

# Design of smart neonatal health monitoring system using SMCC

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Automated health monitoring and alert system development is a demanding research area today. Most of the currently available monitoring and controlling medical devices are wired which limits freeness of working environment. Wireless sensor network (WSN) is a better alternative in such an environment. Neonatal intensive care unit is used to take care of sick and premature neonates. Hypothermia is an independent risk factor for neonatal mortality and morbidity. To prevent it an automated monitoring system is required. In this Letter, an automated neonatal health monitoring system is designed using sensor mobile cloud computing (SMCC). SMCC is based on WSN and MCC. In the authors' system temperature sensor, acceleration sensor and heart rate measurement sensor are used to monitor body temperature, acceleration due to body movement and heart rate of neonates. The sensor data are stored inside the cloud. The health person continuously monitors and accesses these data through the mobile device using an Android Application for neonatal monitoring. When an abnormal situation arises, an alert is generated in the mobile device of the health person. By alerting health professional using such an automated system, early care is provided to the affected babies and the probability of recovery is increased.

**1. Introduction:** Tragic death of two newborns due to abnormal temperature rise in radiant warmer at a hospital in Kolkata has raised a big question regarding the responsibility of medical care unit [1]. To avoid such a pathetic incident [1], automated health monitoring and alert system is required, so that the health persons can take required action when adverse situation arises in neonatal care unit. Wireless sensor network (WSN) [2] can play an important role in healthcare services [3]. If WSN is merged with mobile cloud computing (MCC) [2], then sensor MCC (SMCC) [2] comes into the view. In SMCC, the processing of sensor data is performed inside the cloud. Since we know prevention is better than cure, early diagnosis of the diseases always provides better quality of life. Most of the healthcare unit still use wired environment. Neonatal care unit [4–6] is such an environment, where replacing the wired connections wireless sensors can be used. Current diagnostic system accesses vital parameters through large amount of tangling wires. Doctor or nurse monitors those parameters manually and takes necessary action. Therefore, an alternative is required to monitor the critical parameters of the incubator. Radiant warmer is an incubation system having electronic feedback to increase or decrease the temperature of the body [7]. This device is mainly used to control the temperature, especially to prevent hypothermia of the newborn. Heat loss in newborn, especially for premature babies is rapid. Radiant warmer provides an environment to keep the neonates body temperature in control. In temperate countries or in winter season, babies are placed under radiant warmer for some duration after birth to ensure thermoneutral environment (TNE). Radiant warmer senses body temperature through a wired sensor attached to the skin and displays the measured temperature in the display panel. Temperature can be controlled by increasing or decreasing the intensity of the heat source. Simultaneously, environmental temperature also changes. Continuous monitoring is needed to prevent overheating.

1.1. Motivations and contributions of our work: In currently used radiant warmer, there are two probes: one probe is attached to the body and the other probe is placed in the environment to measure

the environmental temperature. These wired connections limit doctor's activity. Our motivations are:

- To replace these wired connections with wireless sensors to increase the freeness of work environment of health professionals.
- To design an automated system for observing the body temperature, body movement and heart rate of newborn at each time, so that hypothermia, hyperthermia, abnormal body movement and cardiac problem can be detected as early as possible.
- To inform the health person immediately to increase the probability of recovery and survival of the baby.

The contributions of this Letter are:

- A wireless sensing and feedback system is designed based on SMCC which is an integration of WSN and MCC.
- An automated system is designed to monitor the body temperature, body movement and heart rate of newborn at each time using wireless sensors, so that hypothermia, hyperthermia, abnormal body movement and cardiac problem can be detected as early as possible.
- An Android application is designed for neonatal monitoring. After detecting health problem of neonates using the automated system, the health professional is informed immediately through the mobile phone at anywhere anytime using the newly designed Android application. By notifying the health professional by this automated way, the probability of recovery of the baby is increased.

Rest of the Letter is organised as: Section 2 demonstrates the use of WSN in neonatal care unit, Section 3 discusses on hypothermia and convulsion, Section 4 describes the existing wire-based radiant warmer, Section 5 contains our wireless system for neonatal monitoring, Section 6 shows the experimental results and the Letter is concluded in Section 7.

