Development of A Computer Aided Non-Pharmacological Treatment of Insomnia using Automobile Engine In-Cabin Acoustic Noise

Akinlolu Adediran Ponnle
Department of Electrical and Electronics Engineering,
Federal University of Technology,
Akure, Nigeria.

Kehinde Victor Falana
Department of Electrical and Electronics Engineering,
Federal University of Technology,
Akure, Nigeria.

***Abstract*— This paper presents the development of a computer aided treatment of insomnia using automobile engine in-cabin acoustic noise. Insomnia is the medical term given to the inability of an individual to sleep. Conventional pharmacologic approach of its treatment by using sleeping drugs has been faulted because of accumulation of toxins, and its adverse effects on patients, economic impact, and reduced efficacy of the drugs when used for a long time. A lot of sound machines and mobile apps serving as sleep aids using various nature sounds have been developed, some are free, and some come at a cost. Some are effective, while some are not. This work is based on an observed phenomenon that for vehicles moving at high speed, the engine in-cabin acoustic noise coupled with the inflow of fresh air through the windows into the vehicle does induce sleep in the passengers. Engine noise of an automobile on motion was acquired within the vehicle for three different stages of motion: acceleration, constant speed, and deceleration to serve for 'induce sleep', 'deep sleep', and 'awakening' phases respectively. The noise were edited, preprocessed and analysed to determine their characteristics. Analysis of the acquired sounds showed the noise to be pink noise. A computer application in MATLAB with a Graphical User Interface (GUI) was developed and the various sound files were embedded in it. The GUI was used to initiate and play the sounds depending on the sleeping state of the insomnia patient or the one that sooths the mind of the patient. Also, a fan speed controller modulated by the sounds to simulate air-flow when administering the therapy to the patients was developed. The developed application was installed on a Windows based multimedia system and used on ten human subjects with the aid of a pair of headphones in a well-ventilated, quiet and clean room. Eight of the ten subjects found the application of the sound improved their sleeping period and recommended it to be good. With the aid of the developed system, they were gracefully induced to sleep without any medication or side effects.**

***Keywords*— insomnia; sleep; noise; automobile; graphical user interface**

I. INTRODUCTION

Insomnia is the medical term given to the condition of an individual not to be able to sleep, or inability to get the adequate amount of sleep that is needed to wake up with a feeling of having rested and refreshed. It is characterised by persistent difficulty to fall asleep, or difficulty staying asleep, or having sleep of poor quality [1]. Sleep is a behavioural state that is natural to every individual's life. It enhances stress relieve and relaxation, proper functioning and co-ordination of the entire body systems. Sleep is a complex process that is regulated by the brain, and plays a significant role in brain development and memory [2]. There are two main types or phases of sleep:

1. Non-Rapid Eye Movement (NREM) Sleep (also known as quiet sleep).
2. Rapid Eye Movement (REM) Sleep (also known as active or paradoxical sleep).

REM is an advanced stage of sleep, and during this phase, most memorable dreams occur. People who could not have adequate sleep or deep sleep usually become deprived of REM sleep. They can become emotionally uncontrollable, irritable, angered, worried and in conditions of extreme sleep deprivations, they can sometimes begin to have hallucinations [3].

The actual amount of time or duration that everyone needs to sleep and feel refreshed varies from person to person. This may be related to several sleeping factors such as environmental factors, health conditions of the person (e.g. pregnant women), age, hormonal secretion and body metabolic activities [4]. Reference [5] recommends 8 to 9 hours sleep per night for adults, and people over 65 years old should also get 7 to 8 hours sleep per night.

Insomnia is a disorder that is prevalent, and is causing significant medical impairment in daily life of sufferers [6], [7]. In the modern society, due to technological advancement, increase in standard of living, complexities of urban life, increased level of responsibilities both at home, in the family, at work place, and increased expectation of delivery and performance by the society at large, there has been attendant increase in the population of insomnia patients. Insomnia sufferers lose more financially because of increased and greater medical and psychiatric problems, and a reduced quality of life [8] – [11]. Insomnia can also associate with the development of other problems [12], [13].

Insomnia calls for cost-effective treatment, and the most common treatment for it is medication [14]. Research has shown that some drugs are effective in treating insomnia in the short run, but have negative side effects [15], [16]. A person suffering from insomnia is left at the mercy of sleeping tablets which in the long run of usage have toxic effect on the body.

Nowadays, interest is growing in applying established non-pharmacological methods to treat insomnia patients. Literature reveals that various non-pharmacological methods of treatment of insomnia are available, and can be classified as follows: educational methods which include psycho-education, sleep hygiene etc.; behavioural methods which include relaxation therapy, sleep restriction therapy, stimulus control therapy etc.; cognitive methods; and sound therapy i.e. use of unwanted noise with suitable white noise [17] – [19].

It is interesting that noise generated by sounds of nature provides a safe and effective non-pharmaceutical treatment of insomnia. Apart from its being insignificant as an environmental pollution, noise is still an information-bearing signal that conveys information about the nature of the source of the noise and the characteristics of the environment in which it has propagated. Acoustic noise can be used in the field of medicine as an alternative therapy to solve problem of insomnia. According to [20], acoustic intervention offers great potential for the therapeutic use as well as precise side-effect free manipulation of sleep. The human brainwave responds to some selected sound to induce sleep. It has been observed from the knowledge of brain wave entrainment that acoustic noise can help to induce the secretion of a hormone called melatonin, which in essence plays a significant role in regulating sleep.

Reference [21] developed a computer application with Graphical User Interface (GUI) using Microsoft Visual Basic 6.0 on Windows platform to simulate sounds of a moving bus at some different speeds. However, the simulated noise was too characteristically different from the automobile engine noise. Also the software could only be implemented on Windows 98, 2000, XP and Vista. In addition, the software was not tested on human subjects.

