In-House monitoring and measurement of respiration rate using Disposable Paper Sensor

Swagata Barik [a,1], Madhurima Chattopadhyay [b,1], Debjyoti Chowdhury [c,1]

[a] Student, E-mail: swagata.barik.mtaeie22@heritageit.edu.in

[b] H.O.D & Professor, E-mail: madhurima.chattopadhyay@heritageit.edu

[c] Assistant Professor, E-mail: debjyoti.chowdhury@heritageit.edu

[1] Department of Applied Electronics and Instrumentation Engineering, Heritage Institute of Technology, Kolkata 700107, India

Abstract

This present work provides an easily disposable paper-based interdigitated sensor embedded inside the mask for the detection of respiration rate continuously without direct contact with the human body. In present COVID scenario, everyone needs to wear mask for preventing the unwanted spreading of the said virus. But in tropical countries like India, People always complain about a suffocating situation while wearing mask. In order to address this, we have designed a non-invasive paper sensor that can be placed inside the mask (beneath nostril) for measuring breathing rate regularly to find out a cost-effective device capable of monitoring breathing rate. In general, we prefer use and throw type mask, thus the proposed paper-based sensor gives a cost-effective solution compared to the Current appliances of breathing sensing as most of them are burdensome, bulky, inconvenient as well as exorbitant than a paper-based respiration sensor. Essentially, these current approaches undergo through a practical limitation of frequency and time span i.e. static measurement. It is known that the humidity level of a paper changes according to the moisture content. Thus, it can easily detect the inhalation and exhalation through this changing. Moreover, variation of moisture level that happens due to breathing cycle changes the ionic conductivity of the sensor. The interdigitated design is the most suited for achieving higher sensitivity and easy to fabricate. First, we have designed it in Finite Element Method (FEM) based platform and finally this design is implemented with graphite-based electrodes on cellulose paper. Microcontroller based electronic circuitry is used in order to monitor and record the real-time respiration rate. It has been observed that the breathing rate as well as pattern gives a significant variation along with physical conditions and obstructive pulmonary diseases.

Keywords : Paper Sensor; Interdigitated electrodes; FEM based software; Ionic Conductivity; Respiration rate;

DOI Number: 10.14704/nq.2022.20.9.NQ44240 **Neuro Quantology 2022; 20(9):2072-2079**

INTRODUCTION

In the last few years, researchers and developers are looking forward for development of low-cost, simple, easy-to-use, non-invasive, disposable, biodegradable medical diagnostic devices in health management and healthcare system for the fastest analysis as well as reduce the requirement of various instruments in laboratories (Dinesh Maddipatla et.al,2016). Breathing is defined as a vital sign of human being, the process of air flowing in and out of the lungs during inhalation and exhalation (F. Q. AL-Khalidi et.al.,2011). Breath rate and blood-oxygen saturation are two significant measurable signs to monitor health condition.

In worldwide, as of 6:25pm CEST, 1 July 2022, about 545,226,550 affirmed instances of COVID-19, among which 6,334,728 death case, reported to WHO. As per the review at the hour of looking at the patients with at Rush University Medical Center and University of Washington Medicine emergency clinics, unusual breath rate and blood oxygen immersion likewise foresee the death pace of patients who are conceded in medical clinic during COVID-19. As per Henry Huang, MD, Cardiologist in Rush University Medical Center,

