ABUAD Journal of Engineering Research and Development (AJERD)
ISSN (online): 2645-2685; ISSN (print): 2756-6811

Volume 6, Issue 1, 13-21

Development of an Automated Temperature Measuring Device: A Potential Tool for Ovulation Detection

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Date Submitted: 04/01/2023
Date Accepted: 20/03/2023
Date Published: 14/04/2023

***Abstract**: Temperature spike during ovulation is one of the methods of detecting ovulation in women thus aiding fertility awareness. Some of the methods of ovulation detection are intrusive while some methods of temperature measurements are not convenient especially when temperature has to be measured for a long period of time. This research is therefore focused on development of on-the-skin temperature measuring devices using locally available tools and human resources; provision of a non-intrusive temperature measuring device that is convenient for use especially when temperature has to be measured for a long period of time and validation of the developed device with other standard measuring tools as a potential device for ovulation detection. Results obtained indicate that measurement of the automated temperature device calibrated against standard mercury-in-glass thermometer returned a correlation coefficient of 0.790996276; comparison with clinical and infrared thermometer revealed that 45 percent of the 50 respondents subscribed to the use of the device due to the comfort experienced and ease of use. The research concludes that human skin can be a possible means of obtaining accurate temperature with potential for ovulation detection. The developed device is convenient, non-intrusive, portable and easy to use especially when thermometer needs to be held in place to measure temperature for a period of time. Other possible applications include temperature measurements for special needs such as babies, the aged and the physically challenged.*

***Keywords:** Temperature sensor, ovulation detection, automated temperature measuring device, wilcoxon signed-rank test, continuous temperature measurement.*

1. INTRODUCTION

Over the years, cases of infertility have risen in Nigeria and the world at large and this has led to a significant pause in the addition to the population rate of the world due to the inability of women to give birth to their babies. It has been noticed that amongst the different causes of infertility among women, the problem of ovulation has been seen as one of the leading causes of infertility. Most women have little or no knowledge about their fertility. This lack of fertility awareness has led to a lot of couples not knowing the best time to copulate. This, therefore, reduces their chance of conception. The period of ovulation varies from one woman to another which ranges from 21-31 days and which doesn't occur at the same period for different women and also does not occur for the same number of days for each woman. So it is essential to know the exact period that a woman ovulates.

Ovulation is defined as the release of eggs from the ovaries. It occurs when the follicles rupture and release the secondary oocyte ovarian cells. It occurs 15 days after the menstrual period of a woman. The occurrence of ovulation is accompanied by different signs which include; changes in cervical mucus from 60mg to 600mg, changes in basal body temperature, heightened sense of smell, heightened sexual desire a few days before ovulation, mittelschmerz (pain in ovulation). One of the indicators of ovulation is rise in the Basal Body Temperature (BBT). Basal Body Temperature is the temperature when the body is completely at rest, upon waking up. BBT rises slightly (36.10 ^{o}C to 37.20 ^{o}C) when ovulation commences due to changes in the hormones around ovulation. As a result, this slight temperature rise had been regarded as one of the most widely used method to detect the onset of ovulation in women [1]. Measuring the BBT therefore gives women some insight about their fertility window. Wearable devices have been used to measure BBT [2] and as such any device that can measure skin temperature and temperature in clothes is a potential tool for ovulation detection [3].

Clinicians require adequate measurements for diagnosis in the process of their job. Different instruments and methods are used to carry out these measurements. Whatever procedure is used, the convenience of patients is very important to the success of such diagnosis. This work focused on the development of a convenient non-invasive method of measuring ovulation occurrence using on the skin temperature measurement.

2. LITERATURE REVIEW

Clinicians and academics have tried a number of methods to detect ovulation, including using an app and calendar approaches to precisely establish the ovulation day [4]. By analysing 949 luteinizing hormone samples to determine a surge day, it was possible to estimate the likelihood of ovulation for cycles of various lengths. The ovulation data was utilized to evaluate the app/calendar strategies' accuracy. The findings revealed that although the accuracy was low, the periodic days and rhythm procedures proved to be most effective to detect ovulation (70 and 89 percent, respectively).