Reference [22] looked further on the work by developing computer simulated noise using Visual Basic with characteristics closer to engine noise of a Toyota bus. The GUI developed also incorporated other features. However, since the noise was a simulated noise, investigation showed that its characteristics were not so realistic to the actual engine noise. Also the visual basic program used was unable to run the noise on Windows 7 and later editions of Windows operating system.

Reference [23] developed non-pharmacological treatment of insomnia using Cognitive Behavioural Therapy (CBT). CBT is a psychological method of guiding and training people suffering from insomnia on faulty or unhelpful ways of thinking, behaviour and learn better ways of coping with insomnia, thereby relieving them of insomnia effect. This method of treatment requires special training of personnel to guide the patient.

Reference [24] at the Department of Electrical and Communication Engineering (ECE), Adhiyamaan College of Engineering, India designed a rain pink noise sound generator to replicate the sound of the rain by using IC 555 timer. The rain sound is assumed to induce relaxation as well as to help boost concentration in humans. The rain sound makes people sleepy because of the monotonous rhythm it generates.

Reference [20] reviewed various ways of using acoustics before sleep or stimulation during sleep; methodological requirements, advantages, disadvantages; potentials and difficulties of acoustic sleep modulation, as well as adverse environmental influences. The author also discussed possibilities for clinical and research-related applications, and emerging opportunities.

Nowadays, a lot of white noise sound machines, CD/DVDs and mobile apps serving as sleep aids using various nature sounds are being developed, some are available on Play Store, and are deployed as current trends and technologies in this regard. They play sounds which are listened to through headphones or ear pieces. Some of the sounds they use are rain sound, ocean wave noise, sounds of rushing water or waterfall, birds chirping, etc. Some even involves a slow narration of selected bedtime stories by a narrator with a soothing voice. Some of these apps are effective, while some are not depending on the type of sound, the target patient, age, etc. Some even provide features to be able to monitor and analyse sleep patterns for proper sleep schedule recommendation. Some of these apps are simple, while some are very complex that they can be like overkill. Some are free, and some come at a cost.

This work is premised on the fact that a certain type of noise, if continuously listened to, is suitable as sleep induced noise. A case is the generally observed phenomenon of vehicles in continuous motion on high speed, the in-cabin acoustic noise being made by the automobile engine coupled with the inflow of air into the vehicle through the windows, induces sleep in the passengers. This is what is used in this work. The rest of this paper discusses more on insomnia and noise therapy, the materials and methods used in this work, and presentation of results and conclusion.

II. INSOMNIA AND NOISE THERAPY

A. Treatment of Insomnia

There are many possible causes of insomnia. They include psychological and emotional causes;

physical causes; medical condition; and drugs abuse. Over the years, advances in sleep research have led to development and deployment of several treatment measures for treating people with insomnia [25]. These methods include pharmacological and non-pharmacological treatment. Pharmacological treatment is the use of pills, drugs and stimulants, natural cure and psychological methods. Some of the treatment measures take into account the condition of the insomnia patients, the type of insomnia, causes and the symptoms as experienced by the patient. The use of sleeping pills and drugs is now being considered dangerous because of the adverse effect and the patient's addiction to the drugs.

Non-pharmacological treatment involves behavioural treatments (BT), which may include stimulus control, relaxation techniques, sleep restriction therapy, cognitive behavioural treatment (CBT), and the use of sleeping enhanced sound such as white noise. BT is recommended activities that are supervised by an expert to enhance good sleeping habits. BT may be a preferred method when there is a concern of prolonged use of drugs. It is effective for all age, and it does not cause side effects [26] – [28].

The cognitive aspect of CBT for insomnia helps individuals to recognize and work on mentalities that affect ability to sleep. The behavioural aspect of CBT helps individuals to develop good behaviours and habits that promote adequate sleep. Cognitive behavioural treatment for insomnia may involve sleep education, sleep restriction, sleep hygiene, sleep diary, stimulus control therapy, cognitive control and psychotherapy, relaxation training, etc. [29]. CBT can also be offered in an online format (online CBT) to increase access, and studies have shown it to also be effective [14].

B. *Noise and Noise Therapy*

Noise is a random signal having a broad range of frequencies. Those in the audio range are referred to as acoustic noise. Acoustic noise therapy is a revolutionary alternative therapy which uses noise of certain frequencies to help balance the body [30], [31]. It has been observed in medicine that noise, especially white and pink noise (sound of chirping of birds, rain, etc.) when listen to can be an alternative therapy and natural cure to some health disorders such as insomnia. Reference [32] in their study showed that individuals who generated more sleep spindles during a quiet night of sleep also exhibit higher tolerance for noise during noisy night of sleep. Reference [33] in their study demonstrated that steady pink noise has significant effect on reducing brain wave complexity thereby improving sleep quality of individuals.

The following are the reasons why noise therapy is considered:

i. The raw material (noise), is available everywhere and present in day to day activities.
ii. Noise can easily be generated, recorded and stored in a media. Further analysis and processing can be done in the laboratory using appropriate software and equipment.
iii. Noise therapy is one of the alternative therapies with little or no adverse effects on its patients.
iv. It is cheap and easy to administer on the patient.

C. *Colours of Noise*

The colour of noise refers to the power spectrum of a noise signal. The slope of the Power Spectral Density (PSD) for each spectrum determines the respective colour analogy. The colour names (violet, blue, grey, white, pink, brown and red) for the different types of acoustic noise are derived from an analogy between the spectrum of frequencies of the sound waves and the equivalent spectrum of light wave frequencies.

White noise has equal spectral density for the entire frequency spectrum. Pink noise is a random noise with power density that, compared with white noise, decreases by 3dB per octave with increasing frequency (i.e. the PSD is proportional to $1/f$, and is often called '$1/f$ noise'). Brown noise is noise with a power density which decreases 6 dB per octave with increasing frequency (i.e. the PSD is proportional to $1/f^2$). Blue noise power density increases 3dB per octave with increasing frequency (i.e. the PSD is proportional to f). Violet noise is also called purple noise, and its PSD increases 6dB per octave with increasing frequency (i.e. the PSD is proportional to f^2).

