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THE DEVELOPMENT OF PIEZOELECTRIC SENSOR AS PHLEGM DETECTOR IN SIMULATED HUMAN LUNGS

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ABSTRACT

Detection of phlegm sounds may help to identify human with pneumonia-related disease. However, auscultatory findings may be subjected to clinically relevant observer variation. . Phlegm related diseases such as tuberculosis, pneumonia, and bronchitis is a fatal disease if not properly diagnosed and treated. Unfortunately, until now there is still no exact parameter to measure the intensity of phlegm in human or animal lung infected with phlegm related illnesses. Currently, doctors only rely on experience, anatomy knowledge, and visual cues from x-ray images to decide on the patient lungs condition. Piezoelectric is an electrical phenomenon where electric charges will accumulate in a certain piezoelectric material in response to applied mechanical stress. This study demonstrated a prototype sensor designed to have a fixed parameter with real-time analysis to measure the phlegm intensity by utilizing the inherent ability of piezoelectric sensor to detect movement of phlegm substitute in simulated human lungs. The prototype is presented with an Arduino board, a circuit, and a vacuum pump. It was proven, that the prototype was able to detect and differentiate viscous and runny phlegm substitute solution. This finding might be the foundation towards accurate and digitalized detection of phlegm in human lungs. Our result had shown that when the phlegm substitute solution was thick and viscous, will correlate with higher voltage values as detected by the piezoelectric sensor. In contrast, low values in voltage were produced when less-viscous solution was present. Based on these findings, the prototype has proved that it has the ability to measure the intensity of phlegm with a fixed parameter.

Keywords: pneumonia, phlegm, piezoelectric sensor, Arduino.

1. INTRODUCTION

Hippocrates described phlegm as one of the four essential “humours” of the body. Bronchial secretions from the respiratory epithelium and sub mucosal glands, together with inflammatory cells that have migrated from the blood, are found in phlegm. From the 1950s to 1980s, phlegm was analyzed microscopically, and fluid phase component of phlegm were measured to diagnose asthma and chronic bronchitis, and to assess the disease severity. In the 1950s, phlegm testing was developed in connection with the diagnosis of lung cancer and tuberculosis. In relation to asthma, international interest in phlegm testing arise after it was observed that epithelial damage and inflammatory changes are present even in early to stage asthma [1]. Excessive of phlegm production may lead to another disease such as pneumonia, lung cancer and asthma.

Pneumonia is an infection of the lungs that is caused by bacteria, viruses, fungi, or parasites. It is characterized primarily by inflammation of the alveoli in the lungs or by alveoli that are filled with fluid (alveoli are microscopic sacs in the lungs that absorb oxygen). It was proved that one of the symptoms of pneumonia is cough that may produce white, yellow, or green mucus which is phlegm. When an asthma attack occurs, the phlegm production is increased. The smooth muscles located in the bronchioles of the lung constrict and decrease the flow of air in the airways. The amount of air flow can further be decreased by inflammation or excess mucus secretion [2]. Pneumonia is a very critical disease and has been a major cause of child deaths throughout the world. According to the latest World Health Organization (WHO) data published in April 2011, influenza and pneumonia deaths in Malaysia reached 9,417 or 9.20% of total deaths - influenza and pneumonia being the number three killer behind coronary heart disease and stroke [3]. Yet there are still no accurate and digitalized medical devices to diagnose pneumonia. The invention of device such as stethoscope, chest x-ray and chest computer tomography (CT) scan, blood test, sputum test, pleural fluid culture, pulse oximetry, and bronschopy to indicate the possibility that the patient have pneumonia help a lot but the process required the doctor’s in-depth knowledge to diagnose lung related illnesses as well as time consuming and expensive. For instance, the sputum sample needs to be examined in the laboratory first. These kinds of issues resulting into longer waiting time for the patients besides the possibility of inaccurate diagnosis from the medical practitioners.