**2. WSN in neonatal care unit:** Nowadays, sensor technologies and wireless communication technologies have become essential

**Table 1** Body temperature ranges of neonates according to World Health Organization [9]

Health condition of neonates	Temperature range, °C
normal auxiliary	36.5–37.5
cold stress or mild hypothermia	36–36.4
moderate hypothermia	32–35.9
severe hypothermia	<32
hyperthermia	>37.5

**Table 2** Thermoneutral zone according to National Neonatal-Perinatal Database [10]

Weight of the neonate, g	Recommended ambient temperature			
	35 °C	34 °C	33 °C	32 °C
<1500	1–10 days	11 days–3 weeks	3–5 weeks	>5 weeks
1500–1999	NA	1–10 days	11 days–4 weeks	>4 weeks
2000–2499	NA	1–2 days	3 days–3 weeks	>3 weeks
>2500	NA	NA	1–2 days	≥3 days

in our daily life. WSN opens up a new era to the healthcare systems with wearable bio-sensors [5]. Neonatal intensive care unit (NICU) takes special care for neonates in a neonatal unit of a hospital [4–7]. To observe different vital parameters, there are large numbers of wires connected to neonates. Currently, used adhesive sensors create a clumsy environment for care givers. In this context, wireless transmission technology maybe useful to monitor the health of neonates. A home-based health care system is proposed in [8].

**3. Hypothermia and convulsion:** A TNE is essential for normal growth and proper development of neonates. The body temperature of neonates is highly susceptible to environmental temperature. Hence to protect the neonates from thermal stress, it is necessary to take appropriate measures from the moment of birth of the baby. The normal auxiliary temperature of neonates is 36.5–37.5 °C [9]. Table 1 shows body temperature ranges to classify various types of hypothermia and hyperthermia [9].



**Fig. 1** Radiant warmer with wired connection (picture courtesy: Port hospital, Haldia, West Bengal, India)

TNE is an external temperature range at which the oxygen consumption, basal metabolic rate, will be least according to the weight of the baby [10]. Table 2 shows the recommended ambient temperature to be maintained for TNE.

**3.1. Hypothermia:** According to the severity, hypothermic baby is mainly presented to the neonatologist for the following four conditions:

- Condition 1:* Initially, when the baby is in mild hypothermia, i.e. in cold stress, the following features may arise such as whiteness, bluishness of fingers and toes, cold hand and feet etc. All of these symptoms mainly appear due to vasoconstriction of peripheral vessels. Sometimes, the baby may continuously cry or feel tetchiness which maybe the early manifestation of involvement of nervous system due to hypothermia.
- Condition 2:* If hypothermia persists, it can cause depression of the nervous system. This is manifested by less body movement, decreased pulse rate, hypotonia, poor breast sucking, irresistible cry and vomiting. Increased respiratory rate and distressed are manifested when the pressure of pulmonary artery arises.
- Condition 3:* If hypothermia continues for some more periods, it may lead to severity which is characterised by decreased sugar level and oxygen saturation in blood, increased potential hydrogen (PH) of blood etc. Generally, coagulopathy may lead to persistent pulmonary hypertension of the newborn. In most of the severe cases, acute renal failure increases the neonatal mortality.
- Condition 4:* In some cases, persistent chronic cold stress leads to stunting due to decreased anabolism.

**3.2. Convulsion:** Convulsion is characterised by rapid and repeated contraction and relaxation of body muscle. This is manifested by uncontrolled movement of the whole body or any body parts. Convulsion is the most important symptom of seizure disorder. Hence, the term convulsion is sometimes used as a synonym for seizure. However, all of the seizure disorders may not lead to convulsion such as subtle seizure. In that case, increase in the heart rate is one of the most important leading clues to detect convulsion. All convulsions such as symptom, i.e. jitteriness may not occur due to seizure disorder. Convulsion is medically recognised by sudden recurrence or increase in sign and symptoms of neuronal impulse activity within the nervous system. Convulsion or seizure in newborn is a medical emergency, because during convulsion low oxygen supply causes potential damage to the immature neurons in the brain. So, early diagnosis and prompt treatment of convulsion in neonates are of utmost importance.