In [5], the authors developed a low-cost mobile phone ovulation testing tool. The system functions by identifying fern patterns in a small sample of 100 mL of saliva that has been air dried on a microfluidic. Using artificial and human saliva samples to assess the gadget's ovulation prediction accuracy, it was found that the device had a 99% accuracy rate.

In order to assess the fertile window in real-time, a wearable bracelet was created in [6]. It collects data on the skin perfusion, heart rate, HRV, and waist skin temperature (wst) among other variables. The Ava bracelet was put on by all 237 of the study's participants while they slept every night for up to one year, or until they became pregnant. The data that this device acquired was trained using machine learning method. The results of the study show that substantial, concurrent-based fluctuations in WST, heart rate, and respiration rate are identifiable by wearable device. The results of the research inspired the creation of a tool for instantly forecasting the first ovulation as well as the use of machine learning and AI to improve traditional reproductive knowledge tactics. A team of academics carefully examined the numerous applications used to track menstruation and conception, focusing on the applications' accuracy [7]. For material published in the work between Jan. 1, 2010, and Apr. 30, 2019, searches were conducted in databases. A data review and synthesis was used to chart and analyze the data. The study found that regardless of whether they are using the application to monitor their fertility, plan a conception, women prefer tools that are trustworthy and substantial proof. The analysis emphasized the limitation of scientific proof research as well as the absence of fertility, healthcare professionals, and participants in studies.

The research of [8] led to the development of a saliva pattern modification technique on electrolyte pre-deposition to predict ovulation with a high degree of reliability. The scientists discovered that alterations in the saliva structure during the ovulate phase can be controlled by sodium chloride (NaCl) pre-deposition, which has a direct effect on the precision of ovulation prediction. It was discovered that the condition with 100 nmol NaCl pre-deposition was more susceptible to alterations in saliva sequence than the condition without pre-deposition by a factor of two. The effectiveness of saliva-based fertilization prediction tests will be greatly improved by their suggested electrolyte pre-deposition approach, opening the door to commercialization, they claim.

A woman's basal body temperature changes when she is ovulating and it also changes 12-24 hours after ovulation [6]. Throughout a regular 28-day menstrual cycle a normal body temperature is around 36.5 degrees Celsius. Just before ovulation, the temperature is likely to drop to around 36.2 degrees. It is normal for this to happen on around days 13-14 of the cycle. When ovulation begins, this temperature will increase and this continues until it reaches about 37 degrees where it will stay until just before menstruation [9].

In [10], the authors combined the intrusive method of vaginal conforming cap with smart phone application used for ovulation detection in order to estimate the fertility window of 40. 20 of the women used the fertility awareness method with basal body temperature measurement while the other 20 adopted the vaginal conforming cap with smart phone application. It was found that the vaginal conforming cap combined with Smartphone mobile application provides a safer and better birth control in terms of cost without side effect.

The accuracy of Wrist Skin Temperature and Basal Body Temperature in the identification of ovulation was compared by [11]. Samples from fifty-seven healthy women were used in the investigation. Participants put on a gadget during sleep that tracked the temperature of their wrists all the time. Before and shortly after waking up measurements of basal body temperature (BBT) were made using a digital reproductive monitoring equipment with a thermometer. It was evaluated whether at least one temperature shift indicated by the two temperatures might be used to diagnose ovulation. The testing revealed that wrist skin temperature was more responsive than BBT. Because the wrist skin temperature increased more during the postovulatory phase and decreased more during the monthly cycle, there was likely a difference in diagnostic accuracy between these two methods.

A skin-worn sensor to establish a novel technique for confirming the day of ovulation and predicting ovulation in subsequent cycles for the goal of conception in a population with ovulatory dysfunction was created in the work of [12]. The work includes 80 people who each put on a skin-worn sensor at the same time during the night to record temperatures. The vaginal sensor and its associated algorithm were utilized to determine the day of ovulation, and the ovulation findings obtained with the skin-worn sensor and its associated algorithm were compared using a variety of statistical methodologies. The accuracy of determining the day of ovulation and determining the viable window was found to be 66 per cent and 90 per cent, respectively. According to the findings, a skin-worn sensor is a valuable tool for confirming the fertile window and absence of ovulation in a population with ovulation dysfunction, both of which are dictated by ovulation time. The researchers found that a skin-worn sensor could be a valuable tool for predicting ovulation in following cycles, with the 'typical ovulation' group having better accuracy.

