A Survey on Neonatal Incubator Monitoring System

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Abstract--Recently many premature babies have lost their lives due to lack of proper monitoring of the incubator that leads to accidents. A neonatal incubator is an enclosed equipment where a premature infant will be kept in a clean and controlled environment for observation and care. The biological parameters are monitored to ensure the safety of the babies and to prevent death rates. For monitoring the vital signs continuously for pre-mature infants in the hospital it requires sensors and electrodes which is said to be kept in contact to the patient and it can be displayed in a monitor. Any abnormality in the parameter will be indicated by alarm system. In this survey, we concentrate on the available incubator monitoring systems, the biological parameters measured and analyse techniques used in real-time monitoring, transmission of the data.

Index Terms: NICU, Premature new-borns, IoT

1. Introduction

New-born babies who require special attention medically are admitted often to Neonatal Intensive Care Unit (NICU). Most of the infants admitted in the NICU are said to be premature infants. Premature infants are considered to be born before 37 weeks of pregnancy, those who have low birth weight which is lesser than 2.495 kilograms or they could have any medical condition which needs special attention. Now-a-days NICU are well-equipped with advanced machines and devices to monitor which are designed for the special requirement of the infants. Some of the monitoring equipment often used in NICU are cardiorespiratory monitor, blood pressure monitor, temperature, pulse oximeter, transcutaneous oxygen and carbon-di-oxide monitor, Ultrasound, X-Ray, Magnetic Resonance Imaging, Respirator or Mechanical Ventilator. With Internet of Things, medical profession has listed and technologists are trying to merge the various environment together to build a strong monitoring system. Connecting things to internet with standard protocols and suitable architectural changes expedites uninterrupted health monitoring for all day and any place. In this context various incubator monitoring system for neonatal care are discussed in literature review.

2. INTENSIVE CARE REAL-TIME ANALYSIS

[34] Author has done a research approach collaboratively in order to address the necessity to analyse patient’s data in real-time manner that is streamed to detect the significant medical conditions which would indicate any medical complications. Author has stated the advantage from this system that the patient gets benefited because of detecting the signs of the medical condition at the early stage may provide earlier protection for the infants that improves patient’s outcomes potentially and the stay length can be reduced.
3. CONDITIONS THAT AFFECT INFANTS IN NICU

These are some of the conditions that affect the admitted infants in NICU.

A. Intraventricular Haemorrhage

Intraventricular Haemorrhage (IVH) causes morbidity and mortality for new-born infants. Almost 20% of preterm infants who are under 1500g birthweight tend to develop an IVH. During the first few days of life occurs Haemorrhage. Mostly it occurs during the third day from birth. Nearly 10% of IVHs is occurred before the delivery. Extreme Immaturity, pneumothorax, birth asphyxia, sudden increase of arterial blood pressure are the important risk factors for IVH.

B. Periventricular Leukomalacia

Periventricular Leukomalacia (PVL) means the white matter near the cerebral ventricles dies. PVL is developed by 3-4% of premature infants, very low birth weight infants who weight 1500g and 3lb 5oz and 4-10% of those born previously to 33 weeks of gestation. The white matter mentioned is said to be the inner portion of the brain. The periventricular means the part of the white matter which will surround the ventricles. Leukomalacia means it softens the white matter, which brain tissue death is occurred quickly. PVL affects the new-born when they suffer from oxygen deprivation during labour, delivery or at any time of birth. The variation of oxygen and carbon-di-oxide content in the blood causes PVL. A stream analysis of the physiological data can detect these variations.

C. Nosocomial Infection

Infection are common and it is considered to be an important reason of morbidity and mortality respectively for infants. Many infants get infection around the delivery time and also some infants may say to acquire while in NICU care. Infections that acquired by hospitals are called as the Nosocomial Infection. This is considered to be secondary to the original cause for the admission of the infant into NICU. Detecting this infection at earlier stage is less possible because the clinical signs are vague and non-specific till they become well established. Such infections occur in time period of 48hr or more after the infant birth. They are not associated with mother. They are caused by the pathogens. Neonatal network data indicates that 30% of infants those who are born at gestation of 25-28 weeks. More than 45% of infants who are born at the gestation before 25 weeks will face serious nosocomial infection while in NICU. To reduce morbidity and mortality detection and intervention is expected to be done earlier.

