

Design and Construction of a Portable Electronic Sleep Inducer for Low Resource Settings

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Abstract- Good quality restful sleep is indispensable to mental and physical health. However, pressure due to busy life style, work and sometimes physiological factors have placed constraints on adequate and healthy sleep pattern leading to several sleep disorders such as insomnia, sleep apnea and restless leg syndrome. Sleep disorder affects the quality of life of such patients as it grossly reduces efficiency at work and leads to poor mental and physical health. Available drugs to treat this disorder are addictive with strong adverse effects, while existing devices to provide intervention are very expensive. Hence, the development of an affordable, portable electronic sleep inducer with display unit is presented. It uses geomagnetic property of the earth coupled with electromagnetic wave induction to stimulate sleep. The signal frequency was generated by IC4047 coupled with Arduino Uno and ATmega 328p for device control. The output of this electronic sleep inducer is found to satisfactorily produce 5.89 Hz and 3.58 Hz for theta and delta waves respectively, needed to induce sleep. It consumes less power and it is rechargeable.

Keywords- Sleep, Sleep disorder, Insomnia, Geomagnetic wave

1 INTRODUCTION

Sleep disorder is a state of deviation from the normal human healthy sleeping condition usually characterized by inability to fall asleep, prolonged wakefulness between sleep cycles and frequent waking up earlier than normal (Cai et al., 2018; Ulfatjahan et al., 2017). These often result in short non-restive sleep which has adverse physiological and psychological effects on the wellbeing of our body system (Bishop et al., 1996; Qaseem et al., 2016; Ulfatjahan et al., 2017). Everson et al. (1989) discovered that rats deprived of sleep within 11-32 days died while those allowed adequate sleep survived. Thus, indicating the importance of good restive sleep.

In today's hectic work life, where people are made to work extra hours to meet several deadlines in order to keep their jobs or make a living, the human biological clock which dictates the sleeping time and cycle has been drastically distorted. This together with mental and physical stress that usually goes with it tends to increase the occurrence of insomnia among the work force in our society (Lombardero et al., 2019; Lone & Sethi, 2017). Even though, sleep disorder can occur at any age, it has been found to be predominant in the adults and elderly (Lone & Sethi, 2017). This may not be unconnected with the responsibilities attached to such ages. The adverse effects of sleeping disorder include drowsiness at work, inefficiency due to lack of energy, poor focus on tasks, depression, physical weakness, and emotional instability, among others. Insomnia is not a disease, but it is often one of the symptoms of other chronic medical and physiological disorders such as depression, diabetes, and cardiovascular diseases. Sleep disorder cuts across countries as U.S.A is reported to have about 35% of its population struggling with sleep related disorder (Lombardero et al., 2019).

An International survey of 10,182 individuals for sleep related disorder revealed that Japan has 23% while France, Germany, Italy, Spain, and UK altogether have 31% of the population living with sleep related disorder (João et al., 2018). A few solutions have been proposed to resolve sleep disorders over the years. However, there are some shortcomings associated with those proposed techniques which render them not been extremely effective. Among the proposed methods is the Cognitive Behavioural Therapy (CBT). They are behavioural strategies and changes supported by several research works with the aim of changing patients negative believes about sleep into positive ones with the help of the mind and body (Kim et al., 2017).

Components of CBT include sleep hygiene, sleep restriction, stimulus control, cognitive therapy and relaxation. This method is time consuming, requires expert trainer and expensive (Kim et al., 2017). The use of synthetic hormone such as melatonin has been suggested. Melatonin is the hormone responsible for healthy sleep pattern. But it has not been licensed for prescription as synthetic hormone has been found to often have adverse effects (Xie et al., 2017). Hypnotic drugs such as Benzodiazepine are known for its efficacy in treating short-term sleep disorder. Its prolonged usage poses high risk such as tolerance, addiction, poor cognition and day time sleepiness (Xie et al., 2017). Several life style change approach such as yoga and bedroom habit have been proposed and proved to be effective but they are time consuming and often involve routine performance under the supervision of an instructor (Bankar et al., 2013). Over-the-counter supplements such as valerian teas and other extracts do make people sleep but how it works and possible side effects are not known yet (Bent et al., 2006). To overcome these limitations, a portable electronic sleep inducer is proposed in this work.