patients who introduced to the emergency clinic with hypoxemia (beneath 92% O_2/oxygen immersion) or tachypnea (respiratory rate over 22 breaths each moment) had fundamentally very low in-emergency clinic endurance. World Health Organization (WHO) reports that almost 5% of individuals is experiencing respiratory illness like sleep apnea syndrome and around 30 % of individuals in their age of 70 are accounted for to have a respiratory sickness in industrialized developed lands (Se Dong Min et.al.,2014). According to WHO, in the year 2019, about 3.23 million death cases were reported due to Chronic obstructive pulmonary disease (COPD) around the world. Nearly 90% of COPD deaths in those under 70 years old happen in low and middle-income countries (LMIC). Asthma is significant noncommunicable disease (NCD), affecting both children and adults as well as the most widely recognized persistent sickness among youngsters. In 2019, an estimated 262 million people were affected by asthma and among those 4,55,000-death case happened (www.who.int). In rest condition, the respiration rate of normal heathy adult person is 12-20 breaths per minutes. Respiration rate of >27bpm is a vital indicator of heart failure. On the other hand, a RR<12 bpm(bradypnea) is likewise a worry and ought to make the wellbeing proficient aware of thinking about causes. There are two types of strange respiratory rate conditions i.e., Tachypnoea and Bradypnoea. Nervousness, Profound misery, Torment, Fever, work out, Asthma, Aspiratory embolism, Pneumonia, Intense respiratory pain disorder, Hypersensitivity, Cardiovascular breakdown, Shock, Diabetic ketoacidosis, Neuromuscular problems, Ongoing obstructive aspiratory sickness and other similar health issues are responsible for tachypnoea i.e., greater than the normal respiration rate for age (> 22 bpm). Gloom of the respiratory focus, Narcotic excess, expanded intracranial strain, Diabetic trance like state, Weariness brought about by extreme aviation route block, Rest apnoea, Heftiness hypoventilation conditions are responsible for Bradypnoea i.e., respiratory rate lower than normal range for age (<12 bpm) (Wheatley I (2018). Likely 25 million Americans are experiencing this medical problem, 80% of which stay undiscovered. Subsequently, it is vital to have a persistent human breath rate checking framework to notice the medical issue with prompt activity for clinical patients as well concerning non-clinical reason too. In most medical clinic as well as in hospitals, the breath rate is normally estimated by the chest movement without touching the patients specially in emergency room of hospital (Güder, Firat et.al.,2016).

Respiration rate can be estimated by contact or without contact with the human body. A resistive paper sensor is reported for continuous monitoring of breath rate in (Güder, Firat et.al.,2016). Combination of MWCNT/PDMS materials based productive and low-priced paper sensor is reported (Thiyagarajan.K et.al.,2017). An inductive coupling-based method which utilizes a band connected to the patient's abdomen and breast is accounted for in (D. Teichmann et.al.,2010). A breath sensor using strain gauge is also reported in (M. Folke et.al.,2002). Breathing monitoring using airflow measurement technique is discussed in (M. Folke et.al.,2003). A breath checking framework without contact with body by utilizing a fiber grating vision sensor and processor unit is likewise detailed in (H. Aoki et.al,2001). This paper develops a new design of capacitive sensors for breath detecting and depicts the design and creation of a prototype textile-based capacitive-sensor breathing belt (Carey R. Merritt et.al.,2009). Graphite and silver nanoparticles-based paper sensor for long-term respiration monitoring is discussed in (Vivekananthan Balakrishnan et.al.,2019). Carbon based capacitive paper sensor is developed to monitor the respiration rate in this paper (Shahid Malik et.al.,2018).

In this present work, we develop a proficient, simple, low-cost, environment friendly, use and throw type respiratory sensor using graphite materials on a paper substrate for continuous respiration monitoring purpose. This sensor is placed inside a flexible procedure mask beneath the nostril. The whole system basically changes a textile mask into practical veil which can monitor the pattern of respiration rate of individual within a time span.

I.SENSOR DESIGN

In this present work, mixture of proper quantity of graphite dust and adhesive were used to develop a paper-based resistive humidity sensor for real-time breath rate monitoring.

A. Design through FEM based platform

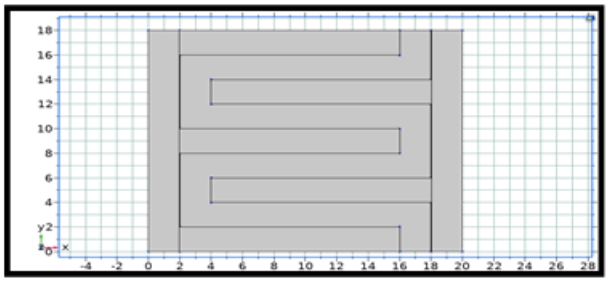

Figure 1: *Schematic diagram of paper sensor in COMSOL Multiphysics Software Tool*

At first COMSOL Multiphysics software was selected to analyze the change of resistance with changing the electrical conductivity. Then interdigitated electrode pattern of sensor was designed based on the current material, physical dimension and layout. The outline of the sensor was designed in COMSOL as shown in figure 1.

The electrodes were made of Graphite and its material properties was set according to Table 1.

