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A Non-Invasive Model for Monitoring Vital Signs in Neonatal Unit using Wrist Measuring Sensors

Sobowale A. A.[1], Olaniyan O. M.[2], Alabi. S. O.[3]
Department of Computer Engineering, Federal University Oye-Ekiti, Ekiti State, Nigeria.[1, 2, 3]
sobowaleadedayo@gmail.com

ABSTRACT

A major technology application is needed in neonatal health care; this refers to the monitoring of vital physiological parameters of premature infants. However, the neonatal monitoring system in most developing countries like Nigeria is not uniform and mostly manual; causing discomfort, data loss and human error. This paper therefore developed a non-invasive system to automate the neonatal monitoring process in the incubators of Neonatal Intensive Care Unit (NICU). The Developed Monitoring System (DMS) consists of a supervisory microcomputer and sensitive sensors for measuring the vital signs. The Conventional Monitoring System (CMS) was used simultaneously with the DMS to collect the vital sign readings of thirty (30) neonates, over a period of one week. A test of significance (t-Test) at 5% level was performed on the data collected from both methods to ascertain the accuracy of the DMS readings. The results of the statistical analysis showed that there were no significant differences between the vital signs readings taken by the DMS and the CMS.

KEYWORDS: Measuring Sensors, Neonatal Monitoring Systems, Non-invasive, Premature Babies, Vital Signs.

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1.0 INTRODUCTION

The importance of effective monitoring of vital parameters in daily neonatal care cannot be overemphasized. Every day in Nigeria, about 700 babies die (around 30 every hour). This is the highest number of new-born deaths in Africa, and the third highest in the world after India and China (OnyebuchiChukwu, 2011). The average length of a normal pregnancy is 40 weeks (280 days) from the date of conception. Babies born before 36 weeks gestation are considered premature, every year, 854,400 babies are born before 36 weeks of pregnancy are completed; this is one in every 8 babies born alive. Prematurity therefore is the leading cause of death for babies in the first month of life – the neonatal period – with 85,700 new-born deaths due to preterm birth every year in Nigeria (Blencowe *et al.*, 2013; United Nations Population Division, 2014; Ogundipe, 2016, Liu *et al.*, 2014). The premature babies born alive are usually in a fragile condition and may be at risk of complications, which is surrounded by uncertainties (Quinn, 2007; Suresh *et al.*, 2014). These infants normally have Very Low Birth Weight (VLBW), less than 1500g, which in many cases lead to critically ill and vulnerable neonates with respiratory and circulatory problems, and with a significant risk of neurological damage. These babies therefore require special monitoring and intensive care involving treatment in an incubator at a Neonatal Intensive Care Unit (NICU).

Continuous health monitoring for the neonates provides crucial parameters for early detection of in adverted events (such as cessation of breathing, heart rhythm disturbances and drop in blood oxygen saturation), and possible complications (such as seizures). Immediate action based on this detection increases survival rates and positively supports further development of the neonates. The survival rate of premature infants is dependent on the continuous monitoring of vital signs; this provides a lot of information about a baby's state of health. Traditional vital signs such as Electro-Cardiogram (ECG), oxygen saturation, respiration and temperature have been routinely monitored at the NICU (Nicklin *et al.*, 2004; STELLA Newsletter, 2010) for treatment by neonatologists.

Vital signs monitoring is the intermittent assessment of temperature, pulse, respiration and blood pressure, and baseline indicators of a patient's health status. If monitored continuously, they could form the basis of raising alarm when the body system malfunctions as a result of diseases or environmental factors. Close monitoring of patients with severe sepsis for example, may improve outcomes by identifying patients at risk of deterioration which can lead to appropriate interventions (Dellinger *et al.*, 2013; Rivers *et al.*, 2001; Jacob, 2012). Monitoring the status of preterm infants in the NICU provides a unique and challenging environment for the design, function and use of sensor-based monitoring equipment (Chen *et al.*, 2010). One of the structural causes of discomfort in the incubator is the monitoring system (Bouwstra *et al.*, 2009; Seoane, *et al*., 2012).