III. MATERIALS AND METHODS

A. *Work Approach*

The work flow in block diagram is represented in Fig. 1.

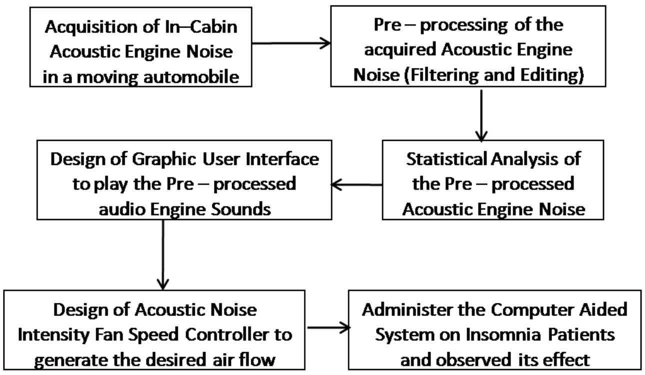

Fig. 1: The work flow in diagram.

Sound of an automobile engine of a moving vehicle (as heard inside the vehicle) was recorded and sampled. The in-cabin engine noise when the vehicle was accelerating, at constant motion and deceleration were recorded as observed. The reason why the recording was done with these three separate stages of the vehicular motion in mind was due to observation, the effects and reactions that each of this stage has on the sleeping habit of people inside the cabin of the moving vehicle.

The acquired samples were edited to remove unwanted portion and to prepare the samples for investigation and analysis in order to determine their characteristics. Mathematical and statistical analysis were carried out on the edited noise samples which include waveform pattern, Probability Density Function (PDF), autocorrelation function, Power Spectral Density (PSD) and spectrograph. Appropriate engine noise PSD models for each type of vehicle motion stage were also developed from these analyses.

A computer application with Graphical User Interface (GUI) was developed incorporating the in-cabin engine sound for easy administration to insomnia patient through the use of headphones. An electric fan simulates the inflow of air into the moving vehicle at each stage of vehicle motion. A fan speed control device was developed and incorporated between the computer (PC) installed with the GUI and the electric fan to vary the speed of the fan thereby regulating the inflow of air for each stage of vehicle motion. The developed computer aided system for insomnia treatment was tested on insomnia patients and its performance was observed and evaluated.

B. Noise Acquisition and Editing

The engine in-cabin acoustic noise of a moving Toyota Corolla 2010 Edition automobile was acquired by an Infinix Hot 6 android smart phone for different stages of vehicle motion: acceleration stage, constant speed stage and deceleration stage to serve for 'induce sleep', 'deep sleep', and 'awakening' phases respectively. To have excellent samples of noise, the recordings were done severally for these stages where the assumed best sample was picked for editing. The noise samples were then saved for editing.

The recorded sound was then played to some people to listen to so as to test-proof the recorded sound by the listeners in order for them to give their assertions on the tune of sound recorded as perceived in their hearing, and to see if the sound has the ability or capability to induced sleep if properly edited and administered to an insomniac.

Cyberlink waveeditor 2 software was used to edit the acquired noise. The software has an advantage of supporting sample rates from 6 to 96 kHz stereo and 8 to 24 kHz mono. It has feature of processing in mp3 and wave which support MATLAB signal analysis. The recorded noise samples were edited to remove the unwanted sections. During filtering and editing, unwanted signals were removed from the recorded sound such as occasional human voice, vehicle horn, sound of the screeching of tires when brakes were applied, and effects of bad roads on the engine noise etc. The edited noise samples were then saved with file names and put in a folder for analysis.

C. Samples' Investigation and Analysis

Investigation and analysis of the edited noise samples were performed in order to know the characteristics of the acquired acoustic noise in terms of waveform pattern, histogram, Probability Density Function, autocorrelation, Power Spectral Density, and spectrogram to have the visual representation of the power of the noise signal at different frequencies as it varies with time.

1) Probability Density Function (PDF): The Probability Density Function (PDF) of a continuous random variable is a function that describes the relative likelihood for this random variable to take on a given value. PDF is used to specify the probability of the random variables falling within a particular range of values, as opposed to taking on any one value. Statistically, the probability for the random variable x is expressed as a function of its PDF, *f(x)* in (1):

$$P_r = \int_a^b f(x)dx \qquad (1)$$

where a and b are the intervals in which *x* lies.

2) Autocorrelation: The autocorrelation of a random signal describes the correlation (resemblance) between values of the signal at different points in time, as a function of the times or of the difference. It is the function of the time-lag within the same continuous time signal. Autocorrelation is used to compare a signal with a time-delayed version of itself. If a signal is periodic, then the signal will be perfectly correlated with a version of itself if the time-delay is an integer number of periods.

Mathematically, autocorrelation R of a random signal is calculated as in (2):

$$R(\tau) = \frac{1}{t_2 - t_1}\int_1^2 s(t)s(t+\tau)dt \qquad (2)$$

where t_1 and t_2 are signal points, τ is the time shift, and s(t) is the signal.

3) Power Spectral Density: Power Spectral Density (PSD) refers to the spectral energy distribution that would be found per unit time for an infinite signal. It is measured in power per frequency (W/Hz). Estimating the PSD in different frequency ranges involves a transformation of the signal from the time domain to the frequency domain. As stated earlier, the pattern of the PSD defines the noise colour in the frequency spectrum. PSD can be obtained from Fourier Transform (FT) of the signal autocorrelation (R) as expressed in (3).

$$P_{psd}(f) = \int_{-\infty}^{\infty} R(\tau)e^{-j2\pi ft}d\tau \qquad (3)$$

where R(τ) is as expressed in (2).