Table.1: Material Properties of Graphite

Property	Variable	Value	Unit
Electrical conductivity	sigma_iso ; sigmaii = sigma_iso, sigmaij = 0	3e3[S/m]	S/m
Relative permittivity	epsilonr_iso; epsilonrii = epsilonr_iso, epsilonrij = 0	15	1
Relative permeability	mur_iso; murii = mur_iso, murij = 0	1	1
Heat capacity at constant pressure	C_p	710[J/kg*K)]	J/(kg.K)
Surface emissivity	epsilon_rad	1	1
Density	rho	1950[kg/m^3]	Kg/m^3
Thermal conductivity	k_iso ; kii = k_iso, kij = 0	150[W/(m*K)]*(300[K]/T)	W/(m.K)

We studied the COMSOL Multiphysics software tool by performing the conductivity studies based on the electrostatic interface in AC/DC module present over here. All studies were stationary. The geometric parameters were changed when we were using the parametric sweep feature during study for each variable. In this study, a global evaluation of resistance (ec.R11, a parameter from the COMSOL library) was executed (S.Satti, M.Shojaei Baghini, 2013).

B. Fabrication of sensor in real time

The real time design and fabrication of paper-based respiration sensor consists of different steps:

a. **Pattern Selection:** At first, an interdigitated electrode pattern (IDE) was preferred for easy and fast sensing.

b. **Geometry selection:** Then the outline structure was printed on filter paper by the printer machine.

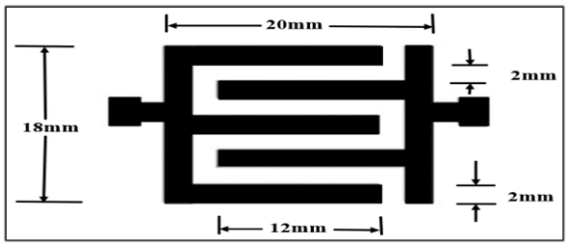

Figure 2: *Sensor geometrical dimension*

In this sensor, the geometry of active sensing area was 2cm X 1.8 cm X 0.02 cm. where distance between two electrodes was 0.2 cm and width of each electrode is 0.2 cm as shown in figure 2. Here we chose this dimension of paper sensor because of measurable resistance. If we increased

the length as well as number of electrodes, then overall resistance increased as it should not possible to measure.

c. **Material selection:** Whatman grade No.1 filter paper from Amazon was used as the substrate. Graphite dust (Weird Graphite Powder manufactured by Stride Enterprises) which was available in Amazon, used for electrodes. Vinegar and Adhesive (FEVIGUM, Pidilite Industries Ltd.) were purchased from local market. Other materials which were used, those were easily available in household.

d. **Composite selection:** After choosing proper dimensions, graphite paste was prepared for deposition on sensor. For preparing the graphite paste 0.5 gm graphite dust was mixed with 0.3 ml of adhesive. At the time of making graphite paste, first we covered the graphite powder with vinegar after putting the graphite powder into a pot and stirred little. After few minutes when graphite put down on the bottom of the pot then the clear liquid on top was removed by a syringe. Then adhesive was mixed with it to keep the graphite suspended [6]. Different amount of adhesive (0.2-0.6 ml) was mixed with 0.5 gm graphite dust and different thick lines of paint (1cm X 0.2 cm) were drawn. Then paint was dried overnight. After that resistance was measured with different amount of adhesive as shown in figure 3. Among those 0.3 ml adhesive with 0.5g graphite dust composite was used for further proceedings. Figure 4(a-e) describes the schematic demonstration of complete preparation of composite.

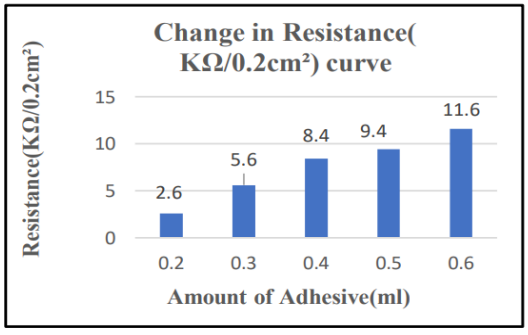

Figure 3: *Change in resistance curve with different amount of adhesive*

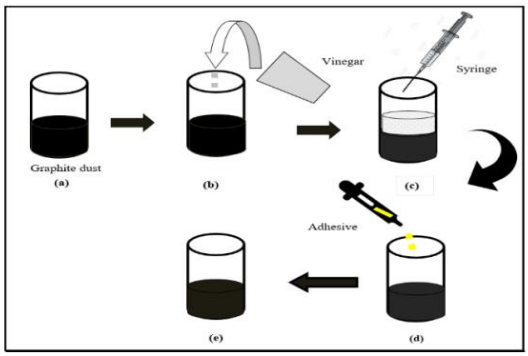

Figure 4: (a-e) *schematic demonstration of the graphite- adhesive composite preparation*