Temperature measurements of human body can be done in different ways including rectal (anus), oral (mouth), tympanic (ear), temporal artery (surface of the head) and axillary (armpit) [13].

From [14], it has been recommended that the best methods of taking adult temperature are by mouth, ear or under the armpit. Each of these methods will require that the thermometer be held in place. For instance, in case of the mouth, the thermometer will have to be placed under the tongue and left there for about a minute. In case of the armpit, the tip of thermometer is placed at the centre of the armpit while the patient’s arm is used to hold it tightly to take the required measurement. In case of the ear, the thermometer is inserted into the ear canal and removed to obtain the body temperature [14]. This insertion can be irritating to some people. Not all these methods are convenient when there is need to measure temperature for a long period of time which are required in some type of diagnosis or examination.

As a follow-up to the work of [15] which confirms the skin-worn sensor as a valuable tool in predicting ovulation; the approach proposed in this will advance this concept. The work does not include intrusive techniques like [16] or the collection and analysis of saliva, wrist skin temperature, waist skin temperature (WST), heartbeat, HRV, breathing rates, and dermal perfusion [6], [8], [11]. This approach presents an automated temperature sensory device having a cuff with embedded temperature sensors that could be attached to human arm skin for measurement and investigates its potential for ovulation detection with a focus on the user’s convenience. The temperature sensing device in this work would be compared with infrared and clinical thermometers which are placed in the armpit mouth or anal cavity of users. The rest of the paper is arranged in the following order. Section 3 is the proposed design and methodology; section 4 is the results and discussion while section 5 concludes the paper.

3. PROPOSED DESIGN AND METHODOLOGY

The approach adopted in this work is divided into two major parts namely the electronic circuit design and the cuff design.

3.1 Circuit Design

This section describes the approach adopted in development of the electronic part of the device. Figure 1 is the block diagram consisting of sensor section, microcontroller section, data presentation session and power section. The sensor section is made of the three sensors. The temperature sensors used in this work were three thermistors in form of beads are attached to the analog input pins A0, A1 and A2 of the Arduino Uno microcontroller. The thermistors used are Negative Temperature Coefficient (NTC) thermistors. Three NTC thermistors were used such that the average readings from the three of them can enhance system accuracy. The block diagram of the developed device is shown in Figure 1 while Figure 2 depicts the circuit diagram. The approach adopted in the sensory device construction is that the three thermistors used for temperature acquisition were woven into a cuff which could be strapped around the arm of the user.

The microcontroller section consists of Arduino Uno microcontroller and it is the part controlling all the activities of the developed device. It is able to receive electronic signals from the sensors using its analog input pins A0, A1 and A2. Based on the program uploaded into it, takes decision and presents results through the presentation section. Flowchart of the program uploaded into the microcontroller is found in Figure 3. When the device is switched on, it initializes by establishing a connection between the sensor, microcontroller and, the LCD and busser. The subject under investigation is supposed to wear the cuff and ensure the three thermistors (sensors) are in contact with her body as shown in Figure 4a and 4b. Average temperature of the user is measured and displayed on the LCD. If the temperature is above a pre-set threshold value, the buzzer automatically begins to sound and stops when it falls below the value.