D. Pneumothorax

One to two percentage of all new-born infants have gas or air in pleural cavity. It separates the visceral from parietal pleura. The lungs are said to be surrounded by a membrane. Its nature is to fold back on itself. There are totally two layers attached to the lungs. One layer is attached to the chest wall and another layer attached to the to the lungs. These layers will experience a movement when we inhale and exhale. For the smooth movement of these layers, the membrane emits a fluid that is used for lubrication. Pneumothorax occurs when some gas or air gets accumulated in-between the two layers.

Table 1: PARAMETERS CONSIDERED

| S.NO | PARAMETERS            | EXISTING SYSTEMS WITH THESE PARAMETERS MONITORED                                      |
|------|-----------------------|--------------------------------------------------------------------------------------|
| 1    | Infant Body Temperature| 1. A monitoring system based on cloud and risk management for premature new-borns    |
2. Alarm signals are transmitted in wireless manner from incubators to neonatal nursing station

| 2 | Incubator Temperature |
|---|-----------------------|
| 1. | An Enhanced noise cancelling system for a Comprehensive Monitoring and Control of Baby Environments |
| 2. | Temperature monitored IoT based smart incubator |
| 3. | Baby Incubator |
| 4. | Real time central monitoring system for infant incubator |

3. Incubator Humidity

| 1. | An Enhanced Noise Cancelling System for a Comprehensive Monitoring and Control of Baby Environments |
| 2. | Temperature monitored IoT based smart incubator |
| 3. | Real time central monitoring system for infant incubator |

4. Infant Body Weight

| 1. | Cloud-based monitoring system and risk management for premature new-borns |

5. Sound Cancelling

| 1. | Design and Development of a Smart Baby Monitoring System based on Raspberry Pi and Pi Camera. |
| 2. | A Noise Cancelling System for a Comprehensive Monitoring and Control of Baby Environments |

6. Gas Density Adjustment

| 1. | Intelligent infant incubator |

The basic Vital signs are considered to be Temperature, Blood Pressure, Pulse rate and Respiratory rate. The system [3] introduced by the author, detects the movements of the baby and produced sound, specifically its crying. The output video which provides the baby’s current position is displayed on a monitor where the infant can observe the baby’s movements while they are in distance from them. As per the authors’ survey [4] he stated that the current available systems can control and monitor the humidity, temperature and the light inside the baby’s room. In this published paper, author tends to construct on the existing related work and provides a suggestion for an enhanced noise cancelling system. It can be used to overcome sound pollution and also it can provide a comfortable environment to the baby. It can comprehensively monitor and control. An enhanced system designed by Soukaina Brangui [5] the author monitors the temperature and weight data in real-time. Cloud server is used to store the data. A variety of warnings are provided regarding the health issues from the new-born’s health state. The alert is pinged directly to mobile phones which are linked with this system. The weight data are uploaded into the cloud server. A graphical Think Speak API is used and the uploaded data is plotted. Saikat Sahoo1 [6] designed a system where the temperature of the infant and bed wet detection is performed. An alarm indicates the high temperature, low temperature, if infant wets the bed its high temperature and low temperature is indicated. When body surface temperature is varied it is recorded and visualized using the LabVIEW program. Ashish.B [7] designed an incubator where the temperature and the humidity of the incubator is monitored and maintained in a monitoring display (laptop). This system is designed using Arduino and Raspberry pi. In a system proposed by Eugene T. Puzio [8], the Incubator temperature is kept constant. If baby wets the bed, humidity transducer is sensed, alarm is triggered by voice alarm, voice colour lamp and lets parents know. Real time central monitoring system for infant incubator [12] is a system where the Temperature and humidity of the incubator is measured. It is characterized in that, further comprising a sound and light alarm is connected with the computer control unit by wire. The Components used are Computer display, large
screen display. In this system [22] main objective considered is the gas density adjusting means. Components used are Surveillance camera, Pumping unit, Display.

4. NON-CONTACT SENSING

To monitor the vital signs continuously for pre-mature babies admitted in the hospital they require sensors and electrodes which is said to be kept in contact to the patient and it can be displayed in a monitor. When they are kept in contact with the skin it may induce stress, pain, irritation and can also vandalize the skin surface of the infant which are delicate in nature. In this the author’s current study is on monitoring of pre-term infants continuously. It has been performed for at least four days consecutively, each of the Neonatal Intensive Care Unit (NICU). A video-based, non-contact methods of monitoring is developed further. They are developed to acquire continuous estimation of heart and respiratory rate, level of oxygen saturation in the babies who are placed inside incubators [2]. An incubator named new born monitoring method based on IoT [19] performs Real-Time monitoring of vital signs. Wrist strap is worn to baby with vital sign sensor module. If any vital sign abnormality occurs, alarm is set-ON. RFID is used to detect the theft of baby. In this system [18] Sensors are placed apart from the baby. Temperature and respiration are monitored. Sounds are cancelled. Components used in this system are Camera, Microphone, and Speakers. All these three components are coupled with computer network for remote monitoring of infants.