e. **Lithography:** After material and proper composite selection, mask for sensor layout with proper geometry were created on COMSOL Multiphysics programming and print out was taken. Then the graphite-based composite as prepared earlier deposited on another paper substrate. After that mask was removed and dried overnight for further proceeding.

f. **Dipped in NaCl solution:** Common kitchen-salt (NaCl) was used to prepare the solution. Here, solution was made using 1 g NaCl into 3 ml of water(de-ionized). While the solubility of NaCl in water was 1g/3ml. On fine settings, we deposited the solution over IDE with uniform hand motion for 1 minute. After that it was dried overnight.

II.SCHEME OF THE PROPOSED DEVICE

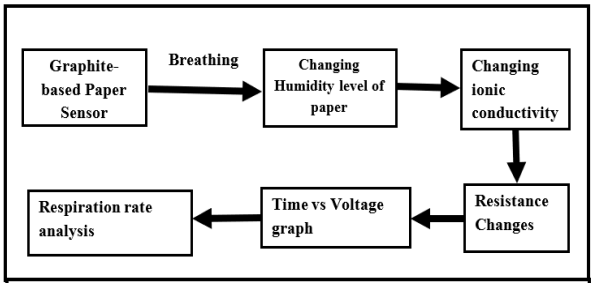

Figure 5: *Schematic block diagram of Respiratory rate measurement system*

By acknowledging current scenario, there need some emergency step to monitor the health condition to control over it. Thus, this work can develop a paper-based, low-cost, simple, non-contact based, easy-to-use, disposable, interdigitated sensor which can be used as a

respiration monitoring system when the sensor is placed inside the mask in this COVID situation. This is basically a real time respiration monitoring system as shown in figure 5 which consists of one highly précised paper- based interdigitated sensor along with microcontroller refurnished with explicit computer programming in form of physical analogue outputs as a real-time response through graphical representation to monitor the respiration rate inside the mask in regular basis.

III.WORKING PRINCIPLE OF THE SYSTEM

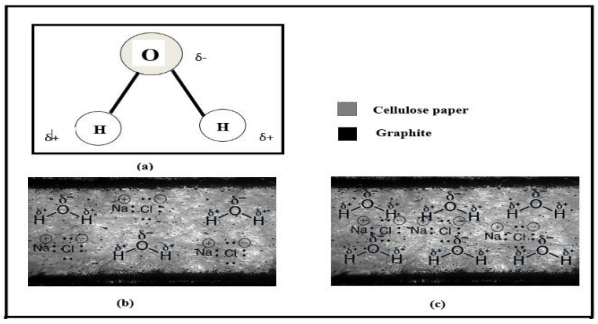

Figure 6: *Schematic representation of (a) water molecule (b) structure of filter paper after adsorption of water, Nacl on the top of the paper during Inhalation (c) Exhalation.*