There are many research studies that have been conducted to diagnose pneumonia. Most of it involve taking out samples from patient using needles and by separating the upper airway air from the lower airway air which requires a person with clinical expertise to perform this procedure. In 2010 a device for sampling lower airway aerosols called Pneumonia Check™ was developed where this specimen collection device was designed to collect aerosol specimens selectively from the lower lung generated during deep coughing [4]. In U.S., a patent number 6,582,376 issued to Baghdassarian in 2003, a device is described which analyses the carbon dioxide concentration during exhalation to determine when an alveolar sample was obtained [5]. Similarly, U.S. patent number 4,248,245, issued to Kempin in 1981, uses a temperature sensor to discern when alveolar air has entered [6]. Both of these methods use chemical and temperature sensors respectively but not piezoelectric sensor. From previous research papers, there is no study done on piezoelectric sensor to detect phlegm intensity yet.

Piezoelectric sensors are designed to receive mechanical stress of the piezoelectric material in response to a change of loads emanating from for instance an acceleration of a seismic mass or from a change in pressure acting on the sensor. This results in a transport of electrons or electrical chargers within the material. This condition provides a change in voltage across the piezoelectric sensor. This voltages value corresponds to the load to which the sensor is subjected [7]. The inherent ability of piezoelectric material to produce electricity when subjected to deformations and vice versa makes it an attractive candidate for particularly in wearable or implantable bio-medical systems [8].The development of thin, flexible, and mechanically pliable piezoelectric devices became possible due to the recent advancement in materials science engineering, mechanics, and electronics. These developments resulted in lightweight, portable and robust electromechanical systems, suitable for mounting on nearly any type of surface with performance characteristics that is at par with conventional, rigid devices [9]. In the past few years, many researchers had successfully demonstrated a sizeable range of different types of devices capable of harvesting electrical energy from mechanical energy resources, each with potential applications in biomedicine [8]. Inorganic piezoelectric elements that are mechanically arranged into flexible or pliable setups and have high piezoelectric coefficients are used in this field. A device may be optimized to achieve low bending stiffness as to avoid unwanted mechanical load on the body and high degree of bendability to imitate to the targeted regions of the anatomy simultaneously with sufficiently high efficiency [10]

Therefore, this research was being conducted as to provide a foundation study towards the development of a technology that can detect phlegm intensity which correlates with the severity of the phlegm-related disease itself. The objectives of this research is to investigate the possibility of piezoelectric sensor being a potential diagnostic tool to detect the intensity of phlegm in human lungs, to detect phlegm intensity at different consistencies incorporating Arduino for real-time analysis, and to determine the optimum feasibility design of a pneumonia diagnostic tool using piezoelectric sensor, Arduino board and breadboard, Arduino and Processing software in C language. Piezoelectric sensor has not yet fully studied and developed as a real-time, user friendly probe to detect pneumonia. Using piezoelectric effect to detect phlegm intensity is a new idea. Innovation needed to be made in order to investigate the best feasibility and usage of piezoelectric sensor; this study presented the application of a lab-scale prototype of piezoelectric sensor in detecting phlegm in simulated human lungs.

2. MATERIAL AND METHODS

A simulated human respiratory system was used for this project as this is a pilot system to test the efficacy of piezoelectric sensor to detect phlegm in human lung. For accurate data collection, the piezoelectric film sensors are placed near the surface of the simulated human lung (surface of the balloons) to detect the vibration and stress of the simulated lungs when air was pumped in or out. These vibrations and stress created from the balloons are collected as electric signal, voltage (V). Glycerol solutions in the balloons are used to simulate the movement of phlegm in human lungs. Figure-1 demonstrates the flow of this project while Figure-2 showed the simulated human lung where the balloons represent the lungs of phlegm infested (contains glycerol) and non-phlegm infested (did not contain glycerol). The balloons were encompasses with different consistencies of glycerol solutions throughout the experiment.