5. TECHNOLOGIES USED

| S.NO | TECHNOLOGIES       | EXISTING SYSTEMS WITH THESE TECHNOLOGIES                                                                 |
|------|--------------------|------------------------------------------------------------------------------------------------------------|
| 1    | PLC                | 1. Incubator system with monitoring and communication capabilities 2. Multifunctional incubator for new-born baby |
| 2    | Wireless Transmission | 1. Intelligent monitor incubator for infant 2. Network monitoring device for nursing baby 3. Remote Real-Time Monitoring and Analysis of Neonatal Graduate Infants 4. Intelligent monitor incubator for infant heating |
| 3    | Zigbee             | Zigbee-based baby incubator temperature monitoring and alarm system                                        |
| 4    | CAN Bus driver     | Infant incubator monitoring device                                                                       |
| 5    | Cloud              | A monitoring system based on cloud and risk management for premature new-borns                             |
| 6    | Bluetooth          | Wireless Transmission Design for Health Monitoring at Neonatal Intensive Care Units                        |
| 7    | PRD                | Motion based detection of respiration rate in infants using video                                         |
A. **PLC System**

Neonatal Incubators has been designed using various technologies. Author Eugene T. Puzio [9] has designed an incubator where the Temperature and humidity of the incubator and Skin temperature of infant is measured. The Components used are Blue light lamps, Ventilation holes, controller, display screen, control buttons and buzzer with PLC system and Wireless Transmission module. In real-time manner, WIFI transmit monitoring data to the host computer located at a nurse station. In this system called multifunctional incubator for new-born baby [11] the Temperature and humidity of the incubator, Skin temperature of infant is measured. The Components used in this are Blue light lamps, Ventilation holes, controller, display screen, control buttons and buzzer with PLC system and Wireless Transmission module.

B. **Wireless Transmission**

In this system [10] is designed to humidify the chamber. A control box is connected by a wireless manner with the camera, the control tank respectively further heating unit, and humidifier, a temperature sensor and a humidity sensor are electrically connected. In this system [14] The skin temperature of infant, temperature and humidity of the incubator, Oxygen and Carbon-di- Oxide concentration in incubator weight, heartbeat, Blood pressure and oxygen saturation are monitored. All these are transmitted to computer via network (internet). Infant Kin can observe their infant’s nursing condition in their workplace or family by the network and det information in time. A computer is authorized to browse and download the vision-frequency picture and monitoring data. Robert Greer [33] has designed a system to monitor the new-born infant’s physiological data remotely outside NICU. It is done by providing a simple mobile application where data can be monitored live. To establish communication between vital sign monitor and the remote server Wi-Fi and 3G us used. In [15] Real time monitoring of temperature and humidity of the incubator is done. If any abnormality occurs, a alarm is sent to nurse station. The Components used are WIFI, Camera, Battery, Micro Controller, Captive touch screen.

C. **Zigbee technology**

It is a high-level communication protocol which is used in low power digital radios and to create PAN. Specification: IEEE802.15.4. In Zigbee-based baby incubator temperature monitoring and alarm [17] incubator’s temperature is measured monitored and alarm can be realized. WSN constructed through Zigbee is used.

D. **CAN Bus driver technology**

Controller Area Network is considered to be a robust vehicle bus which is a standard design and provides communication without the host computer with each other in application. In infant incubator monitoring device [21] CAN Bus driver technology is used. Temperature and Inferred Carbon-di-Oxide is measured. Alarm is audible when monitor fails. Components used in this are Single microchip, monitoring unit, CAN bus protocol converter, keyboard, display.

E. **Cloud technology**

Cloud computing enables Virtual Machine storage or an application instead of building computer infrastructures. An enhanced system designed by Soukaina Brangui [5] the author monitors the temperature and weight data in real-time. Cloud server is used to store the data. A variety of warnings are provided regarding the health issues from the new-born’s health state. The alert is pinged directly to mobile phones which are linked with this system. The weight data is uploaded into the cloud server. A graphical Think Speak API is used and the uploaded data is plotted. The system developed by Saikat
Sahoo[29] the vaccination and child’s growth is monitored in real-time and a application based on
cloud which is Integrated Child Health Record cloud (iCHR cloud) is used.