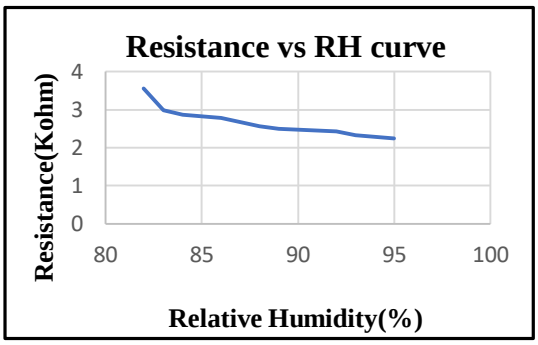

Figure 7*: Change in resistance of the paper-sensor vs relative humidity*

The paper sensor takes advantage of the hygroscopic character of filter paper and adsorbing water from ambience propensity. For example, at seventy percent relative humidity (RH), paper retains up to ten percent of its weight when it dips in water. The ionic conductivity of the paper depends on the amount of water present on the outer layer of the cellulose paper which shows the progressions in moisture available on paper because of breathing cycle determines breath. At the time of exhalation, the relative humidity of human breath is 100 %, and accordingly, builds how much water on the sensor. While taking in, how much water on the outer layer of the cellulose strands is decreased on the grounds that the encompassing environment quite often has a low RH than the breathed-out air. During this breathing system, changes in ionic conductivity is the reason for changing the dielectric property of filter paper because of progress the dampness. Because of breathing, water particle structures hydrogen holding with polar - OH groups available on the filter paper. As well as after preparing the sensor, the sensor is dipped into the Nacl solution (Nacl=1gm and H_2O=3ml). So, Nacl solution is also responsible for changing ionic conductivity of paper as shown in figure 6. Initially, Variation in the resistance of breath sensor changes relative humidity (RH) from 82% - 95% considering one electrode pair at normal temperature in a closed chamber is presented in figure 7. Then, at that point, chamber is additionally furnished with DHT11, humidity and temperature sensor connected with Arduino data acquisition (DAQ) framework to monitor, record and report the data.

IV.EXPERIMENTAL SET-UP

The experimental set-up to develop the response of the paper-sensor in normal condition is shown in figure 8. This figure shows the schematics of the fabricated paper-based breath sensor interfaced with microcontroller, controlled by Arduino Programming Language and PyCharm Programming language for signal processing and monitoring the respiration rate and its patterns. The fabricated sensor as shown in figure 9(a) is placed inside the safety mask using double sided tape beneath the nostril. A SERVOTEX disposable respiratory mask is used due to low-cost and easily availability in market. An optical microscope images of different parts of paper sensor i.e., gap between two electrodes and graphite electrode are shown in figure 9(b), (c). Utilizing a standard humidity and temperature sensor (DHT11), it is recognized that the humidity and temperature inside the mask changed between 82% - 95% and 32°C – 33.8°C respectively for the duration of breathing inside a closed chamber without the interruption environmental impacts. In the current review, breathing through nose for about 1minutes

wearing the sensor mounted mask is taken. At long last, the paper sensor is incorporated with an Arduino unit to make a breath checking unit.

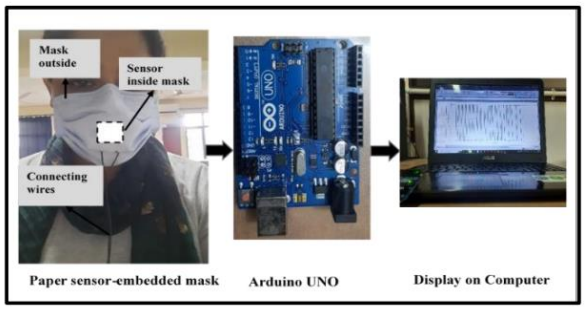

Figure 8: *Overview of paper sensor-based respiration rate monitoring system*

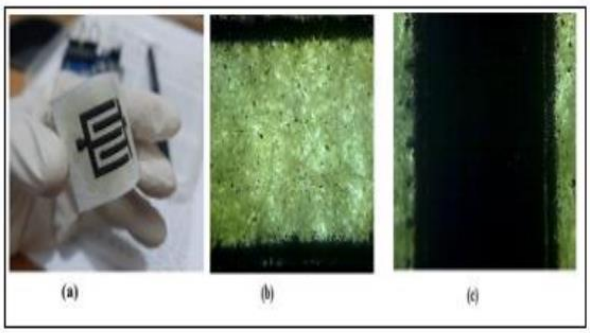

Figure 9: *(a)Fabricated sensor; (b), (c) optical microscope image of sensor*

V.RESULTS AND DISCUSSIONS

The moisture contented paper is reason of changing the relative humidity. We studied the characteristics of resistance vs electrical conductivity in COMSOL Multiphysics software. Observing of breathing rate was done on a healthy adult human being (Female: 24 years old) to concentrate on the possibility of the sensor execution. During the inhalation and exhalation, the humidity level of sensor was varied. Variation of resistance of breath sensor during study, relative humidity changes from 80% to 95% is introduced in figure 7. It is seen that for higher humidity region i.e., between 80%-95%, the sensor shows low sensitivity. The above perception may be credited to the adjustment of the ionic conduction process into the paper brought about by various concentration of water molecules, subsequently the change of resistance of the gadget with changing humidity level around them.