Recent laboratory studies have shown that magnetic fields have strong influence on brain waves (Lewczuk et

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al., 2014; Wang et al., 2019). The brain generates different wave patterns due to rigorous electrical activities taking place inside it. These waves can be obtained through electrodes as Electroencephalogram (EEG) signal when placed on scalp and are classified as alpha, beta, theta and delta waves (Wang et al., 2019). Environmental electromagnetic waves includes radio wave, 50/60Hz power line waves, waves from equipment and the earth magnetic waves (Lone & Sethi, 2017). Geomagnetic waves are ultra-low frequency waves from the Earth's magnetosphere with fairly regular oscillation in records of the magnetic field. Since the geomagnetic wave changes with activities such as relaxing, studying, meditation and sleeping, it often affects hormonal balance and brain wave pattern (Lone & Sethi, 2017).

Ulfatjahan (2017) proposed an electronic sleep inducer using IC 555 as the timer and oscillator to produce two frequencies of 2Hz and 5Hz and operates within a one hour range. His design doesn't have a display unit and requires intermittent replacement of battery as it's not rechargeable. Sumukh et al. (2017) came up with another design using IC 4093 and a single output frequency range of 1.5Hz - 5Hz without a display unit. Sumukh's design offers only one frequency. It's not flexible and has no display unit.

This paper proposes an electronic sleep inducer with two frequency units for delta and theta wave band, thus providing for flexibility, a display unit and solves the problem of intermittent replacement of battery by incorporating a charge controller in the design. This design could prolong sound sleep without drugs using IC 4047, Arduino Uno board coupled with Atmega 328p and a digital display unit.

2 THEORETICAL BACKGROUND

Earlier scientists concluded that a sleeping brain is inactive, however, recent studies have shown records of significant muscular and cortical activities during sleep, challenging earlier believe (Fink et al., 2018). This has led to extensive research on brain neural network dynamics in relation to sleep.

2.1 CLASSES OF BRAIN WAVES

There are three main classes of brain waves. The beta wave has the highest frequency range of (14Hz-30Hz) and characterized by active brain, being at alert, concentration and a relatively high level of anxiety as shown in Fig. 1(a). The alpha wave reflects relaxed mind with frequency (8.0Hz-13.9Hz). Alpha wave supports active learning, focus, meditation, and there is increased serotonin secretion (Hasan, et al., 2013). This marks the introductory stage of sleep as shown in Fig. 1(b).

The theta wave (4.0Hz-7.9Hz) begins the stage of rapid eye movement (REM) sleep. Theta wave is characterized by dream, trance, and deep meditation in the unconscious mind (Castronovo et al., 2018; Sumukh, Aishwarya, & Priya, 2017). This stage helps to increase the secretion of catecholamine which improves learning and memory (Ulfatjahan et al., 2017). The delta wave band of (1.0-3.9Hz) is characterized by dreamless sleep, secretion of

growth hormone and rejuvenation of the body. It's a state of very deep sleep shown in Fig.1(c).

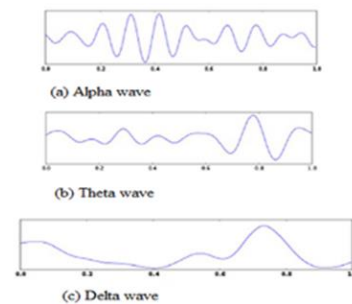


Fig. 1: Brain waves (Roohi-Azizi et al., 2017)

2.2 THE SLEEP THEORY

Sleep is broadly divided into two: Rapid eye movement (REM) and Non-rapid eye movement sleep (non-REM). Sleep is a mixture of sets of multiple non-REM cycles to REM cycles on average of 90 minutes/cycle (Bishop et al., 1996). Non-REM and REM sleep modes are associated with activities in the autonomous nervous system. Non-REM sleep is characterized by increased parasympathetic activities, reduced cardio-parasympathetic drive and diminished muscle tone (Fink et al., 2018). REM sleep on the other hand, is associated with variation in blood pressure, respiratory rate and autonomic instability (Fink et al., 2018). The rapid eye movement in REM sleep as well as the attributed EEG features is regulated by neuronal activities in the sublaterodorsal region of the pons (Saper and Clifford, 2017). Symptoms of insomnia are presented in Table 1.