For a finite set of N sampled signal *x*(*n*), the classical PSD can also be estimated from the Discrete Fourier Transform (DFT) as expressed in (4)

$$S_{xx}(k) = \frac{\left| \sum_{n=0}^{N-1} x(n) \exp\left(\frac{-j2\pi nk}{N} \right) \right|^2}{N},$$

where k = 0, 1, 2, … , N-1. (4)

Appropriate engine noise PSD models for each type of vehicle motion stage were developed using curve fitting in MATLAB Software.

D. *Software Application and the Graphical User Interface (GUI)*

A computer application with Graphical User Interface (GUI) was developed using MATLAB incorporating the in-cabin engine sounds for easy administration to insomnia patients through the use of headphones. The GUI contains buttons to initiate the administration of the noise for each motion stage as desired by the user, and also to control the speed of the fan. The GUI developed is named as NOISOMNIA THERAPY 2.1, and was designed to ensure simplicity in its usage. The developed GUI is shown in Fig. 2. Three different noise samples of the three vehicle motion stages i.e. Acceleration, Constant Speed and Deceleration serve for 'induce sleep', 'deep sleep', and 'awakening' phases respectively. The GUI has buttons which perform different functions when clicked or pressed from the PC through the mouse. In addition to the buttons, it also has slide button to control its volume. This is to allow whoever is administering the sound to adjust the sound level depending on how the patients react to the sound. The GUI has a window to display the waveform of the noise signal being administered for each phase of sleep. Lastly, it has at top right hand corner a section briefly describing the application.

The GUI is used to play the recorded sound based on the mode or phase that soothes the mind of the patients. Since, the application was designed with support software (MATLAB), any system with Windows operating system running MATLAB is preferred. These include the following: Windows XP, Windows Vista, Windows 7, Windows 8 and Windows 10, and minimum of 4GB RAM.

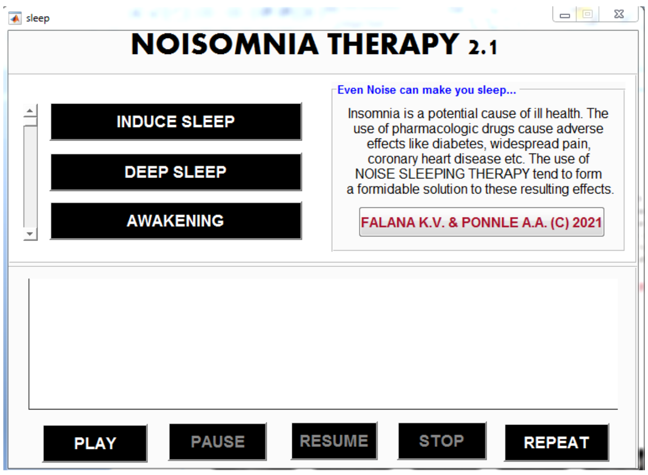

Fig. 2: The developed GUI.

E. *Fan Speed Control by the Acoustic Noise Intensity*

An electric fan provides inflow of air to simulate or represent the natural air sensation experience in the cabin of a moving vehicle at each stage of motion. A fan speed control device was developed and incorporated between the PC installed with the GUI and the electric fan to vary the speed of the fan thereby regulating the inflow of air for the 'induce sleep', 'deep sleep', and 'awakening' sleep phases. The fan used is a DC fan, and the speed control is noise intensity based. The design of the speed control system was achieved with the use of some integrated circuit amplifiers, Darlington Transistor TIP 122 and other discrete electronic components. The circuit diagram of the developed speed control is shown in Fig. 3.

The audio input from the Personal Computer (PC) is a weak signal (100mV to 2500mV) and thus it is necessary to amplify the signal. The audio signal is amplified with the help of U_1 (LM386), which is an a.c. amplifier with an internally set voltage gain of 20 (26dB) by default. The output of the amplifier gives approximately 2V to 5V equivalent to the voltage amplitude of the input audio signal from the PC. The voltage produced from the U_1 is rectified by D_1, C_4 and R_3 to obtain a DC signal needed to drive the power transistor Q_1 (TIP122). However, the DC output from the D_1, C_4 and R_3 network (maximum of 5V) is not sufficient to drive the fan which is a 6V fan, hence U_2 (LM358 DC amplifier) was incorporated with a set gain. The gain of U_2 is set with R_4 and R_5 resistors, and for the values shown in Fig. 3, the set gain is approximately 1.5. Therefore, for every varying input DC signal to U_2 (LM358), it is multiplied by a factor of 1.5 producing about 7.5V which is sufficient to drive the base of transistor Q_1 and the DC fan.

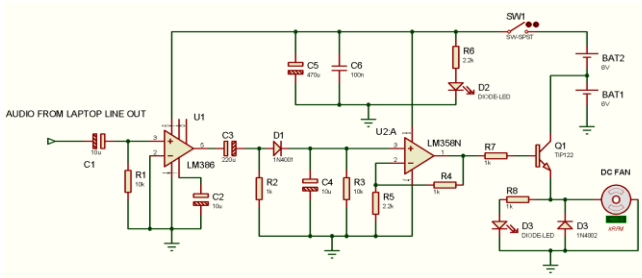

Fig. 3: The developed acoustic noise intensity based fan speed control circuit.

The power transistor Q_1 (TIP122**)** is a Darlington pair NPN transistor with a good collector current rating of about 5A and a DC gain of about 1000. It can also withstand about 100V across its collector- emitter, hence, can be used to drive heavy loads. The bias of the transistor depends on the intensity of the input audio noise which then varies the voltage at the emitter. By connecting the DC fan to the emitter, the speed of the fan varies accordingly. Light Emitting Diode (LED) D_3 helps to give visual indication of the varying voltage to the DC fan. LED D_2 is a 'power on' indicator. The supply voltage to the control system is

12V from two 6V batteries in series, while the load (the DC fan) is supplied with 6V through Q_1 as shown in the figure.