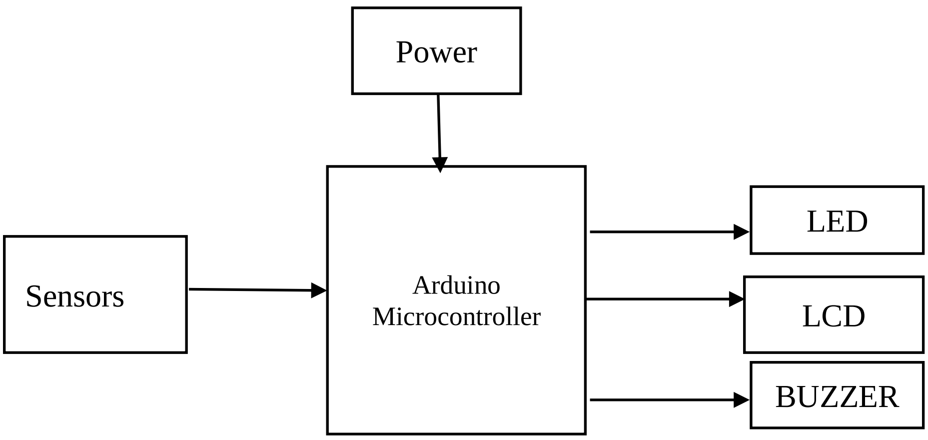

Figure 1: Block diagram of the system

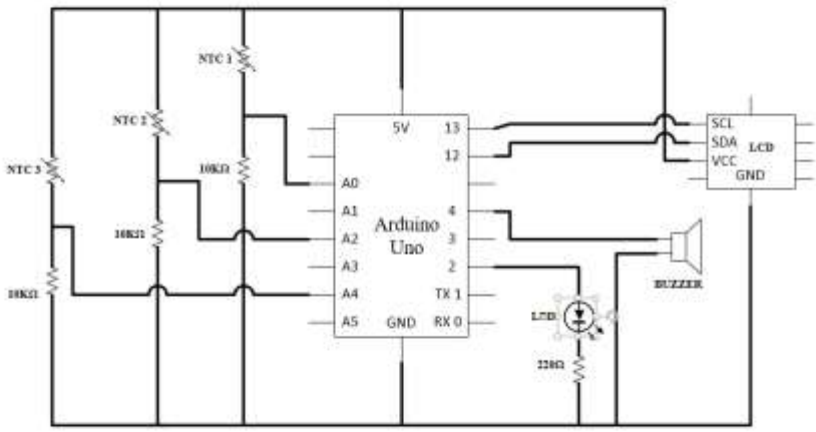

Figure 2: Circuit diagram of the system

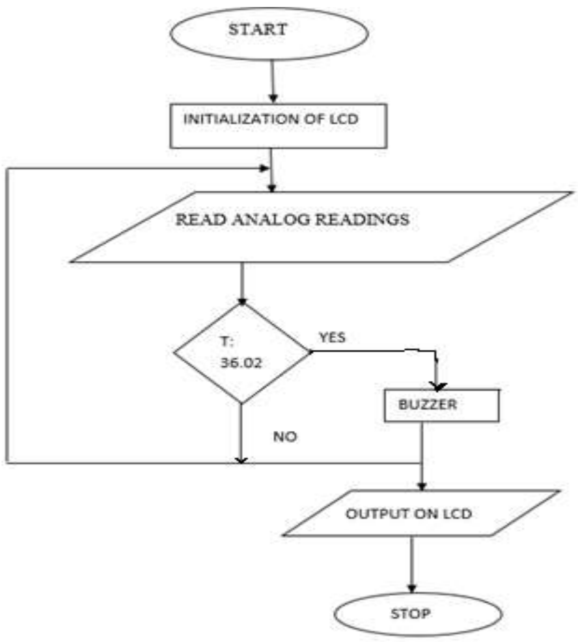

Figure 3: System's Flowchart

Figure 4a) Coupled ovulation detection device b.) Ovulation detection device under coupling

3.2 Cuff Design

An important part of this device that ensures the comfort of the user is the way the cuff was designed. As shown in Figure 5a and 5b, three temperature sensors are carefully embedded in the cuff to detect human temperature one the cuff is fastened round the arm of the user. The material used for the cuff is made of very soft fabric of about 1Fig m. The softness is to assure the comfort of the user and the length is selected to cater for different ages of users with a metal channel through which the fabric is passed to ensure adjustment of fabric length to fit different with of arms. To hold the cuff in place, a Velcro fastener is provided where the fabric is attached.

Figure 5 a.) Temperature sensors and fabric of the cuff b.) Parts used for holding the cuff in pace

3.3 Calibration

In order to validate the developed device, it was calibrated against a standard mercury-in-glass thermometer as shown in Figure 6. Any standard temperature measuring device can be used for this purpose but we choose to use mercury-in-glass thermometer.