However, the challenges faced by the neonates in these incubators located in the NICUs vary between developing and developed countries. It is disheartening that these vital signs are still collected manually in some developing countries like Nigeria. Most hospitals in Nigeria still operate manual health management information system and the quality of neonatal care provided by Nigerian hospitals is not uniform (Okonkwo *et al.*, 2010; Sobowale *et al.*, 2011). In the same vein, the currently available neonatal monitoring systems in Nigeria collect vital signs manually with the use of thermometers, causing discomfort for the neonates. Then, they record this data into printed forms manually, the collected forms are sent to a doctor who goes through all of them looking for any symptom of abnormality and then takes decision regarding the patient's treatment. Accuracy is not guaranteed with this manual system due to human error. Results are often misplaced, figures or results forgotten, measurements not taken right on time and the experience of the care workers becomes a determinant of expertise. In order to surmount these challenges, the need for higher but non-invasive technologies arises. While describing the conventional method as ritualistic, many diseases of children such as pneumonia, meningitis, and sepsis among others make taking vital sign a very important procedure.

In order to have adequate, comfortable neonatal monitoring system for developing countries, there is need for an appropriate tool for measuring, analyzing and monitoring the neonates' vital signs (Sobowale, 2016). Therefore, to address this shortcoming, this paper developed a non-invasive model to automate the neonatal monitoring using measuring sensors attached to the neonates that can read vital signs automatically and display the readings on a monitor placed at the nurses' station. Figure 1 shows the manual method of collecting neonate's heartbeat rate which is very well accomplished by palpating a pulse at the base of the neonate umbilical cord.

Figure 1: Manual method of collecting vital signs (Blyth, 2011)

2. MATERIALS AND METHODS

The architectural design of the developed neonatal monitoring system is shown in Figure 2. The architectural design consists of the following components: sensor modules attached to the neonate, a microcontroller, clinical database server, computer system and users of the outputs. The figure 2 below shows how the architectural design components are functionally related.

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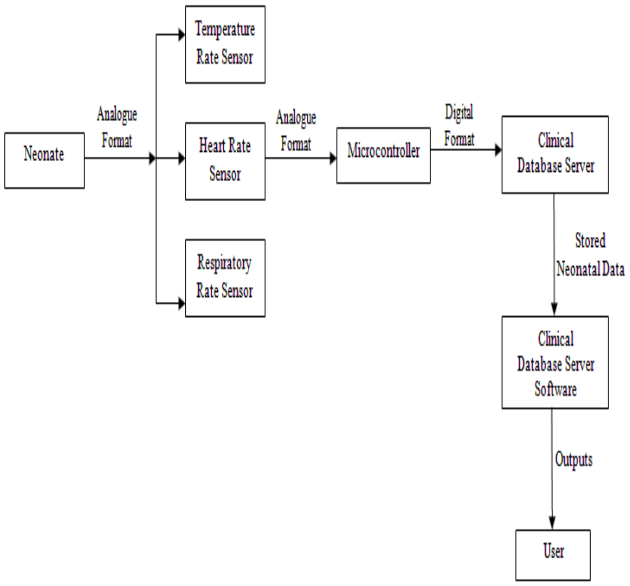

Figure 2: The Developed Neonatal Monitoring System Architectural Design (Author, 2021)

The function of each of the components is discussed below.

2.1 Sensor Modules Attached to the Neonate

Sensor modules or straps with one sensor dedicated to a vital sign were attached to the neonates' body to collect readings of the vital signs; Temperature, Heart rate and Respiration rate (THR). The read vital signs were collected in analogue format by the sensors and transmitted to the microcontroller inside which transmitted data were converted to digital format.