F. *Testing and Administering the Computer Aided System on Insomnia Patients*

The following components were used alongside the computer system on which the software was installed:

1. 6V DC Fan.
2. A pair of Headphones.
3. Suitable/comfortable bed, and
4. Quiet or secluded environment.

NOISOMNIA THERAPY 2.1 was administered on insomnia patients by playing the sound at different modes for different sleep phases from the PC. The test was carried out on ten volunteers (subjects) with insomnia complaint, six males and four females. Each subject was given a questionnaire to complete for documentation purposes. The age differences of the subjects were considered. The youngest was five years old and the oldest was seventy years old. They all voluntarily gave their consent to be tested with the developed system. Testing of the software on the subjects was carried out in a room that was well ventilated and quiet. The fan provides proper air circulation. The subjects made use of headphones while listening to the recorded sound incorporated in the software. The subjects reacted to sleep at different times and slept for different periods due to their differing psychological/emotional conditions.

It must be noted that the necessary physical condition(s) that would make the noise therapy work effectively on the patient has to be provided, and could sometimes vary from individual to individual. For example, during administration of the therapy, one individual requested for a room that is painted with sky-blue colour.

IV. RESULTS AND DISCUSSION

A. *Noise Analysis*

Study of the characteristics of the automobile engine in-cabin acoustic noise used in this work is very important. Since the noise is stochastic in nature, the characteristics are mostly statistically described.

1) Waveform: Fig. 4 is the amplitude against time characteristics of the acoustic noise signals. The figure shows the waveform for Acceleration, Constant Speed and Deceleration stages of the vehicle. From the MATLAB display and signal estimation, the acquired automobile engine in-cabin acoustic noise signals have the following parameters and characteristics:

- The three signals have sampled frequency of 44.1 kHz.
- The constant speed waveform amplitude is relatively flat with time, the acceleration waveform amplitude relatively increases with time and the deceleration waveform amplitude gradually reduces with time.

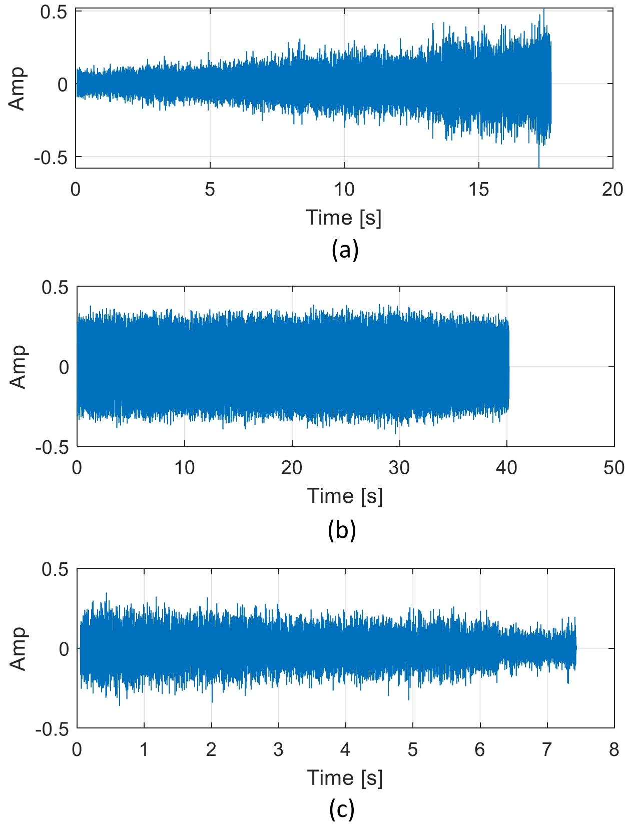

Fig. 4: Waveforms of the Recorded Noise Signals. (a) Acceleration, (b) Constant Speed, (c) Deceleration.

2) Histogram and Probability Density Function (PDF): Fig. 5 are the histogram descriptions of the acoustic noise signals. The figure shows that the constant speed signal has values outside the range -0.2 to +0.2 than the signals of the other two stages. This can be understood from Fig. 4 which shows the constant speed waveform amplitude to be relatively flat with time, whereas the acceleration waveform amplitude relatively increases with time and the deceleration waveform amplitude gradually reduces with time. The PDF plots in Fig. 6 corroborate the results obtained from the histogram.

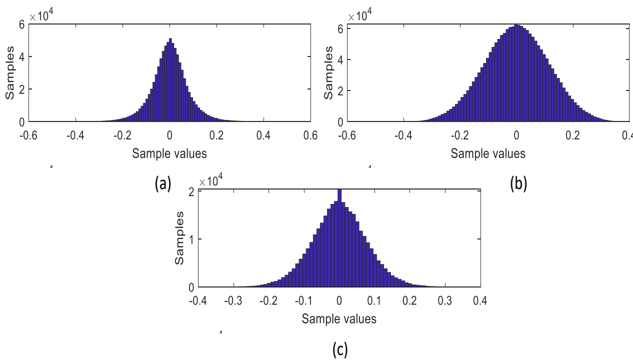

Fig. 5: Histogram of the Recorded Noise Signals. (a) Acceleration, (b) Constant Speed, (c) Deceleration.

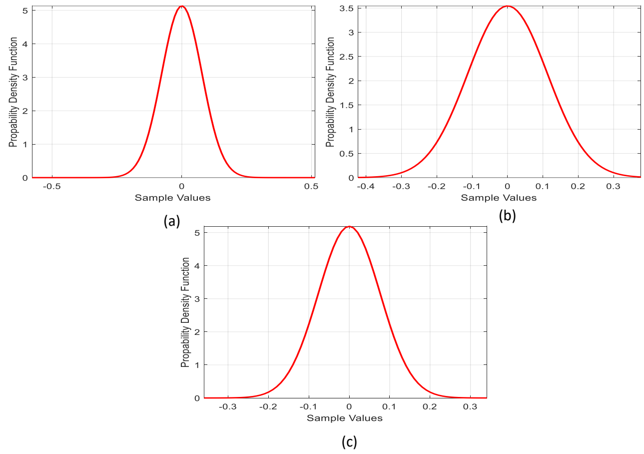

Fig. 6: PDF of the Recorded Noise Signals. (a) Acceleration, (b) Constant Speed, (c) Deceleration.

