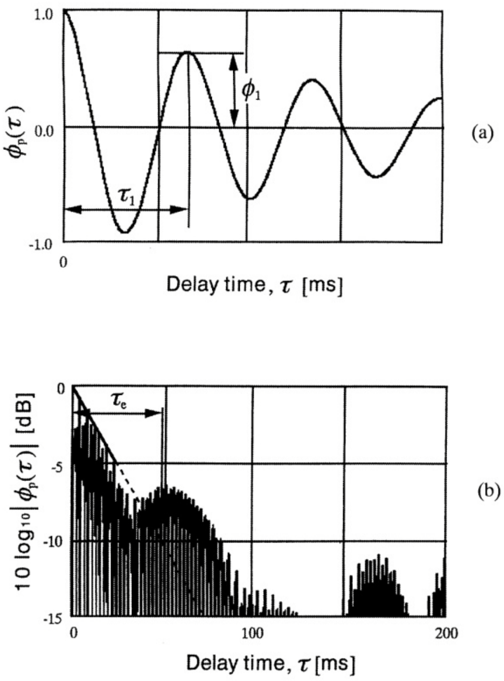

Figure 3. Definition of independent factors extracted from the normalized ACF. (a) τe defined by the ten-percentile delay (at −10 dB), obtained practically from the decay rate extrapolated in the range from 0 dB to −5 dB of the normalized ACF; and, (b) τ1 and φ1 in the fine structure of the normalized ACF.

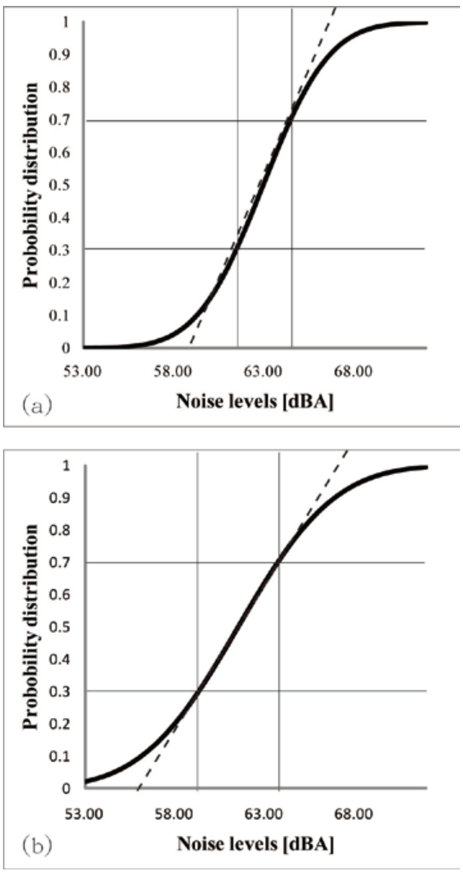

Figure 4. Two samples of generating the noise concentration rate (NCR) in two different hospitals. (a) Indicates the curve recorded in Hospital B, and (b) is Hospital C. The NCR were calculated by a linear part of probability from 0.3 to 0.7 as below:

$$B : T(0.4*12)/(64.491-61.430) = 1.568 hr / dBA$$

$$C : T(0.4*12)/(63.749-59.310) = 1.081 hr / dBA$$

RESULTS AND DISCUSSION

Autocorrelation Function (ACF) and noisiness rate

The measured factors extracted from the ACF are shown in **Figure 5**. The ACF curve indicates sound similarity in time domain, and the regression straight line indicates the slope of the ACF curve decay in the initial part (see **Appendix B**). They interpret as the variation of noise at lobbies in the periods of measurements. The effective duration of the normalized ACF, τe, of noise, LeqA (15min) correlates well with the noisiness degrees generated by the questionnaire. The correlation coefficient is 0.76 ($p < 0.05$) as illustrated in **Figure 6**. On the other hands, the correlation coefficient between normalized ACF, τe, of noise, LeqA (15min) and the noise concentration rate (NCR) is only 0.54 since ACF is a detector of repeated degree in continuous temporal phenomena and not an temporal averaging evaluation. Furthermore, we have calculated the running ACF (2T =2 hr, running step = 1hr) to compare with the noisiness degrees (see **Appendix C**) generated by questionnaire. But, there is no outstanding result found by ACF, τe (minimum, maximum or mean value).