2.2 Microcontroller

The PIC18F452 microcontroller with Analogue-to-Digital Converter (ADC) was used for this work. The microcontroller was connected to the sensitive sensors; it consists of a transducer which takes in the analogue readings from sensors and converts them into discrete format. It also consists of an internal memory that stores the readings from the sensors in discrete format; it then transmits the stored readings to the clinical database server at intervals.

2.3 Clinical Database Server

A 3.2 GHz dual-core processor, 250 GB Hard Drive and 2GB RAM computer system was used as the Clinical Database Server (CDS). It consists of MySQL database server used for storing the digital format of the vital signs readings of the neonates. The outputs of the microcontroller are continuously transferred to the server for storage. The CDS is the server unit for all the data associated with the CDSS.

2.4 Monitor

A monitor is connected to the CDS for the purpose of displaying the stored readings and predictions of the developed system. The readings are temperature, respiration rate and heart rate of the neonates. The monitor provides a clear view of the state of each neonate per time.

2.5 PC Running CDS Software

This is the computer that runs the CDSS software and the software loads the stored neonatal data (THR) from the clinical database server.

2.6 Users of CDSS Outputs

Users of the CDSS outputs are decision makers which include neonatologists (neonates' specialist doctors) and specialized nurses. The results of classification can be obtained by users for evaluation or further actions.

2.7 Implementation of the Developed architectural design for the Monitoring System

The design is such that the sensor straps are attached to the neonates' body to collect readings of the vital signs (THR). The sensors read the vital signs in analogue format; this is converted to digital by the Analogue-to-Digital Converter (ADC). The read data is equally transmitted to a local web server located with the nurses via Radio Frequency (RF), the report will be displayed in graphical format on the server. This provides an accurate, clear view of the state of each preterm per time, thereby aiding the decision making of the professionals thereby reducing the neonatologists' workload.

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The design was implemented at the Children Intensive Care Unit (CICU), Ladoke Akintola Teaching Hospital (LAUTECH) and Lifeline Hospital (a pediatric specialist hospital) Ionone, Oshogbo. The readings of the three vital signs were taken from thirty (30) neonates over a period of one week for each neonate. The readings for each neonate were taken correspondingly from two sources; the Conventional Monitoring System (CMS) and the Developed Monitoring System (DMS). The readings of the CMS were generated with the use of thermometer for temperature, pulse reading/stethoscope for heartbeat and respiration while that of the DMS was generated from sensitive temperature, heartbeat and respiration measuring sensors attached to the wrist of the neonate. The vital signs are measured every four-hour interval by the CMS; basically by 6:00am, 10:00 am, 2:00pm and 6:00pm daily while the DMS can take readings at every hour interval. Neonates in critical condition(s) are however given twenty-four monitoring based on the state of the neonate.

The readings from the two systems (CMS and DMS) were taken and recorded by the specialist nurses in two separate charts for each neonate and sixty charts were generated for the thirty neonates used in this research work. Figure 3 shows the developed model flow chart and the sequence of operations performed on the vital signs readings in which the system is initialize and then attach to neonate body before collecting vital signs readings. The vital signs readings in analogue format were converted to digital format thereby the average, t-test and level of significance calculations were performed on both DMS and CMS readings.

2.8 Statistical Analysis of Vital Signs Readings

The basic vital signs (THR) readings generated from the Developed Monitoring System (DMS) were compared to the readings from the CMS using statistical analysis software package. This analysis was employed to ascertain the accuracy of the readings of the DMS. The means of difference statistical formulae was used to perform the test of significance on the vital sign readings. It can also be called paired T-test formulae. The software tool (Statistical Package for Social Scientist (SPSS) version 19.0) was used to analyse the readings collected