F. Bluetooth technology

Wei Chen [30] has designed system with wireless transmission technology. BlueSMiRF and Arduino
pro mini is used. A neonatal jacket is designed for the infant to monitor in non-invasively. The
system data are transmitted and received from multiple sensors within 20m range. Here a
temperature and LDR x2 is used and a display monitor is used for the display.

G. A fiber optic sensor for detecting respiration

New born normal respiratory rate is said to be 40 to 70 breaths per minute. Author Arika Dhia [31]
has reported a design of respiratory sensor using fiber optics technology for this incubator
application. This sensor functions based on the light intensity difference due to the thorax movement.
This movement is occurred during the respiration. The data is processed in Arduino Uno
microcontroller and it is measured real time and displayed in LCD. Author’s simulation result states
that the design is capable of measuring the respiratory rate, number of breaths from 10 to 130 per
minute, the error rate of 0.595\% and hysteresis error rate is 0.2\%.

H. PRD

Author Daniel Myklatun’s system [32] the respiratory rate of the infant is monitored. It uses video
processing and video recording. Here a phase-based-respiration detection (PRD) has been tested on
small test set videos. It is performed on infants in asleep state where every breath is noted manually.
This is done by providing a truth signal. Author also states that PRD is more robust and promising
when compared with the difference-based method. PRD is tested on two adults. Then the respiratory
rate is compared to a truth signal which is obtained by pneumographic thorax. Author gives a
summary of the strength of their research and the Artemis which is the resulting environment in his
article.

6. INDICATIONS USED FOR ALARM

Systems were designed to sense and monitor the data. When any abnormality occurs according to the
given condition, it is notified by using alarm systems. Many types of alarms have been used. Following
are the system with types of alarms used for notifications online monitored new-born incubator [13]
is a prototype where it shoots the state of the baby inside the incubator and transmits the picture to the
monitoring main machine (MMM). The MMM is kept inside the monitoring room. If any abnormality
occurs, alarm is indicated through Short-Message Transmitting module (SMS) to nurse’s cell phone.
In this system [15] Real time monitoring of temperature and humidity of the incubator is done. If any
abnormality, alarm is sent to nurse station. The Components used are WIFI, Camera, Battery, Micro
Controller, Captive touch screen. Infant incubator and infant warmers with single patient and twin
patient control [16] the incubator’s temperature is monitored. Here manual mode may be used. Warmer
Skin: temperature of the infant is monitored. Alarm is triggered if temperature falls. Infant incubator
[20] is a prototype where real Time monitoring of infant’s physical condition is performed. If any
unexpected condition occurs, medical staff will be notified through alarm. Alarm used are Warning
lights and sirens. Components used are Monitor, camera, UV-germicidal lamp. Neonate warms up
case monitoring system [23] the temperature and humidity of the incubator, Vital signs are monitored.
Zigbee, 3G network are used. Real Time transmission is done. If any abnormality automatic alarm to
staff’s mobile with bed label and abnormal condition. Components used are Processing unit, Data
acquisition unit (DAU), Communication unit.
7. CHALLENGES IN DESIGNING NEONATAL INCUBATOR

One of the main challenges in designing an incubator is impact of emf. In this system [24] author has stated that impact of emf on infant health is unclear. Hence system must be designed with minimum emf exposure. This system [25] is an incubator which consist of a canopy. It controls an amount of light selectively and is transmitted into it. The light transmitted into the incubator is detected using configured sensor. It is also to convert the transmitted light into electrical current further. Smart incubator’s glass (SIG) is used here. In this incubator [26] the Chamber’s movement is regulated up and down. Chamber’s cover can be Open and Close. Temperature of chamber’s body is noted. In the prototype Infant incubator [27] Hood’s speciality which is Non-closed cylindrical shell. In a system called neonatal incubator [28] the author has concentrated on Sound Cancelling (i.e.) the external sounds are cancelled.

8. CONCLUSION AND FUTURE SCOPE

On designing an incubator, the Impact of emf on infant health is unclear. Hence system must be designed with minimum emf exposure. It can also be designed. The system must also be designed cost effective manner with the ability to measure maximum parameters and efficient technology. Non-Contact sensing od the parameters can be encouraged. Incubator can also be designed in portable manner by considering energy efficiency and useful technologies.

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