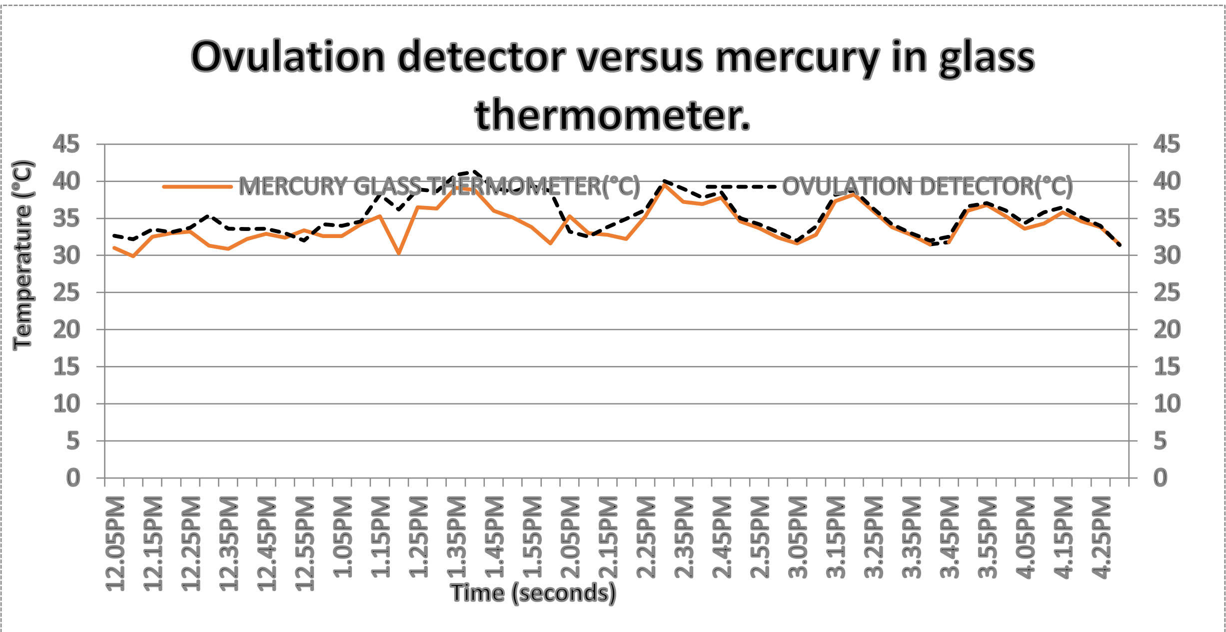

Figure 6: Comparison between the mercury thermometer temperature reading and the ovulation detector reading.

4. RESULTS AND DISCUSSION

To further validate the performance of the device, its measured values were compared with the values of a clinical thermometer and infrared thermometer. Temperature measurement was done physically on fifty (50) subjects using the developed device, digital clinical thermometer and the infrared thermometer while questionnaires were also administered to them after the temperature measurement. The result of the temperature measurements is found in Figure 7, while questionnaire responses obtained were further analysed with descriptive and inferential statistics, and the report given in Figures 8 to 10 and the result section.

4.1 Hypothesis used for the Inferential Statistics of Measured Values of Compared Devices

The research posits following hypotheses and theoretical framework of the model:

H 1: There is no difference between the values measured with infrared and clinical thermometers.
H 2: There is no difference between the values measured with infrared thermometer and the developed device.
H 3: There is no difference between the values measured with clinical thermometer and the developed device.