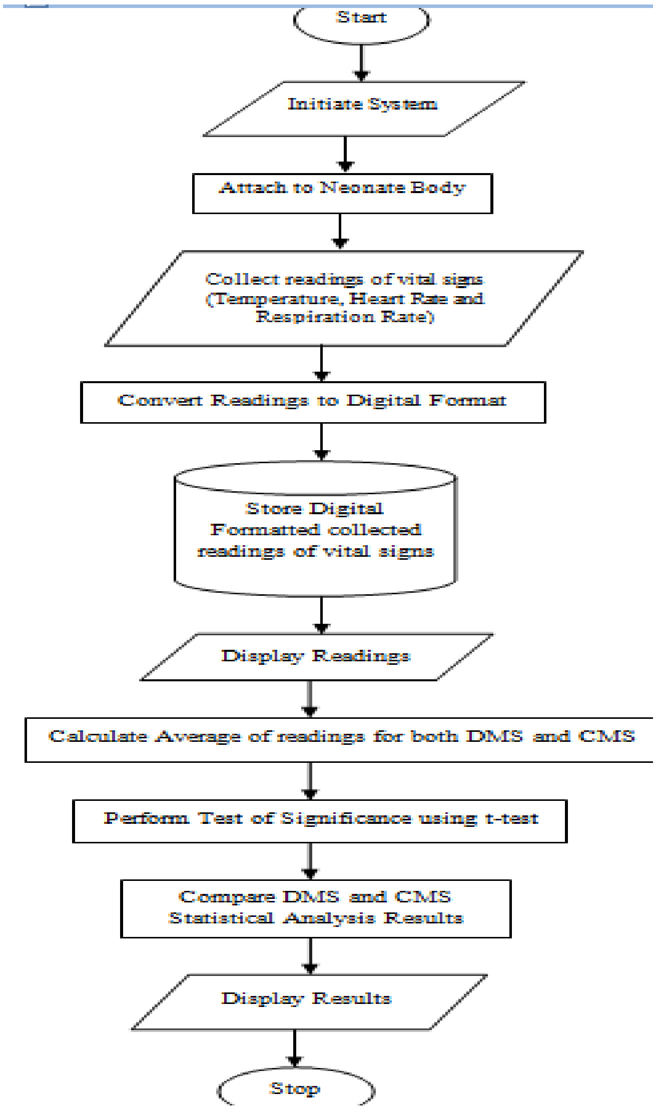

Figure 3: The developed neonatal monitoring system flow chart (Author, 2021)

3. RESULTS AND DISCUSSION

The average of the readings taken for each vital sign over a period of one week for each neonate were calculated and recorded for both CMS and DMS as shown in Table 1. The test of significance was performed on each of the three vital signs by the statistical package using Paired Sample t-test formulae. The calculated p-values are shown in Table 2 and Table 3.

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Nevertheless, it can be observed from Table 3 that the Paired Sample Test of the temperature reading (collected from the temperature sensors (DMS) and thermometer (CMS)), heart beat reading (collected from the heart beat sensors (DMS) and pulse feeling (CMS)) and respiration reading (collected from the respiration sensors (DMS) and by counting number of breaths per minute (CMS)) gave p-value of 0.255, 0.082 and 0.299 respectively. The result shows that there were no significant differences between CMS readings and the DMS readings at 5% significant level since the p-values are greater than 0.05. The readings from the CMS and DMS are represented graphically in Figure 4-6. The Table 1 below shows CMS and DMS average temperature, heartbeat and respiration readings collected for 30 neonates' while Table 2 shows t-test data analysis of neonates' vital signs (temperature, heartbeat and respiration) that comprises of mean, standard deviation and standard error mean for both CMS and DMS and Table 3 shows calculation of level of significance with 95% confidence interval that contains the true mean of the survey.

Table 1: Average Readings of the Collected Vital Signs for 30 Neonates.