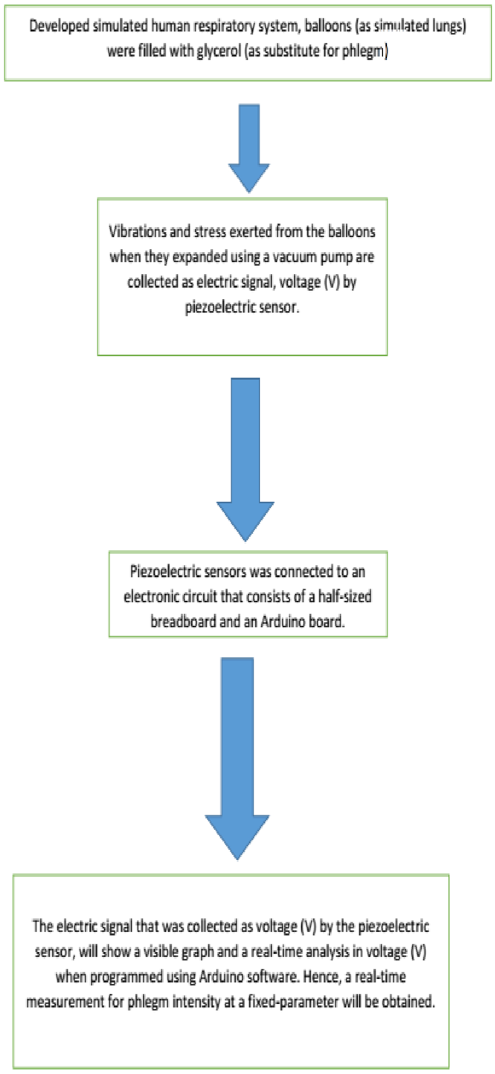

Figure-1. Flow chart of the project.

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Figure-2. Simulated human lung using balloons.

Piezoelectric film sensors were connected to an Arduino board, a half-sized breadboard, and a laptop. The Arduino software and Arduino Processing software was in C language that was applied in this project. These software programs was used to help the Arduino to perform tasks and from this it will generate a real-time value of voltage and a visible graph when the programs was executed. From this graph, a measure for phlegm intensity using glycerol solutions versus voltage was obtained. The full set for the prototype was shown in Figure-3 where it was demonstrated that as the manual vacuum hand pump was pressed, the balloon expanded and will cause some friction with the piezoelectric sensor which in turn will be translated as increase or decrease of voltage units depending on the volume of the glycerol in the balloons.

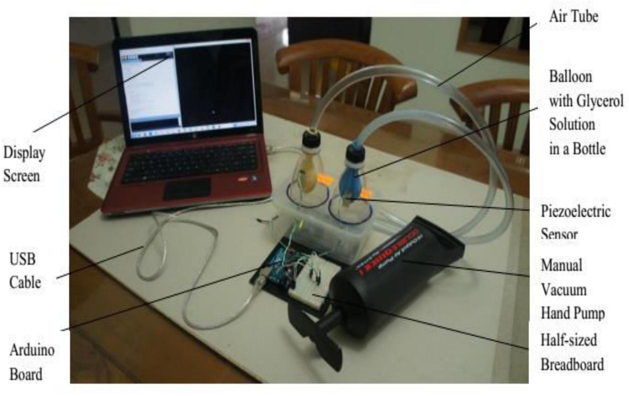

Figure-3. The full set of the piezoelectric sensor prototype for the detection of phlegm.

The electric signals that was obtained as voltages (V) using piezoelectric film sensors at different consistencies of glycerol solution was collected and tabulated in a table. For every consistency, several voltages values are collected and the mean of the voltages are calculated. Since Arduino board is supplied by the voltage of 5V, the range of result for the voltage values is between 0V until 5V. Zero voltage values is the minimum voltage values while five voltage values is the maximum voltage value that can be obtained. Arduino have discrete values of 0 until 1023. Therefore, in order to convert the analogue reading which goes from 0 to 1023 to voltage 0V until 5V needed to be divided by 5V. This was already programmed in the Arduino software

The concentration of glycerol that is used in this research project is 87%. For each ml of glycerol solution, it consist of 87% of glycerol and 13% of water. Since glycerol solution is being simulated as phlegm, the volume of glycerol needed to be kept in subtle increase. This is to allow for the data to be feasible for further analysis. Therefore, the volume of water was kept constant at 5ml throughout the experiment.

3. RESULTS AND DISCUSSIONS

From the graph shown in Figure-4, it was demonstrated that as the volume of glycerol increases, simultaneously the voltage detected by the piezoelectric sensor increases too. This proves that the piezoelectric film sensors are able to detect the different consistencies of the glycerol solution in the balloons. The voltages increases with elevated degree of glycerol concentration and almost reach the maximum voltage values that can be measured by the piezoelectric sensor.