Table 1. Symptoms of Insomnia

Night-time Symptoms	Day-time Symptoms
Incessant inability to fall asleep	Depression
Non-restful night sleep	Memory impairment
Difficulty falling back to sleep after waking up between sleep	Sleepiness
Inability to fall back to sleep after waking up early	Tiredness and anxiety

Causes of Insomnia

- Life challenges such as work problems, financial concerns, anxiety, stress, fear, and emotional tension.
- Restless leg syndrome caused by discomforting sensations in the body part or leg which causes one to move it intermittently.
- Shift work and jet-lag causes a disturbance in the human circadian rhythm and distorts the sleeping clock.
- Abuse of over-the-counter prescription sleep aids (Hasan et al., 2013).

3 METHODOLOGY

The proposed device employs the principle of electromagnetic induction which explains the interaction of electric and magnetic fields. The brain constantly produces neural frequencies of different amplitude based on activities. Studies have shown that electric stimulation using delta rhythm applied with surface electrode on

subjects scalp was able to induce a similar wave pattern in the frontal cortex, hence improving slow wave/delta wave sleep with enhanced memory (Marshall et al., 2006). The electromagnetic waves generated in the coil of the design follows from amperes law and the magnetic field produced can be represented by Equation (1) from biot-sarvat's law (Gajek and Awrejcewicz, 2018).

$$B(r) = \frac{\mu}{4\pi} \int_{l_1}^{l_2} I_s \frac{r-1}{|r-1|^3} dl \quad (1)$$

Where r is the distance between any location x in the vicinity of the field and the centre of the solenoid, I_s is the distance between the solenoid centre and the infinitely small solenoid length dl , μ is the magnetic permeability of the field environment while l_1 and l_2 are the limits.

Our world is surrounded with magnetic fields from diverse sources such as electronic devices and solar storms. The geomagnetic field of the earth which has influence on the brain wave is employed to create neural frequency waves responsible for relaxation and sleep in subjects to solve sleep disorders such as insomnia (Wang et al., 2019). Analytically, the geomagnetic field of the earth could be represented by a collection of spherical harmonics of Gaussian coefficient and attributed Legendre polynomial (Navabi and Barati, 2017) as shown in Equations (2) and (3).

$$B = -\nabla V \quad (2)$$

where potential function V is given as

$$V(r, \phi, \theta) = R_e \sum_{n=1}^N \left(\frac{R_e}{r} \right)^{n+1} \sum_{m=0}^n [g_n^m \cos(m\phi) + h_n^m \sin(m\phi)] P_n^m(\theta) \quad (3)$$

where g_n^m and h_n^m are Gaussian coefficients,

R_e is the equatorial radius of the earth,

ϕ , r , and θ are the co-elevation, geocentric distances, and East longitude from Greenwich respectively,

ϕ , r , and θ are the international Geomagnetic Reference Field (IGRF).

The main components of the proposed design are shown in Fig. 2. The power supply unit (PSU) consists of the rechargeable 12V battery and AC mains. It powers the device. The Arduino Uno board host the ATmega 328p which together controls the operational modes of the system by communicating with the IC 4047 in the pulse signal generating section and the display unit (it displays the frequency of the mode in operation). The coil generates electromagnetic wave induced by the signal generating unit.

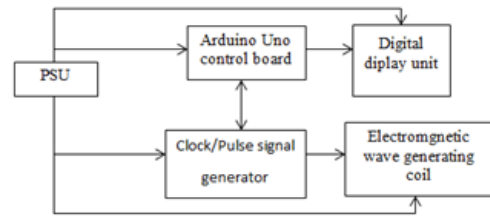


Fig. 2: Block diagram of the design

The proposed theta and delta frequencies are 6Hz and 3Hz respectively. However, based on physically available resistors and capacitors, the calculated frequency varies a little from the generated frequency. The frequency f is obtained from Equations (4) and (5).

$$T = 4.4RC \quad (4)$$

where T is the period, R is the resistance of resistor and C is the capacitance of capacitor. $R = 2\text{ k}\Omega$, $R = 1\text{ k}\Omega$ and $C = 40\text{ }\mu\text{F}$ are selected.

$$f = \frac{1}{T} \quad (5)$$

The calculated delta wave frequency is 2.84Hz while the calculated theta wave frequency is 5.58Hz.