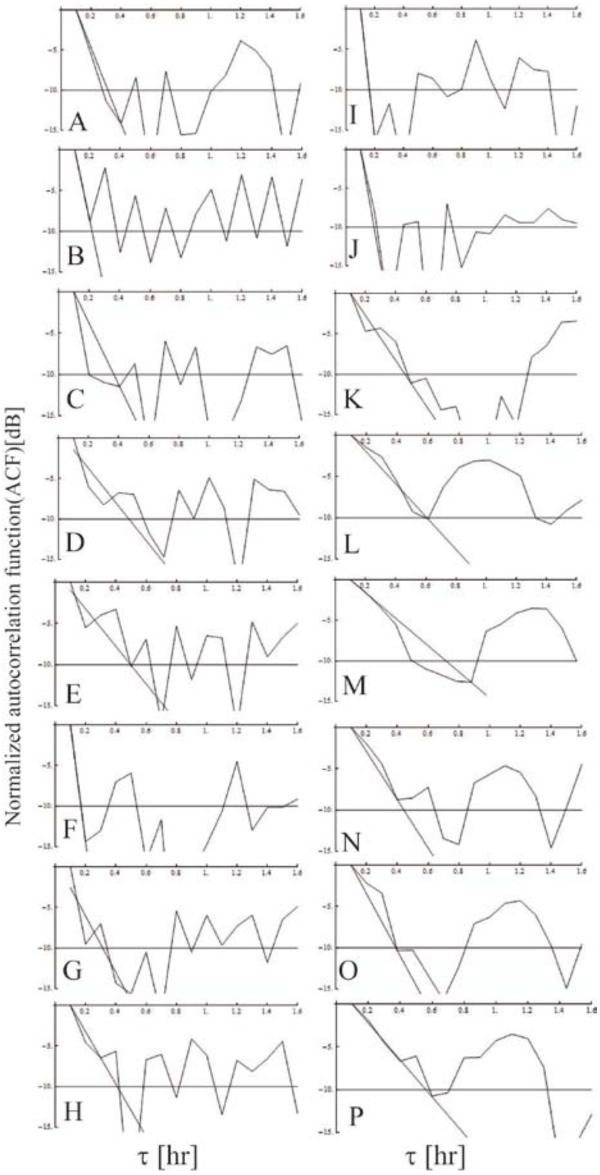

Figure 5. The ACF curve indicates sound similarity in the time domain, and the regression straight line indicates the slope of the ACF curve decay in the initial part. They show the different concentration level of noise sensation in life interference.

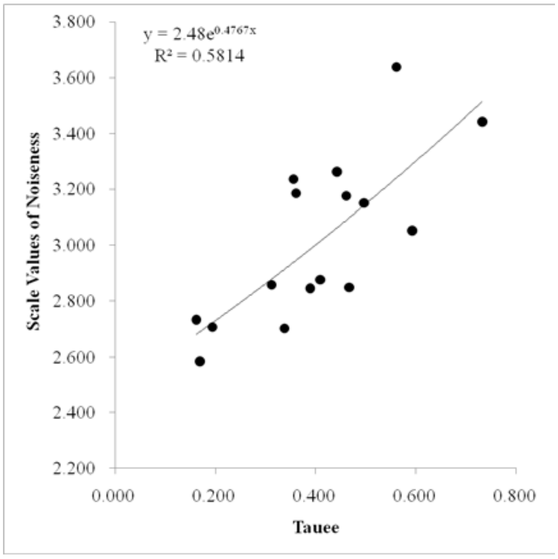

Figure 6. The effective duration of the normalized ACF, τe, of noise, LeqA (15min) correlates well with the noisiness degrees generated by questionnaire as shown.

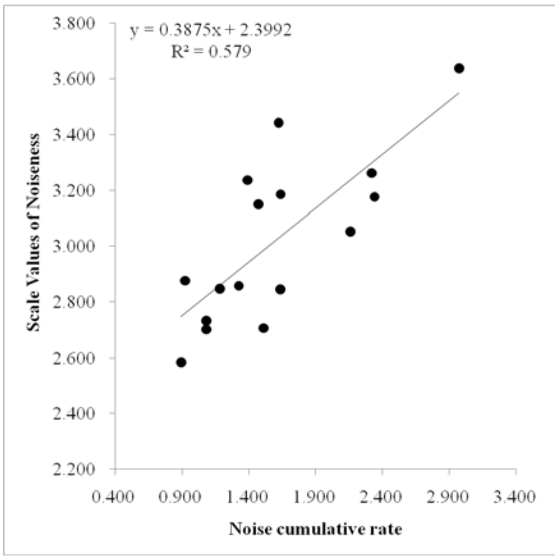

Figure 7. The noise concentration rates (NCR) in each hospital harmonies well with the noisiness degrees generated by the questionnaire.