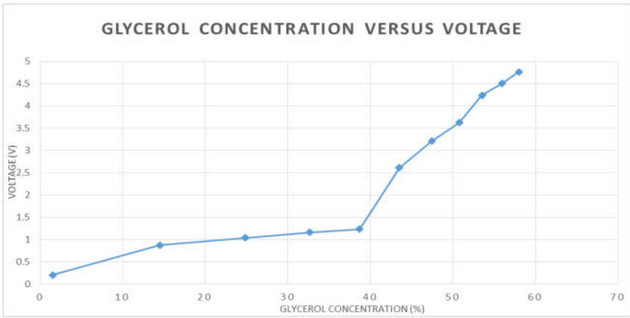

Figure-4. Line graph of glycerol concentration versus voltage where it was demonstrated that the prototype is able to detect varying consistencies of glycerol which act as a substitute for phlegm in this study.

The Arduino Processing software is an additional visual aid that is added to this research project to complement the result from previous section where it was clear that the prototype piezoelectric sensor can be used as a potential diagnostic tool to detect pneumonia. The graph that is chosen for the Arduino Processing software is an ellipse. This graph may also work at a real-time analysis. That is, when the manual vacuum hand pump was pressed and the voltage was detected by the piezoelectric sensor, an ellipse graph will be automatically generated on the laptop. For a low voltage values, the ellipse graph that is obtained is small as seen in Figure-5 while for a high voltage values, the ellipse graph obtained is bigger in size as demonstrated in Figure-6.

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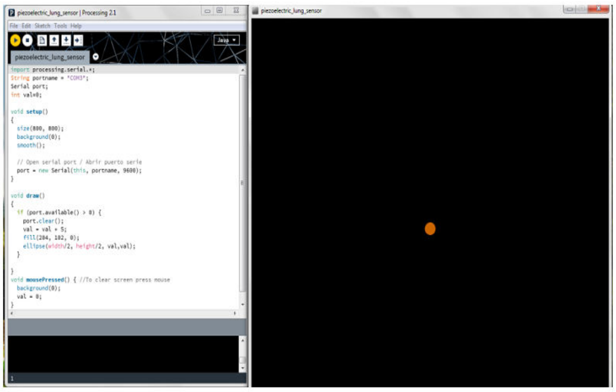

Figure-5. Low electric signal detected by the piezoelectric sensor as processed by Arduino. This small dot is correlated with lower volume of glycerol in the simulated human lung.

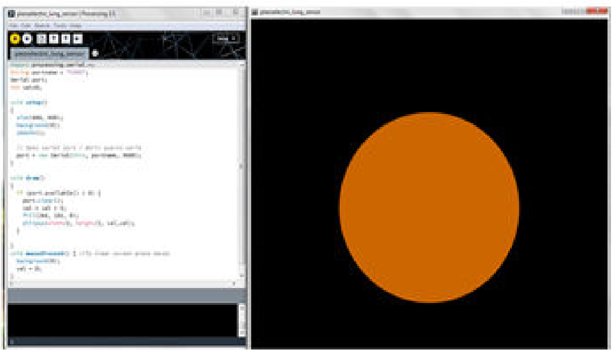

Figure-6. High electric signal detected by the piezoelectric sensor as processed by Arduino. This large ellipse is correlated with higher volume of glycerol in the simulated human lung.

These directly show that this prototype could be tested to a possible pneumonia patient and it may generate real-time analysis that might further expedite the diagnosis process. In an actual world where the prototype should be tested on a real live patient, the scenario is as follows. If a patient has pneumonia, the phlegm that is in their lungs will exert high vibration and stress. As a result, the piezoelectric sensor will receive high value of voltages from these vibrations and stress. Thus, creates a big ellipse graph using Arduino Processing software. Low voltage values resulted in smaller ellipse graph which signaled that the patient may not have pneumonia or a serious phlegm related diseases.

It was shown in this study that piezoelectric sensor was able to detect vibrations and stress from different consistencies of glycerol solutions, this means that these sensors may also be able to detect phlegm in a human lungs. Glycerol solution exhibits almost the same sticky properties as to phlegm. If this prototype is to be used to an actual patient of pneumonia, it will most probably detect high value of voltage. In contrary, the non-pneumonia patient will result in a lower voltage value. The expected result for the non-pneumonia patient cannot be 0V because there are still errors that may occur and piezoelectric sensor can still detect vibration and stress from the human respiratory system.