4 CIRCUIT DESIGN

The circuit of the design is as shown in Fig. 3. It consists of the power supply section using a 12V/500mA transformer to supply a 9V DC source through a bridge rectifier (KBL408) and LM7812 voltage regulator (Ewetumo et al., 2019). The main components of the circuit are the microcontroller ATmega 328p and IC 4047 with the Arduino Uno board and the display screen.

IC 4047 was used as a wave shaper and timer as well as to reset the entire operation. IC 4047 is used in this design as it has low power consumption, high noise immunity with standardized symmetrical output characteristics aside the free running operating modes, 50% duty cycle, oscillator output, and good frequency stability. Pin 1 and 2 of the IC 4047 served as timer and two of it was incorporated in the circuit design represented by U3 and U1. Capacitors C1 and C2 were connected between pin 1 and pin 3 of U3 and U1 respectively while resistor R6 and R7 are connected between pin 2 and pin 3 of the U3 and U1 IC respectively.

The component R6 and R7 as well as C1 and C2 were used to control the yield frequency, limit the current and store charges. The resistors are equally used to determine how fast the capacitors will charge or discharge if the resistor value is low the capacitor will charge faster and vice versa. Pin 10, 11 and 13 are the output pins of IC 4047. Pin 10 and 11 are the frequency generator and produces same frequency while pin 13 generates multiple frequencies utilized as an indicator point to which LED resistor was connected.