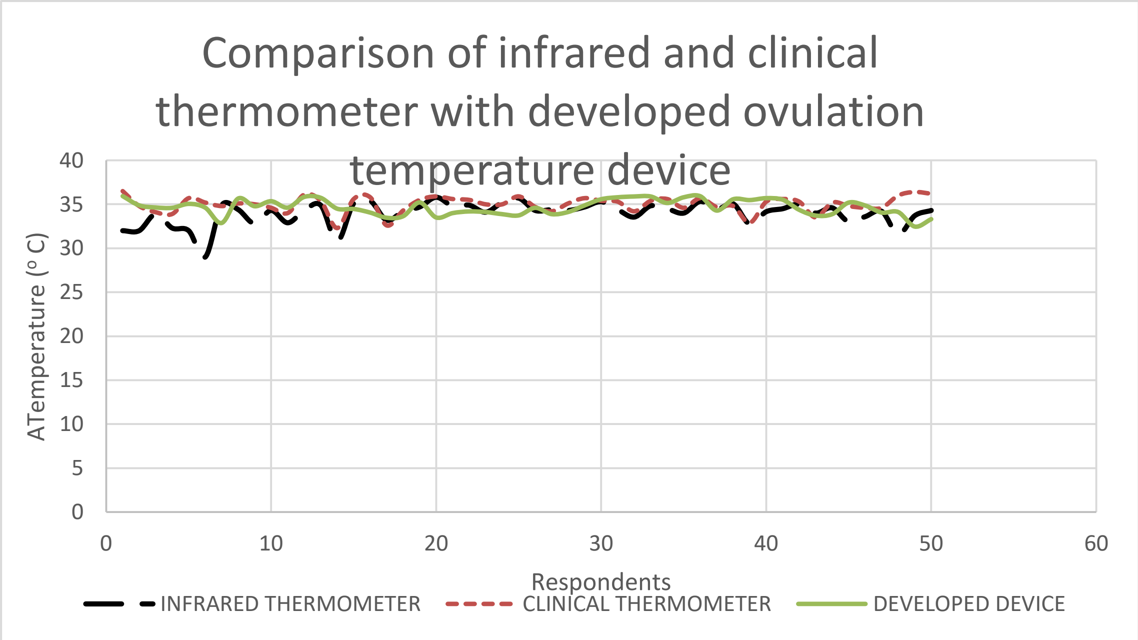

Figure 7: Comparison of temperature between developed device, infrared and clinical thermometer

4.2 Result of Descriptive Statistical Analysis of the User Evaluation of the Device.

1) Gender of respondents

The Figure 8 is the column showing the respondents by gender. Out of the fifty respondents, 41 are males representing 82%, while there are 9 females which is 18%.

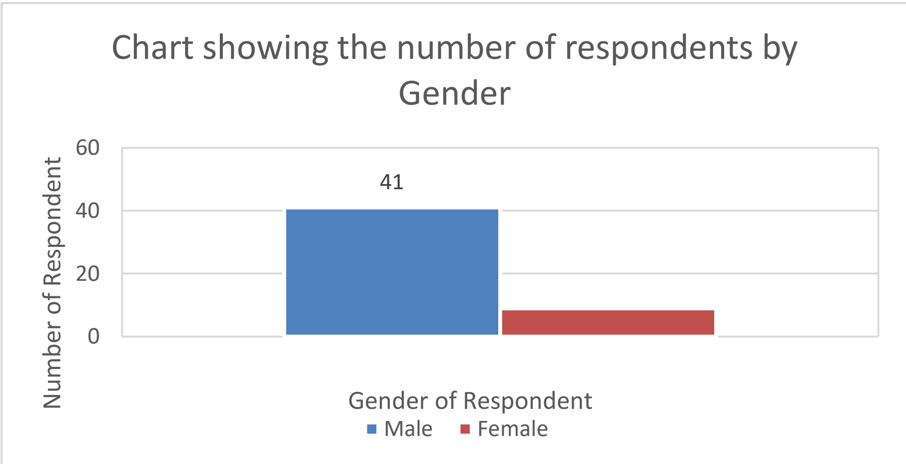

Figure 8: Respondents by gender

2) Age of the respondents

The column in Figure 9 shows the respondents by age. The respondents of age between 20 and 24 years has the highest frequency of 26, while the age 40 and above has the lowest frequency of 2. The age from 15 to 19 has frequency of 6, while age between 25 and 29 and age between 30 and 39 have frequency of 8 and 4 respectively.