4. CONCLUSIONS

In the field of biomedical self-powered system which includesself-energy generation, real-time diagnosis/therapy, continuous health/wellness monitoring and clinical medicine, highly efficient flexible piezoelectric thin-film technologies played a large role [8]. However there is no research being conducted to date that have employed the ability of piezoelectric material to detect the intensity of phlegm in human lungs and translated it into voltage readings. In this research, a device that detects phlegm intensity at different consistencies using piezoelectric sensor incorporating Arduino for real-time analysis was developed. The device allows medical practitioner or veterinary doctor to detect the abnormality flow of the respiratory system of a patient with phlegm related illnesses such as pneumonia, haemorrhagic septicaemia, bronchitis, and tuberculosis at a fixed parameter. From the overall development of the research, few key-points can be summarized, which is piezoelectric sensor has a high potential to be one of a diagnostic tool to detect phlegm related illnesses such as pneumonia. The prototype piezoelectric sensor developed in this study also able to detect phlegm intensity at different consistencies while incorporating Arduino and its software for real-time analysis, the device that was developed has the ability to diagnose a patient with phlegm related illnesses with a fixed parameter which is in voltage (V) and the device that was developed provides a real-time result and a visual graph for indication of the thickness of the phlegm in human lungs. In conclusion, the device that detects phlegm intensity at different consistencies using piezoelectric sensor incorporating Arduino for real-time analysis is well functioning and can produce a reading with a fixed parameter.

Every technology that is developed must have its very own advantages and disadvantages including the prototype developed in this study. The first major problem of this device is that the piezoelectric film sensor is an ultrasonic sensor. Therefore, it is very sensitive that even with little hit with the fingertip will effects the voltage reading of the device. In order to solve this problem, the device needs to be place in a place where there is a minimum disturbance. For future work, a vacuum box that is suitable to place a half-sized breadboard and an Arduino is designed to minimize and eliminate the disturbance from the surrounding environment. If this device is used in a clinic or a hospital, it will make sure that the device is in the vacuum box and is place independently. Either it is place inside concrete walls or better yet in a small vacuum chamber. Next problem is the prototype. The pressure of the manual vacuum hand pump is not yet known. In this research, the manual vacuum pump is used to simulate the air that flow in a human respiratory system when one inhale and exhale. This is only for simulation, but in order to get more accurate result than now, the average pressure of human lungs needs to be determined. For future work, the device needed to be tested to an actual human or animal with pneumonia illnesses to explore the full potential of this technology.

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REFERENCES

[1] 1 Melder. 2005. Sputum induction literature review and proposal for a protocol. pp. 1-50.

[2] World Health Organization. 2004. Global Immunization Data. 2004.1-3.

[3] Dockrell D., Whyte M., Mitchell T. 2012. Pneumococcal Pneumonia: Mechanisms of Infection and Resolution, Chest. 142(1): 482-491.

[4] Scholz T. L., Midha P. A., Anderson L. J.& Ku D. N. 2010. PneumoniaCheck: A Device for Sampling Lower Airway Aerosols. Journal of Medical Devices. 4(4): 41005.

[5] Baghdassarian O. 2003. Alveolar breath collection device and method. United States of America.

[6] Kempin H.-f. 1981. Method and device for determining and separating the alveolar air proportion from the breathing air. Dragerwerk Aktiengesellschaft (DE): United States of America.

[7] Kim H. S., Kim J.-H. & Kim J. 2011. A Review of Piezoelectric Energy Harvesting Based on Vibration. International Journal of Precision Engineering and Manufacturing. 12(6): 1129-1141. http://doi.org/10.1007/s12541-011-0151-3

[8] Salim M., Salim D., Chandran D., Aljibori H. S. & Kherbeet A. S. 2018. Review of nano piezoelectric devices in biomedicine applications. Journal of Intelligent Material Systems and Structures. 29(10): 2105-2121. http://doi.org/10.1177/1045389X17754272

[9] Henderson R. 2002. Piezoelectric Ceramics: Principles and Applications. Mackeyville: PA: APC International Ltd.

[10] Dagdeviren C., Shi Y., Joe P., Ghaffari R., Balooch G., Usgaonkar K., Rogers J. A. 2015. Conformal piezoelectric systems for clinical and experimental characterization of soft tissue biomechanics. Nature Materials, 14, 728. Retrieved from http://dx.doi.org/10.1038/nmat4289