3) *Autocorrelation*: Fig. 7 shows the autocorrelation of the recorded signals. The displays show the autocorrelation of the signal is positive with maximum value of 1 at 0 time lag (which is expected being autocorrelation), and tend to negative value just above 0 time lag. The correlations tend to reduce to zero (no correlation) as the time lag values increase, which is also expected being noise signals (i.e. random). Careful observation of the figures show that the autocorrelation plot for the constant speed quickly tends to approximately zero after few time lags with few ripples, but for the acceleration and deceleration, the ripples continue for several time lags though slowly reducing in amplitude. Also the periodicity of the ripples in the constant speed is longer than that of the other two stages. Presence of some ripples in the autocorrelation plots shows that though the engine acoustic noise is random, nevertheless there are some periodic signals (or sinusoids) in the acoustic noise with higher presence in the acceleration and deceleration signals than in the constant speed signals. In other words, the plots show that the constant speed signal is much closer to noise signal than that of the other two stages.

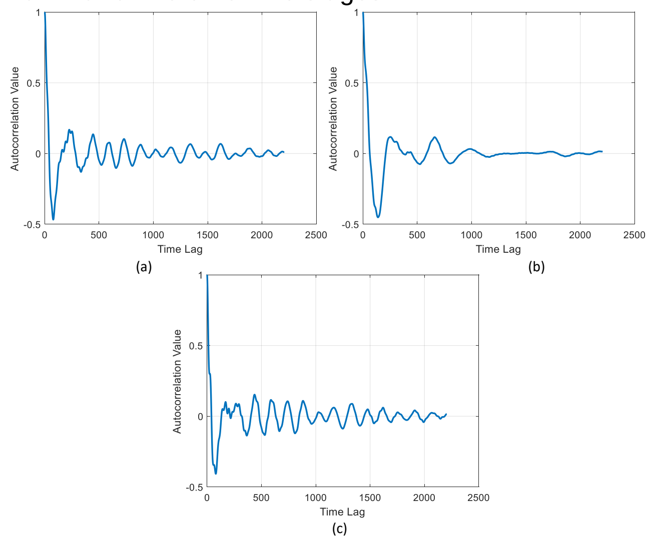

Fig. 7: Autocorrelation of the Recorded Noise Signals. (a) Acceleration, (b) Constant Speed, (c) Deceleration.

4) *Power Spectral Density and Spectrogram:* Fig. 8 shows the Power Spectral Density (PSD) of the noise signals. The PSD estimate shows higher power spectral density at low frequencies than at high frequencies. These are also shown by the spectrogram in Fig. 9 that there is high power at low frequencies than at high frequencies throughout the duration of the sound. Therefore the signals are pink noise which is good for inducing sleep.

The behavior of the PSD plots can be divided into three frequency regions: f ≤ 5 kHz, 5 kHz < f ≤ 15 kHz, and f > 15 kHz. For frequency components up to 5 kHz, the PSD of all the three plots decreases non-linearly with frequency, characteristic of pink noise. However, for the constant speed stage, the non-linear decrease of the PSD continues throughout the spectrum except for a short bulge around 15 kHz. This shows that the constant speed noise is more of pink noise than the other two. The spectrogram for the constant speed noise reveals that the bulge around 15 kHz does not occur throughout the duration of the noise, but only for some period.

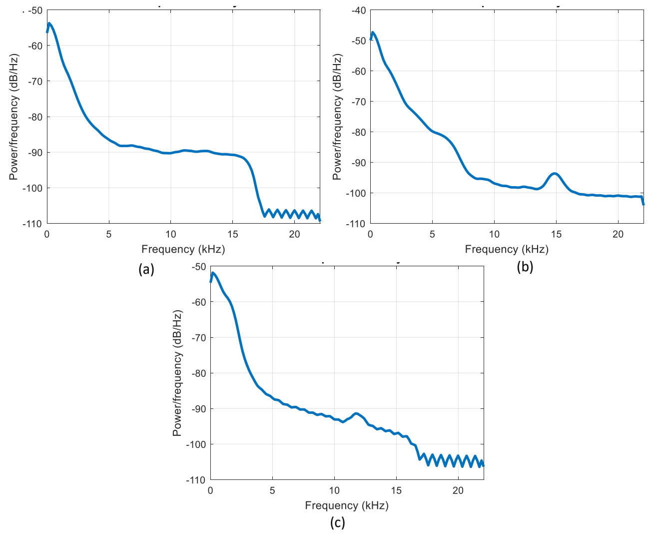

Fig 8: PSD of the Recorded Noise Signals. (a) Acceleration, (b) Constant Speed, (c) Deceleration.

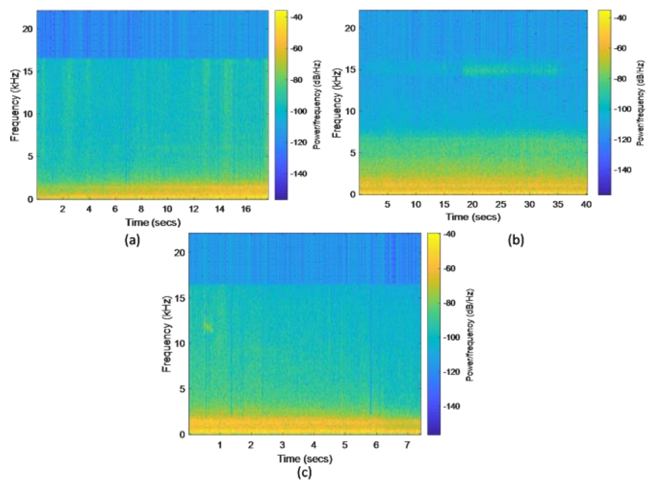

Fig. 9: Spectrogram of the Recorded Noise Signals. (a) Acceleration, (b) Constant Speed, (c) Deceleration.