Noise concentration rate and noisiness rate

The noise concentration rates (NCR) in each hospital were gathered by the probability curve described above as shown in **Figure 4**. NCR is a factor of persuasibility on a numerical concentrative degree in periodic dynamics. In this study, NCR values of 16 hospitals are quite agreeable with the noisiness degrees generated by the questionnaire. The correlation coefficient is he same as the normalized ACF, τe, of noise illustrated by **Figure 7**.

DISCUSSION & CONCLUSION

For evaluating fluctuation noise in the lobbies of hospitals, the equivalent sound levels (Leq) not considered to not sufficiently perceive acoustical properties. Ando [2] proposed that the preferred sound field is decided upon four orthogonal factors, they are (1) Listening levels; (2) Initial time delay between direct and first reflection; (3) Reverberation time and (4) Interaural cross-correlation. We give a hypothesis, of which for conversation in the lobbies of hospitals, a gauge of speech intelligibility is required. This criterion is demanded in a situation of lower reverberation condition as known [14]. Hence, we

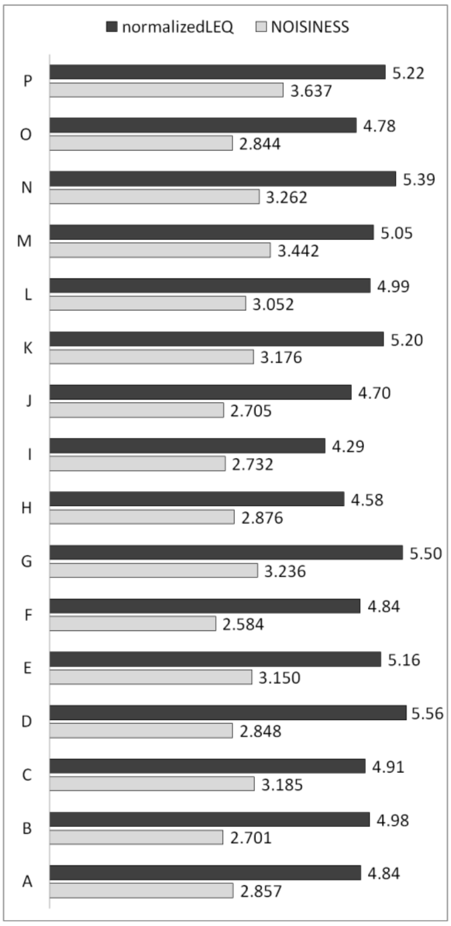

Figure 8. The noisiness degrees generated by questionnaire using 5 degrees qualification comparied with the normalized LeqA levels (outdoor) recorded in 16 lobbies of hospitals.

recorded noise level and RT20 in the hospital lobbies, simultaneously. On the other hands, we found that higher outdoor/indoor noise levels will not certainly obtain the worst noisiness degrees generated by questionnaire. **Figure 8** indicates the noisiness degrees generated by questionnaire using 5 degrees qualification and the normalized LeqA levels (outdoor) recorded in 16 hospital lobbies. It shows that Hospital **B**, **D** and **F** have a good architectural condition; they obtained a lower noisiness degree under a higher outdoor noise levels. We were surprised that they are in a similar reverberant environments of a range from 0.8 to 1.1 seconds (**Figure 9**). The material's absorption of the lobbies' interior or their volumes are the benefits of noisiness reduction.

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APPDENDIX

A. 15 minutes continuous equivalent continuous noise level

The noise percentage levels used here to response the statistical phenomina of the indoor noise in the day time for 16 hospitals (**Figure A1**). We could find a trend of correlation between L 10 levels and the scale values of noisness (**Figure A2**). An approach is to calculate the slope of probabilities of noise varying from 0.3 to 0.7 in each hospital stated as above. Furthermore, the noise levels recorded in the day time for 16 hospitals approximatelly behavoured as normal distribution, the averaging process is fair to get a comparison between averaging noise isolation and scale values of noisness (**Figure A3**).

B. Effective duration of the normalized ACF

To obtain a degree of similar repeative features of the noise signals, the effective duration of the normalized ACF of noise