	Temperature (ºC)		Heart Beat (bpm)		Respiration(c/m)	
BABIES	**CMS**	**DMS**	**CMS**	**DMS**	**CMS**	**DMS**
1.	36.90	36.80	144.00	144.10	49.80	49.60
2.	36.90	36.80	140.70	140.50	48.10	47.60
3.	36.90	36.80	143.50	142.10	45.90	45.70
4.	36.90	36.90	158.20	152.00	65.80	65.40
5.	36.90	36.80	136.00	135.50	45.50	45.10
6.	37.40	37.30	144.70	143.80	54.60	54.30
7.	36.90	36.70	142.30	142.10	48.60	48.30
8.	36.90	36.80	153.20	143.00	53.00	52.80
9.	37.00	36.80	146.50	147.00	49.10	48.90
10.	36.70	36.70	147.00	156.60	44.00	43.80
11.	36.70	36.60	148.50	145.00	45.00	44.70
12.	36.60	37.00	142.90	144.90	45.90	45.70
13.	36.90	36.90	144.00	144.00	49.60	49.78
14.	36.50	37.00	143.20	153.00	49.10	48.90
15.	36.60	37.00	145.60	145.00	47.50	47.30
16.	36.80	36.80	143.30	158.50	47.20	47.20
17.	36.90	36.90	143.00	157.00	52.90	52.90
18.	26.90	26.90	144.00	155.50	38.10	38.10
19.	28.90	28.90	139.00	150.00	36.30	36.30

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	Temperature (ºC)		Heart Beat (bpm)		Respiration(c/m)	
BABIES	**CMS**	**DMS**	**CMS**	**DMS**	**CMS**	**DMS**
20.	13.50	14.00	52.80	52.80	20.10	19.60
21.	37.20	37.20	145.20	145.00	45.40	48.40
22.	36.80	36.80	145.90	145.60	48.40	48.30
23.	37.00	37.00	143.40	143.30	48.80	48.50
24.	36.50	37.00	142.60	142.50	45.90	47.60
25.	36.60	36.60	146.50	146.30	49.30	49.10
26.	32.90	32.90	128.80	128.80	45.90	45.90
27.	37.40	37.40	145.80	145.50	52.00	52.00
28.	36.90	36.80	144.90	144.60	42.90	47.90
29.	36.90	37.10	135.00	145.10	48.40	48.30
30.	36.90	36.90	145.20	145.10	46.60	48.60

Source: Author's Compilation, 2021

Table 2: T-Test Data Analysis of the Vital Signs

Paired Samples Statistics

		Mean	**N**	**Std. Deviation**	**Std. Error Mean**
Pair 1	Conventional Temperature	35.3600	30	4.76232	.86948
	Developed Temperature	35.4033	30	4.69097	.85645
Pair 2	Conventional Heart Rate	139.6900	30	17.01734	3.10693
	Developed Heart Rate	142.8067	30	18.07858	3.30068
Pair 3	Conventional Respiration Rate	46.9900	30	7.20121	1.31476
	Developed Respiration Rate	47.2193	30	7.17194	1.30941

Source: Author's Field Survey, 2021

Table 3: Calculation of Level of Significance

		Paired Differences							
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	Df	Sig. (2-tailed)
Pair 1	Conventional Temperature - Developed Temperature	-.04333	.20457	.03735	-.11972	.03306	-1.160	29	.255
Pair 2	Conventional Heart Rate - Developed Heart Rate	-3.11667	5.97616	1.09109	-5.34820	-.88513	-2.856	29	.082
Pair 3	Conventional Respiration Rate - Developed Respiration Rate	-.22933	1.18765	.21683	-.67281	.21414	-1.058	29	.299

Source: Author's Field Survey, 2021

Figure 4 to 6 show the graphical relationships between CMS and DMS weekly temperature, heartbeat and respiration record for thirty (30) neonates. From the chart, it can be deduced that the CMS and DMS average temperature (35.3600 and 35.4033), heart rate (139.6900 and 142.8067) and respiration (46.9900 and 47.2193) respectively have no significance difference as each reading for a neonate flows in the same sequence for both CMS and DMS on the charts shown in Figure 4-6.