For frequency components between 5 kHz and 15 kHz, the PSD for the acceleration stage is relatively flat close to -92 dB/Hz (appears whitish in this range). The PSD for the deceleration stage varies from -88dB/Hz to -98dB/Hz, while the PSD for the constant speed stage decreases from -80dB/Hz to approximately -100dB/Hz (the one with longest variation in dB/Hz in this range). This shows that the acceleration stage sound contains more of white noise than the other two. White noise contains all frequency components of equal amplitude and is known to induce sleep by stimulating the brain wave entrainments. Therefore, the PSD of the acceleration stage sound shows that it can induce sleep, and this informs its being used for the 'induce sleep' phase in this work. The constant speed sound has wider variation in amplitudes of higher frequency contents than the other two, though it shows relatively flat variation within 10 kHz and 22 kHz; therefore as stated earlier, the PSD shows that the constant speed sound is more of pink noise than the other two. This informs its use for 'deep sleep' stage in this work.

B. *Power-Frequency Models*

Fig. 10 shows the curve fitting to model the power-frequency characteristics of the noise signal for acceleration, constant speed and deceleration respectively using MATLAB. The estimated mathematical models (red line on the PSD plots) were obtained as polynomial functions of order 3 expressed in a general form in (5).

$$P_{SD}(f) = a_3 f^3 + a_2 f^2 + a_1 f + a_0 \qquad (5)$$

where a_3, a_2, a_1 are the coefficients of f^3, f^2, f respectively, and a_0 is the PSD at $f = 0$.

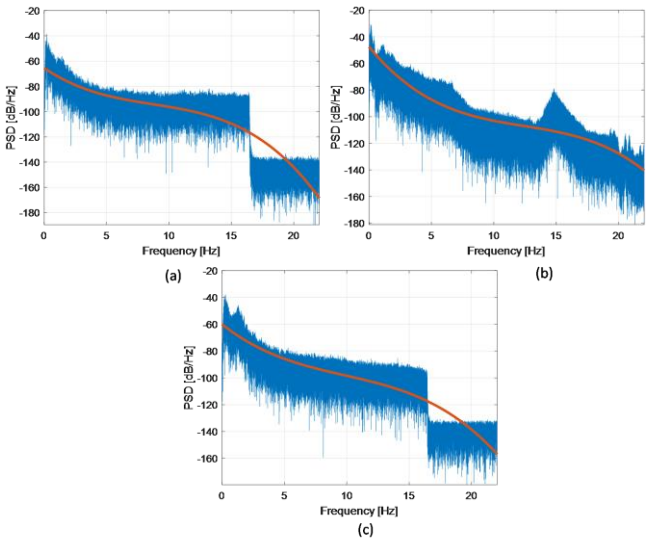

Fig. 10: Curve fitting for Power-Frequency Model of the Recorded Noise Signal for (a) Acceleration, (b) Constant Speed, and (c) Deceleration.

From MATLAB, the mathematical expression for the signal's PSD with frequency for acceleration stage is expressed in (6):

$$P_{SD}(f) = -0.0246 f^3 + 0.6984 f^2 - 8.165 f - 62.25 \qquad (6)$$

The mathematical expression for the signal's PSD with frequency for constant speed stage is expressed in (7):

$$P_{SD}(f) = -0.0199 f^3 + 0.7565 f^2 - 11.11 f - 47.9 \qquad (7)$$

The mathematical expression for the signal's PSD with frequency for deceleration stage is expressed in (8):

$$P_{SD}(f) = -0.0171 f^3 + 0.5466 f^2 - 7.68 f - 59.53 \qquad (8)$$

where the PSD is in dB, and f is in kHz.

From the actual PSD plots, at $f = 0$, a_0 (in dB) tends to negative infinity as there is no DC component in the signals. At values of f slightly above 0, a_0 becomes valid as indicated in the model curve expression for each stage. Also, equations (6-8) show that a_1 (coefficient of f) is negative and more significant than a_2; and a_2 is more signifant than a_3. Interpretation of this is that the PSD is more dependent on f than on f^2 while it is least dependent on f^3. Observing the a_1 and a_2 coefficients, those of constant speed are the highest, followed by those of acceleration, and least for deceleration.

C. *Effects of the developed System on some Insomnia Patients*

Fig. 11 shows the GUI outlook when initiated for different phases of sleep while administering the therapy. Fig. 12(a) shows a typical system setup in the laboratory during testing, and Fig. 12(b) shows a subject being administered the therapy.

Table 1 shows the information and response of the subjects that were administered with the developed system for treatment of insomnia. Total numbers of test listeners are ten; male subjects are four, and female subjects are six. The maximum hour of sleep per day for the subjects before being administered with the developed therapy was 2 hours while the minimum is 45 minutes (though not shown in the table). After the administration of the therapy, sleep duration ranges from 1 hour to 5 hours.

Eight of the subjects showed good response to the therapy. One subject found the therapy fairly pleasant and was able to sleep for 1 hour 10 minutes. However, another subject found the therapy very unpleasant, irritating, and did (could) not sleep at all throughout the duration of the administration of the therapy. The case of the particular adolescent could be chronic, and further types of medical treatment should be recommended. Nevertheless, with the results in Table 2, 80% of the subjects found the application of the therapy improved their sleeping period and therefore recommended it to be good and suitable for use.