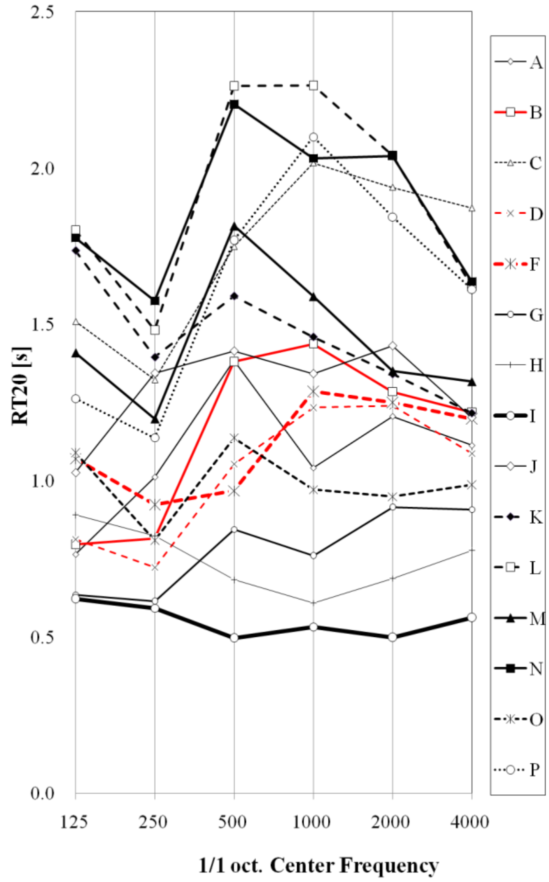

Figure 9. The reverberation times (RT20) were evaluated in each-hospital lobby except E (RT20 measurements have been rejected). The red dashed line indicates that a preferred condition of conversation was considered.

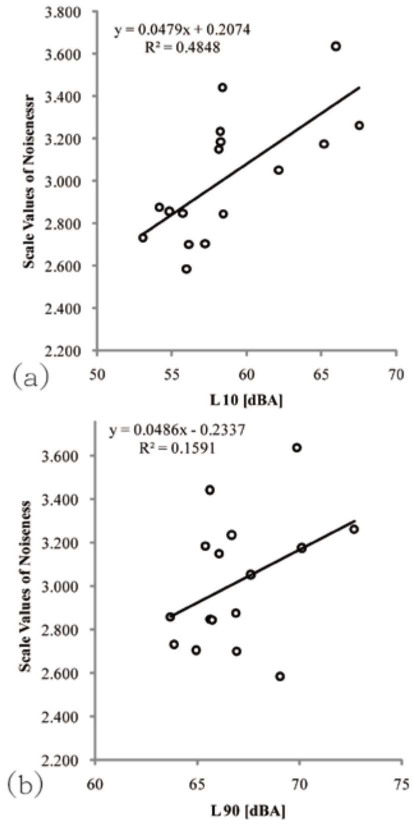

Figure A2. The noise percentage levels (L%) in each hospital are correlated with the noisiness degrees generated by questionnaire is found only on (a) L 10, but (b) L 90.

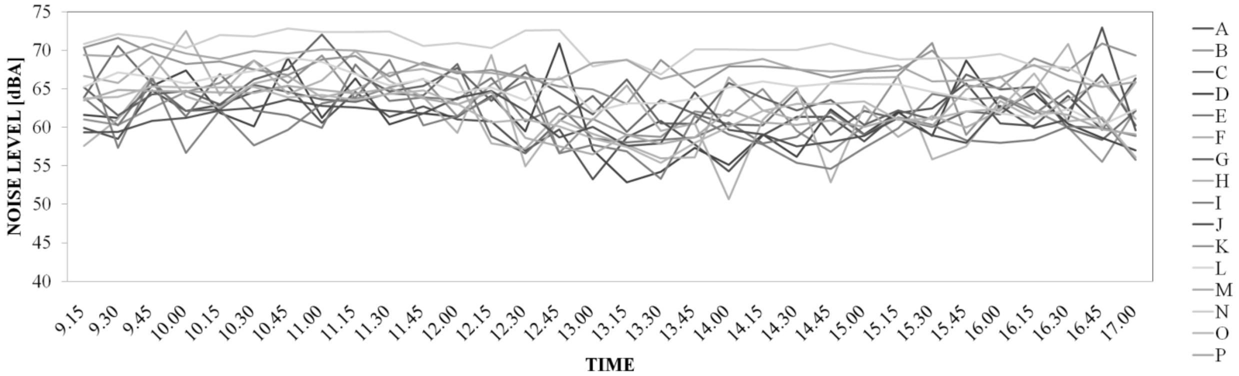

Figure A1. The noise levels (LeqA, 15min) in each hospital were surveyed from 9:00 to 17:00 in lobby of 16 hospitals. They show that the variation is quite different among them.