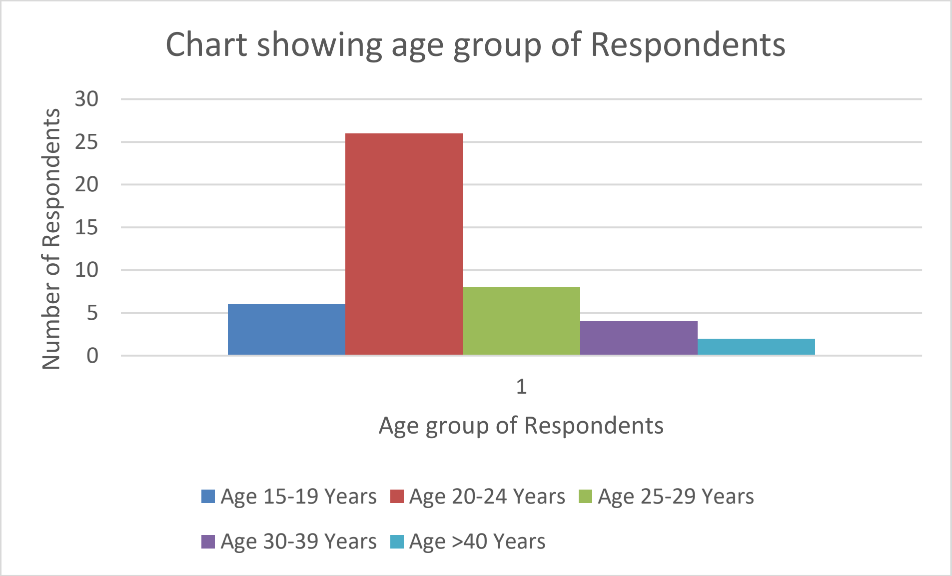

Figure 9: Respondents by age

3) Respondents' previous use of thermometer.

All the fifty (50) respondents indicated previous use of a thermometer, especially among the three (3) under consideration. This is indicated by the 100% of the Figure 10.

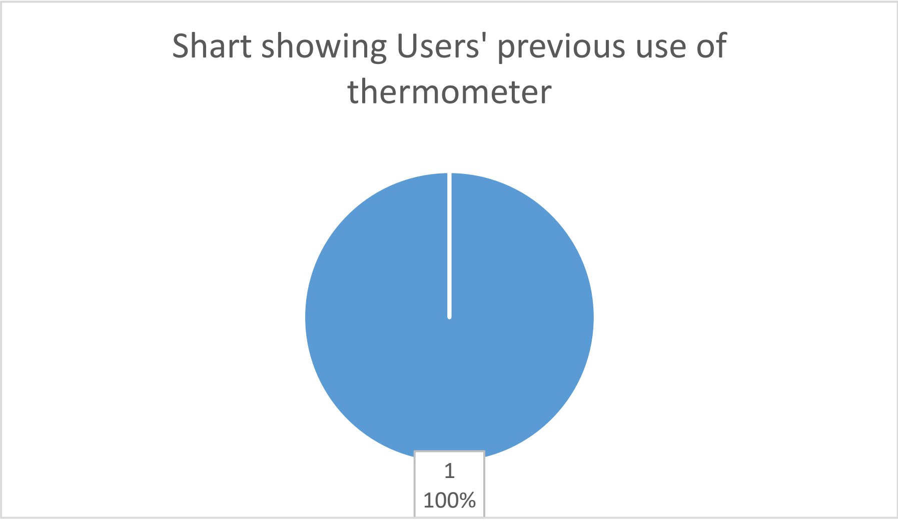

Figure 10: Respondents by previous use of thermometer

Based on users' experience with the developed device, out of the fifty (50) respondents, 45 representing 90% respondents were in affirmative, while only 4 representing 8% decline to recommend the developed device for use. One (1), representing 2% respondent was undecided on whether to recommend or not. More work will be done in future to improve the accuracy and efficiency of the device. The summary of this report is given in Table 1.

Table 1: Respondents by recommendation of the developed temperature sensor for use in the hospitals

Response	Frequency	Percentage (%)
Yes (Agreed)	45	90.0
No (Disagreed)	4	8.0
Undecided	1	2.0
Total 50	**100.0**	

4.3 Result of Inferential Statistics of the Survey

1) Normality test on the dataset used:

It is a normal practice before analysis for normality test to be performed, in order to ascertain the suitability of parametric test or otherwise, for the analysis. A test of normality using absolute z-values of skewness and kurtosis were used. The z-value was computed using skewness value divided by standard deviation, and kurtosis value divided by standard deviation. The condition is, If the z-value is within the range ± 1.96 for n <50 or ± 2.00 for n $\geq$50. The dataset generated from question 4, which is about convenience of use of temperature sensors, indicates a z-value of skewness and kurtosis of 0.2611 and -0.7054 respectively. This confirmed the normality of the dataset, and thereby support the use of parametric test to analyze this data. In the case of question 5, which focused on ease of use of the temperature sensors, the z-value for skewness and kurtosis are -1.421 and -0.1146 respectively, which supported conduct of parametric test on the data. Question 6, which entails user friendliness of the temperature sensors, also indicated z values of -1.9021 and 0.3776 respectively from skewness and kurtosis. This also supported the application of parametric test on this data.