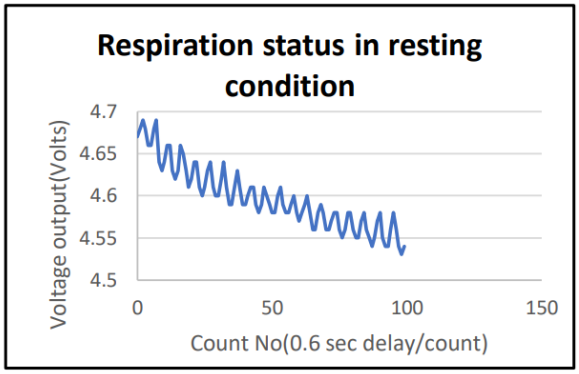

Figure 10*: Pattern of respiration with breathing time in resting condition*

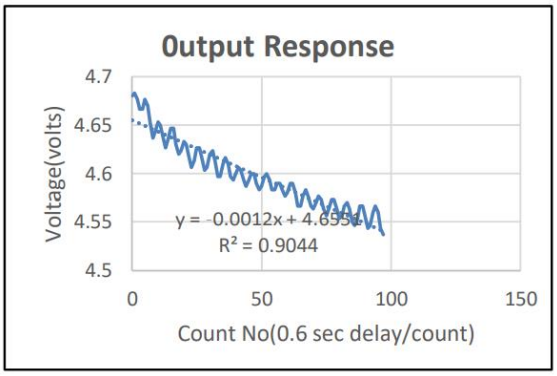

Figure 11: *Output response after applying moving average filter in fig.10 in resting condition*

The humidity level of the sensor was varying during breathing cycle. In resting condition, the curve indicated the high value during inhalation whereas a lower value during exhalation time with exponential decaying pattern as shown in figure 10. Here amplitude of the output pattern is ~ 20 mV and count no is 100 with 0.6 second delay that means 1minute time. Output pattern after applying moving average filter on figure 10 with liner trendline, equation and R-squared value is shown in figure 11. After applying moving average filter through software programming, pulse is generated with the linear trendline equation (zero-crossing) to count breaths per minutes(bpm) as shown in figure 12. Here respiration rate (RR) is 17 bpm as highlighted in figure 12. A healthy adult's normal, resting breathing pattern is estimated by a spirometer. The graph shows ordinary consequences of flow rate (L/s) during breathing in rest condition as shown in figure 13. From figure 10 and figure 13, we can observe that the breathing pattern and the breathing rate (17 bpm) are same in resting condition for same volunteer.

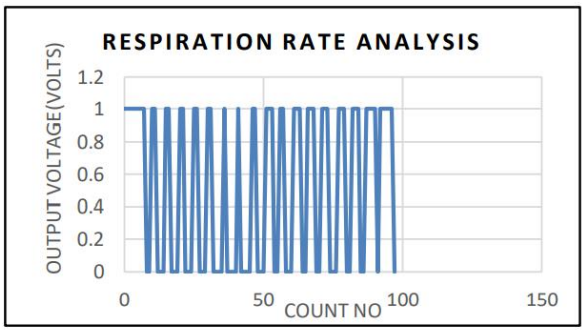

Figure12: *Pulse generation after applying zero crossing detector in figure 11 in resting condition*