V. CONCLUSION

This work has shown that sounds of the automobile engine of a moving vehicle (as heard inside the vehicle cabin), can be used in the treatment of people with insomnia instead of the prevalent use of drugs. To this effect, a computer aided system to treat insomnia based on automobile engine in-cabin acoustic noise has been developed and its performance on tested subjects showed it to be satisfactory.

The automobile used for this work was Toyota Corolla 2010 Edition. This work has provided information on the characteristic nature of its engine in-cabin acoustic noise in terms of its waveform, autocorrelation, power spectral density and spectrogram; and established the effectiveness of its acoustic noise for treatment of insomnia through the provision of a computer application for its administration. Other automobiles of different editions and types can also be used to determine different engine noise effectiveness on insomnia patients.

In this twenty-first century, the field of medicine is gradually changing from a conventional method dominated by chemotherapy and surgery to one that promotes the body's own healing ability and hence noise therapy will play a big role in this paradigm shift.

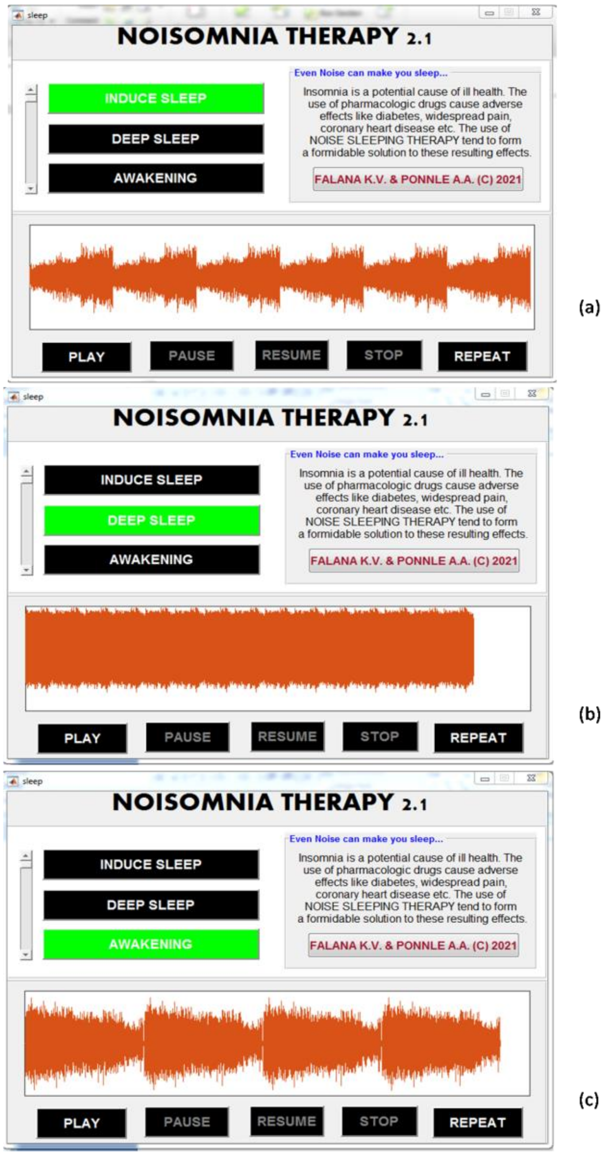

Fig. 11: GUI outlook for the three different noise samples when administering the therapy. (a) Induce Sleep, (b) Deep Sleep, (c) Awakening.

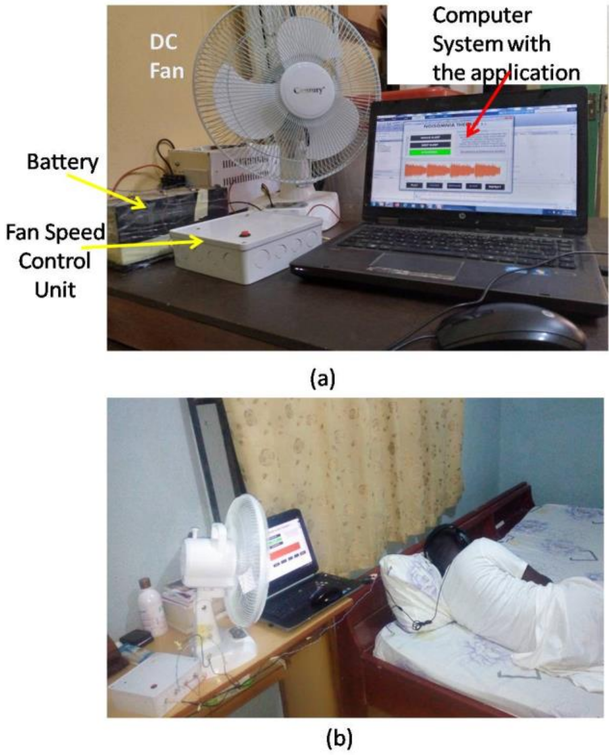

Fig. 12: (a) System setup during testing, (b) A subject receiving the therapy.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

TABLE 1: Response of the administered patients.

Subjects	Age (Yrs)	Sex	PSI	FAS	ASD	Sleep Duration (Hrs)	Remarks
A	62	M	2 years	Pleasant	Yes	4	Good
B	5	F	4 months	Pleasant	Yes	5	Good
C	30	M	8 months	Pleasant	Yes	4	Good
D	45	M	1.5 years	Pleasant	Yes	3	Good
E	14	F	3 months	Unpleasant	No	NIL	No
F	25	M	1.7 years	Pleasant	Yes	4	Good
G	70	F	Above 2 years	Pleasant	Yes	5	Good
H	50	M	10 months	Fairly Pleasant	Maybe	1 hour 10 minutes	Fair
I	18	F	4 months	Pleasant	Yes	3	Good
J	5	M	5 months	Pleasant	Yes	4	Good

PSI – Period of suffering from insomnia; FAS - Feeling about the sound; ASD – Able to sleep with the sound?

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