A normality test was conducted on the datasets measured by the three thermometer devices. The results indicates that the dataset are not normally distributed. Hence the reason for Wilcoxon signed-rank test (a non-parametric).

2) Result of Wilcoxon signed-rank tests:

i. A Wilcoxon signed-rank test showed that statistically, there is a significant difference between the measurement of body temperature with infrared thermometer (mean rank 11.67) and clinical thermometer ($Z = -5.48$, $p = 0.000$). Since this probability is less than 0.05, we will not accept the null hypothesis (H1). It is not out of place to say that, there is statistical difference between the values measured by infrared thermometer and clinical thermometer.

ii. The measurement of body temperature using an infrared thermometer (mean rank 28.66) and the developed device ($Z = -2.698$, $p = 0.007$) differed statistically significantly, according to a Wilcoxon signed-rank test. Since this probability is smaller than 0.05, the null hypothesis will not be accepted (H2). It is accurate to state that there is a statistical difference between the readings obtained from developed device and infrared thermometers.

iii. According to a Wilcoxon signed-rank test, there is no statistically significant difference between measuring body temperature with a clinical thermometer and the developed device ($Z = -1.796$, $p = 0.073$). We shall accept the null hypothesis because this probability is more than 0.05 (H3). It is accurate to state that there is no statistically significant difference between the data obtained from developed sensors and infrared clinical thermometers.

4.4 Discussion of Results

The cuff accommodating the three thermistors, apart from keeping the sensors in close contact with users' body, also shields the sensing device from environmental interference such as wind which could negatively affect the values obtained from temperature measurement device. As it can be seen in figure … the cuff makes it very convenient for users to measure their temperatures especially when it comes to babies, the aged or physically challenged compared to placing clinical thermometers in their armpit or mouth. Even though, the infrared thermometer provides some degree of convenience in measurement by holding it at some few distance from the body being measured, the developed device is more convenient than the infrared thermometer and clinical thermometer when the temperature have to be held in place to measure for a long period of time. For ovulation detection, it proposes a non-intrusive method of temperature measurement which will be more convenient for ladies wanting to detect their ovulation period compared with the work of [16] where the temperature measuring device had to be placed in the armpit and worn as under wear by the ladies. From Figure 4, the correlation result of 0.7909962763 between the developed device and mercury-in-glass thermometer is approximately 1 which implies a good reliability of the developed device in regards to temperature measurements. The comparative analysis of the three types of temperature devices with statistical test as shown in Figures 6, 7 to 9 revealed that, there is no statistical difference between the values measured by both clinical thermometer and the developed ovulation detection device, however the developed device can still be improved for better accuracy. It can be inferred that with further improvement; As compared to infrared thermometers, the proposed technology promises to also be capable of measuring the temperature of humans as accurately and consistently as a clinical thermometer. This is also similar to the work of [17] in which significant difference was found between infrared thermometer and the automated temperature scanner sensor developed but no significant difference between clinical thermometer and the automated temperature scanning device. Deviating from the established method of measuring temperature such as rectal (anus), oral (mouth), tympanic (ear), temporal artery (surface of the head) and axillary (armpit) [13], this work confirms the possibility of human skin (arm – above the elbow) as a means of accurate temperature measurement for ovulation detection using BBT in agreement with [10]

5. CONCLUSION AND RECOMMENDATION

In this research, a non-invasive, wearable and convenient method of temperature measurement is proposed. Due to the cuff bearing temperature sensors, it will be good for people with special needs such as babies, the aged and the physically challenged. Measurements obtained show good degree of reliability compared with mercury-in-glass thermometer. With further improvement, could be used in place of clinical thermometer especially when readings have to be done over a period of time and thermometer needs to be held in place. It was found to have no significant difference with clinical thermometer and higher in accuracy than non-contact infrared thermometer. The work reveals that human skin can be a possible means of obtaining accurate temperature and the possibility of using the developed device for ovulation detection. Future work would include improving accuracy of the developed device, incorporation of a mobile app for remote temperature logging over a secured network and web technology and testing of the developed device in detecting ovulation occurrence in women.

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