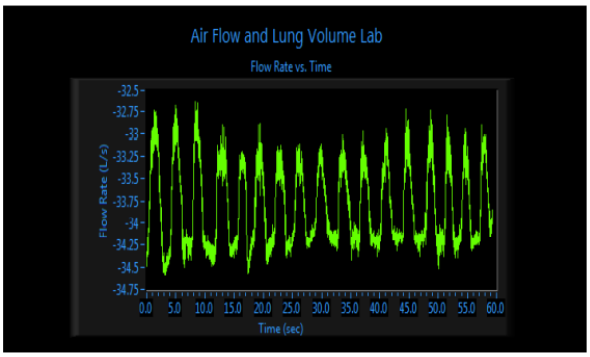

Figure 13: *variation of flow rate with time through Spirometer*

VI.CONCLUSION AND FUTURE SCOPE

In this present research work, a graphite-based light-weight disposable paper sensor was developed for monitoring and measurement of breathing rate. The simplicity of manufacture techniques, high moisture sensitivity, low-cost, environment friendly materials and the its application towards long haul human breath observing proves the innovativeness of this system. The main limitation lies with the sensor is that we can measure respiration rate continuously for 5 minutes at a stage because by that time it is saturated with the moisture inside the mask. So that after every 5 minutes we have to spend some time to make the sensor dry up. The sensor electrodes lose its flexibility when it is wrinkled on various occasions. We have studied respiration rate other than resting conditions like light walking, free-hand exercise, running and found a significant change in the pattern. In addition, we can further use it for asthma patient while suffering from breathlessness and found again the signature changes. In coming few months, we employed our sensor to study those condition as well as to study the Chronic obstructive pulmonary diseases (COPD) whether it can identify any pattern from the respiration behavior. In any case, the entire framework including signal processing and proper fabrication process needs some upgradation to turn it into a feasible commercial product. In future by proper recognition of different breathing pattern, we can differentiate between the changing of breathing rate due to different physical activities and changing of breathing rate because of respiratory sickness like asthma, pneumonia, Chronic obstructive pulmonary disease (COPD), COVID-19 etc. for real-time applications in health care monitoring.

References

Dinesh Maddipatla et.al, "Development of a Printed Impedance Based Electrochemical Sensor on Paper Substrate",2016 IEEE SENSORS, INSPEC Accession Number: 16597167, DOI:10.1109/ICSENS.2016.7808785, IEEE,2016.

F. Q. AL-Khalidi et.al, "Respiration rate monitoring methods: A review", Pediatric Pulmonology, vol. 46, pp. 523–529, 2011.

Se Dong Min et.al, "Simplified Structural Textile Respiration Sensor Based on Capacitive Pressure Sensing Method", IEEE SENSORS JOURNAL, VOL. 14, NO. 9, SEPTEMBER 2014.

WHO reports: https://www.who.int/health-topics/chronic-respiratory-diseases#tab=tab_1.

Wheatley I (2018) Respiratory rate 3: how to take an accurate measurement. Nursing Times [online] 114; 7, 21-22.

Güder, Firat, Alar Ainla, Julia Redston, Bobak Mosadegh, Ana Glavan, T. J. Martin, and George M. Whitesides. 2016. "Paper-Based Electrical Respiration Sensor." Angewandte Chemie International Edition 55 (19) (April 5): 5727–5732. Portico. doi:10.1002/ anie.201511805.

Thiyagarajan.K et.al, "Flexible, Highly Sensitive Paper-Based Screen Printed MWCNT/PDMS Composite Breath Sensor for Human Respiration Monitoring", DOI 10.1109/JSEN.2020.3040995, IEEE Sensors Journal,2017.

D. Teichmann, J. Foussier and S. Leonhardt, "Respiration monitoring based on magnetic induction using a single coil," in Biomedical Circuits and Systems Conference (BioCAS), Paphos, Cyprus, 2010.

M. Folke, F. Granstedt, B. Hok and H. Scheer, " Comparative provocation test of respiratory

monitoring methods," J Clin Monit Comput, vol. 17, pp. 97-103, 2002.

M. Folke, L. Cernerud, M. Ekstro and B. Hok, "Critical review of noninvasive respiratory monitoring in medical care," Med Biol Eng Comput, vol. 41, p. 377–383, 2003.

H. Aoki, Y. Takemura, K. Mimura and M. Nakajima, "Development of non-restrictive sensing system for sleeping person using fibre grating vision sensor," in International Symposium on Micromechatronics and Human Science, Nagoya, Japan, 2001.

Carey R. Merritt et.al, "Textile-Based Capacitive Sensors for Respiration Monitoring", IEEE SENSORS JOURNAL, VOL. 9, NO. 1, pp.71-78, JANUARY 2009.

Vivekananthan Balakrishnan et.al, "Paper-based Electronics Using Graphite and Silver Nanoparticles for Respiration Monitoring", IEEE Sensors Journal , Volume: 19, Issue: 24,pp.11784-11790, 15 December 2019.

Shahid Malik et.al, "Respiration Monitoring Using A Flexible Paper-based Capacitive Sensor", 2018 IEEE SENSORS, DOI:10.1109/ICSENS.2018.8589558, IEEE, 2018.

S.Satti, M.Shojaei Baghini, "Sensitivity Optimization of Microfluidic Capacitance Sensor using COMSOL Multiphysics", IIT Bombay, Mumbai, Maharashtra, India,2013.