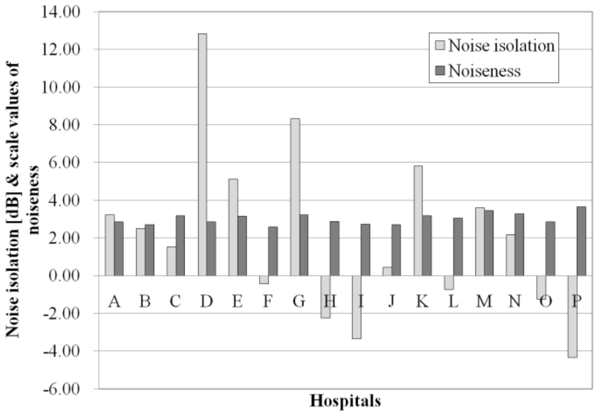

Figure A3. The averging differences of 15 minutes continuous equivalent continuous noise level (LeqA) at indoors and outdoors in the lobby of 16 hospitals. The amount of noise isolation between indoor and outdoor is not significantly correlated with the scale values of noisiness derived from the questionnaire.

was analyzed as a phenomenon of stationary random processing (SRP). Concerning SRP for noise, the estimation of finite length data (N) for the effect of sound field has to discuss a statistical error, and it has two conditions should be considered. (1) The average values of signal X(t) are constant and indenpent within arbitary time domain; (2) ACF of signal is also independent in any time span, but only associates with the distance (τ) between two time positions (t_1, t_2). And it equal to the expectation of time square average as a definition.

$$\Phi_x(t_1,t_2) = E(X(t_1)X(t_2)) = E(X(t)X(t-\tau)) = \Phi_x(\tau).......(A1)$$

Where $\Phi_X(\tau)$ is

$$\Phi(\tau) = \lim_{N\to\infty}\frac{1}{N}\sum_{n=1}^{N} x(n)x(n+\tau).............(A2)$$

But for a finit length data (N) will only obtain an estimation of ACF

$$\hat{\Phi}(\tau) = \frac{1}{N}\sum_{n=1}^{N} x_N(n)x_N(n+\tau)...............(A3)$$

And the real length of signal for calculation are N-τ, thus

$$\hat{\Phi}(\tau) = \frac{1}{N}\sum_{n=1}^{N-\tau} x_N(n)x_N(n+\tau).............(A4)$$

The expectation of error for estimating are

$$error[\hat{\Phi}(\tau)] = E\{\hat{\Phi}(\tau)\} - \Phi(\tau)...................(A5)$$

Where

$$\begin{aligned} E\{\hat{\Phi}(\tau)\} &= E\{\frac{1}{N}\sum_{n=1}^{N-\tau} x_N(n)x_N(n+\tau)\} \\ &= \frac{1}{N}E\{\sum_{n=1}^{N-\tau} x_N(n)x_N(n+\tau)\}..............(A6) \\ &= \frac{1}{N}\sum_{n=1}^{N-|\tau|}\Phi(\tau) = \frac{N-\tau}{N}\Phi(\tau) \end{aligned}$$

Therefore, the expectation of error are

$$error[\hat{\Phi}(\tau)] = -\frac{\tau}{N}\Phi(\tau).......................(A7)$$

The conclusion are,

(1) When N closes to infinity, error will decrease to 0.

(2) As $\tau \ll$ N, the estimatation of ACF are almost equal to the real one.

Calculating τ_e , ACF of noise signal in this study, only initial part of normalized ACF (approximately 0 to -5 dB) showed the decay for all data. As indicated as **Figure 5**, the example shows the normal style in our analysis, the initial part within 0.5 hours were employed for straight line regression well. It satisfied that estimating error was in keeping with under $\tau \ll$ N (e.g. N(2T) = 4 hr) for ACF calculation.

C. Running ACF of the noise levels (LeqA)

The running ACF of noise measurements at the day time in the lobbies of 16 hospital are calculated by running step = 1 hr (2T = 2hr) illustrated at **Figure A4** as a reference of the ACF calculated in 2T = 4 hs..

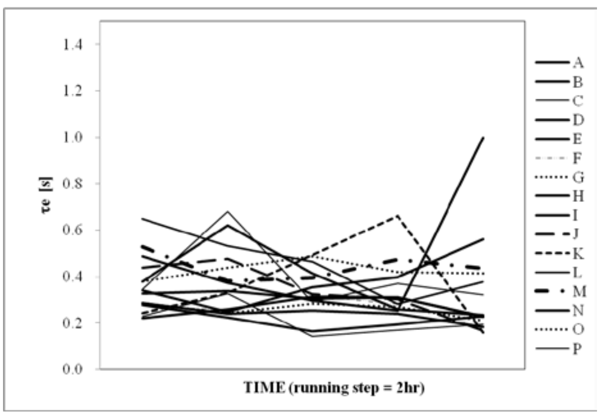

Figure A4. Running ACF are calculated as 2T = 2 hr (running step = 1 hr).