Figure 4: CMS weekly Temperature Record Chart for a neonate (Field Survey, 2021)

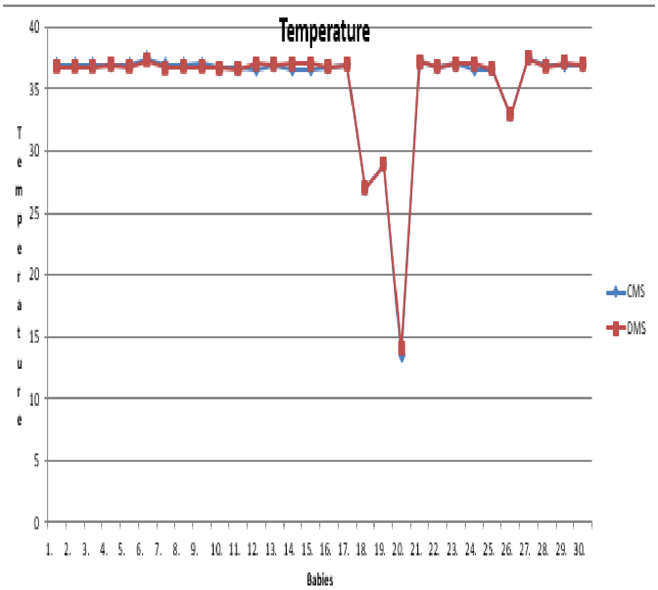

Figure 5: DMS weekly Heat Beat Record Chart for a neonate (Field Survey, 2021)

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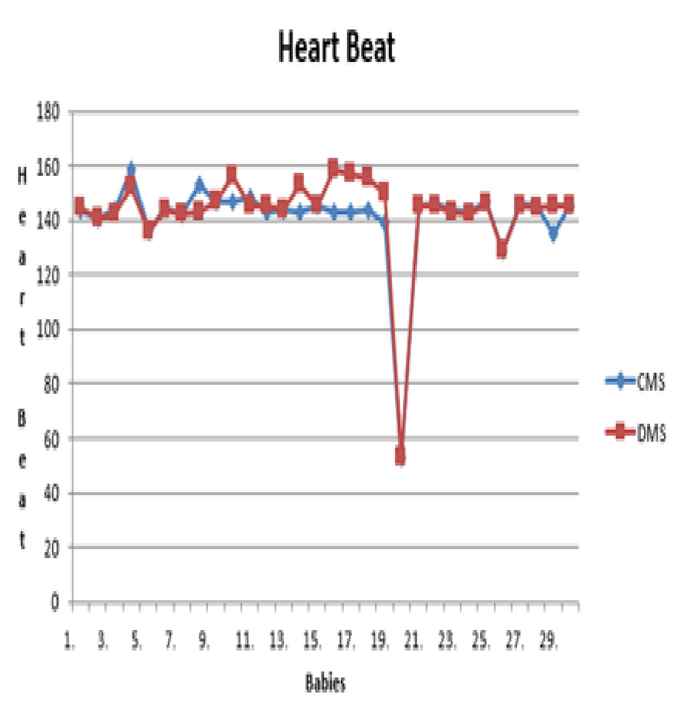

Figure 6: DMS weekly Respiration Record Chart for a neonate (Field Survey, 2021)

4. CONCLUSION AND FURTHER WORK

In this paper, neonatal monitoring system has been developed and a non-invasive neonatal monitoring system has been implemented. The developed system collects readings of the vital signs of neonates from measuring sensors attached to the wrist of the neonates. The vital signs readings were taken simultaneously with the conventional monitoring system and the developed. The result of the comparison shows that there's no significance difference between the two sources, this proves that the reading of the developed system is reliable and it has eliminated the inconvenience experienced by the neonates from manual handling. More so the nurses can monitor the readings on the monitor placed at the nursing station; this assists the neonatologist and specialist nurses for on-the-spot assessment of the neonates for decision making that improves the recovery and mortality rate of the neonates.

The research work could be extended to measure or include more factors than the three basic vital signs temperature, heart beat rate and respiration. The research work could also be extended to cover adults and other areas of health could be monitored and remotely reported to the physicians anywhere, anytime.

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