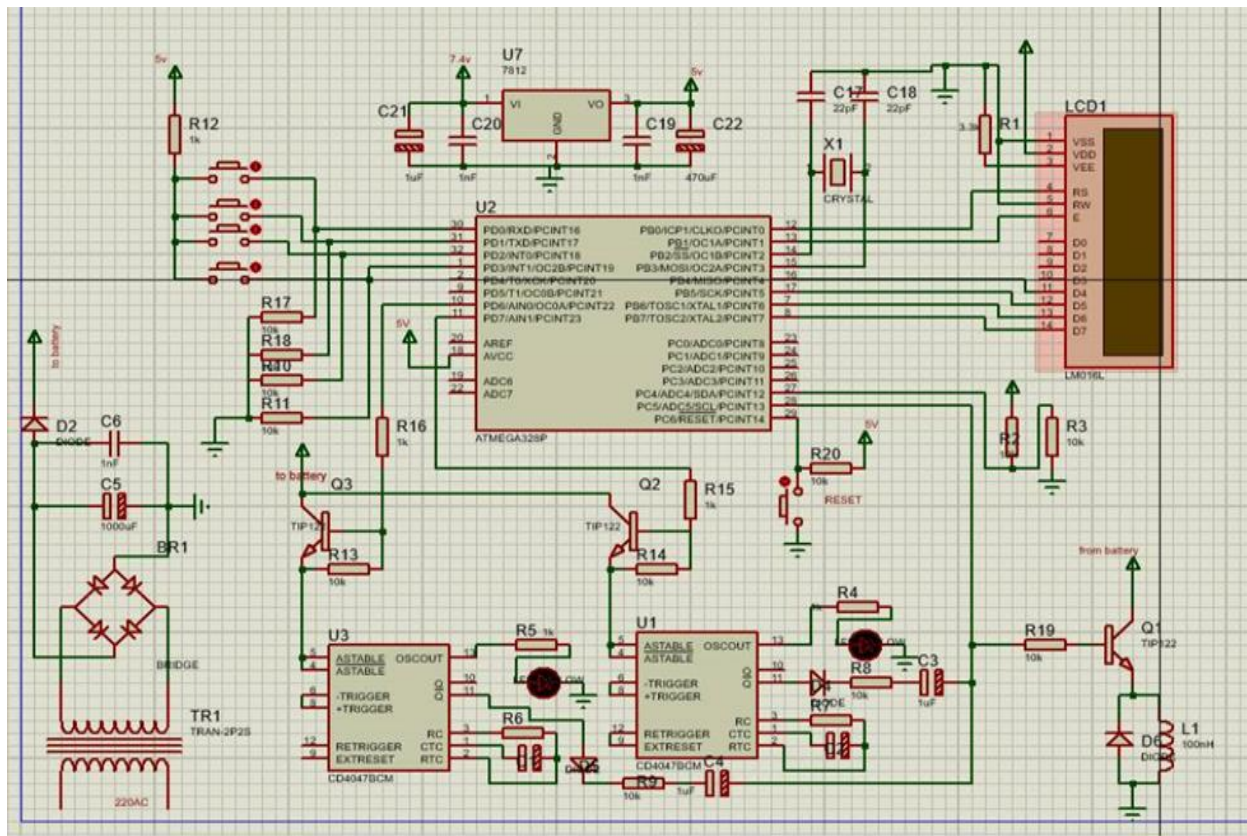


Fig. 3: Circuit diagram of the design

Pin 11 is connected to base of transistor TIP122 which drives the inductor. The inductor was constructed by winding a 0.3mm enamel wire at 640 turns on a 40mm long, 8mm diameter metal stud. Insulating tape was used to protect coil winding (Ulfatjahan et al., 2017). One advantage of this design is generation of two most beneficial neural wave modes, theta and delta so that user can switch between the two for relaxation and deep sleep.

U3 produces theta waves with frequency 5.58Hz and U1 produces delta waves of 2.84Hz respectively by calculation. On either mode, the generated signal is sent via pin 28 to the ATmega328p which sends it through its output pin to LCD display. The battery charging section ensures that the device can be used for a long time without intermittent requirement for battery replacement, thus, making it user friendly. Fig. 4(a) shows the Arduino Uno board been programmed while Fig. 4(b) shows the process of soldering of components on the electronic board.

This device has a power ON/OFF button. It equally has a reset button to overwrite existing program and two LED indicators showing operation of each of the two brain waves. The theta mode has 30 min and 60 min pre-set buttons A1 and A2 respectively. The delta mode has 30min and 60min pre-set buttons B1 and B2 respectively as shown in Fig. 5.

5 PERFORMANCE EVALUATION

A clamp multimeter detected a reading when placed near the perforated end of the plastic casing, indicating presence of electromagnetic field. The UNI-T UT203 clamp multimeter was used to read the output

frequencies of generated theta and delta wave as shown in Fig. 6(a) and (b). These readings were obtained by connecting the positive terminal (red test lead) to pin 11 (the output pin of IC4047) while the COM terminal (black test lead) is connected to ground.

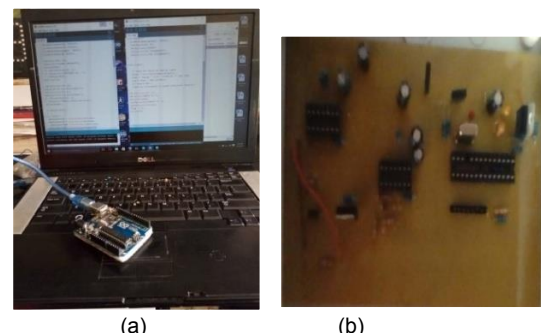


Fig. 4: (a) Arduino Uno board during programming and (b) soldering stage.

The meter output reading for theta mode was 5.896Hz instead of the calculated 5.58Hz while delta mode reading was 3.576Hz instead of the 2.84Hz calculated. Tolerance in the resistance and capacitance values are responsible for these slight deviations.



Fig. 5: The sleep device in ON state.



(a) Theta output frequency (b) Delta output frequency

Fig. 6: Theta and Delta output frequencies obtained from the meter.

The display screen of the device is programmed to show the expected average frequency of 3 Hz to denote delta wave when delta wave button (B) is pressed ON and 6 Hz when the theta wave button (A) is ON. The 3 Hz and 6 Hz are not readings from the device but just illustration of the expected average frequency for delta and theta waves to educate the user. Clinical tests on humans will be done in future in collaboration with medical experts.

6 CONCLUSION

The device was able to generate the delta and theta brain wave frequencies needed to induce prolonged sleep and reduce frequency of wake up(s) between sleep at night. The device charges smoothly eliminating intermittent replacement of battery while the display helps inform the user of the operating mode and its standard frequency. Hence, sleep quality is enhanced by this device and it is safe. However, it is recommended that subsequent designs should increase its portability by reducing dimension and incorporate sound therapy to further increase its flexibility and effectiveness. The intensity of the electromagnetic wave generated can also be improved upon. Several laboratory tests are needed on sleep disorder patients to further validate its efficacy.

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