**4. Existing radiant warmer with wired connection:** To control hypothermia currently radiant warmer is used in NICU. Here, we have highlighted the problem of this system. Radiant warmer, as shown in Fig. 1, is the conventional way for managing hypothermia in neonates.

Insensible water loss is of huge concern under the warmer in this system. Radiant warmer is used to produce radiant heat from an electrically heated quartz crystal. The heat generated from this rod is reflected on the baby's body surface and its surrounding environment from a reflector. It is parabolically arched above the heat generator rod. There are two modes of control in this system: (i) skin servo mode and (ii) manual mode. In servo control mode, the generated heat from the quartz crystal is controlled by a controlling unit which gets input from baby's skin temperature and surrounding temperature simultaneously. However in manual mode, the healthcare providers set the desired temperature according to their choice. Hence, there is always a chance of over or under heating the baby and surrounding environment. So, the servo control is the preferred

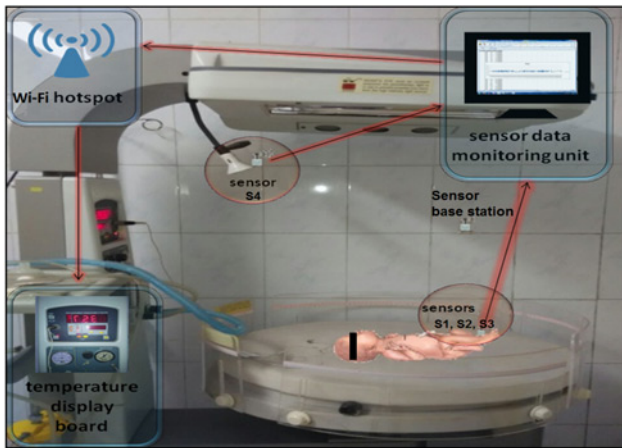


Fig. 2 W-RW (picture courtesy: Port hospital, Haldia, West Bengal, India)

one. Sometimes, manual mode is necessary for pre-warming or re-warming the clothes. In both modes, temperature is measured through a wired probe. Wire limits the freeness of health professional and causes irritation to neonates. In our system discussed in the next section, wireless system is used to overcome this problem.

**5. SMCC-based neonatal health monitoring system:** The wireless radiant warmer (W-RW) is shown in Fig. 2. The working principle of our SMCC-based system is presented in Fig. 3 and described as follows:

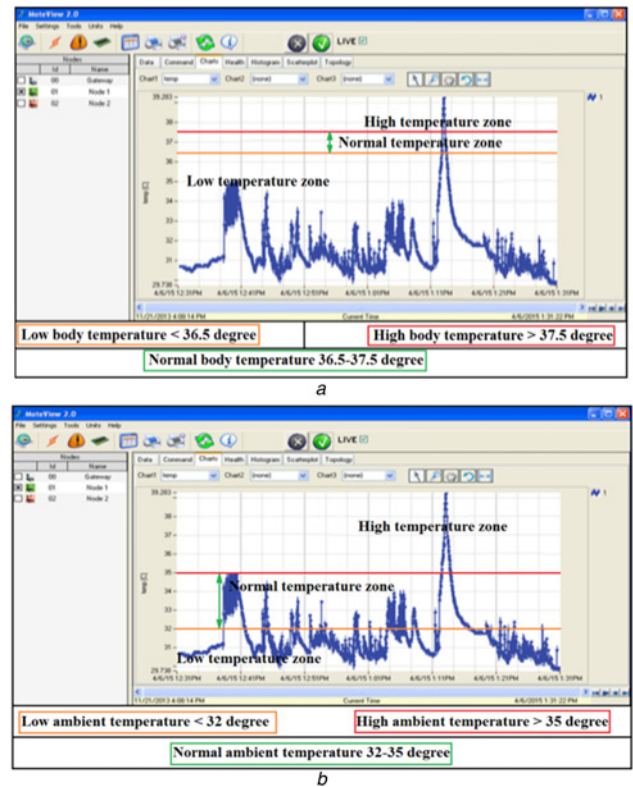


Fig. 4 Body and ambient temperatures  
a Body temperature (°C)

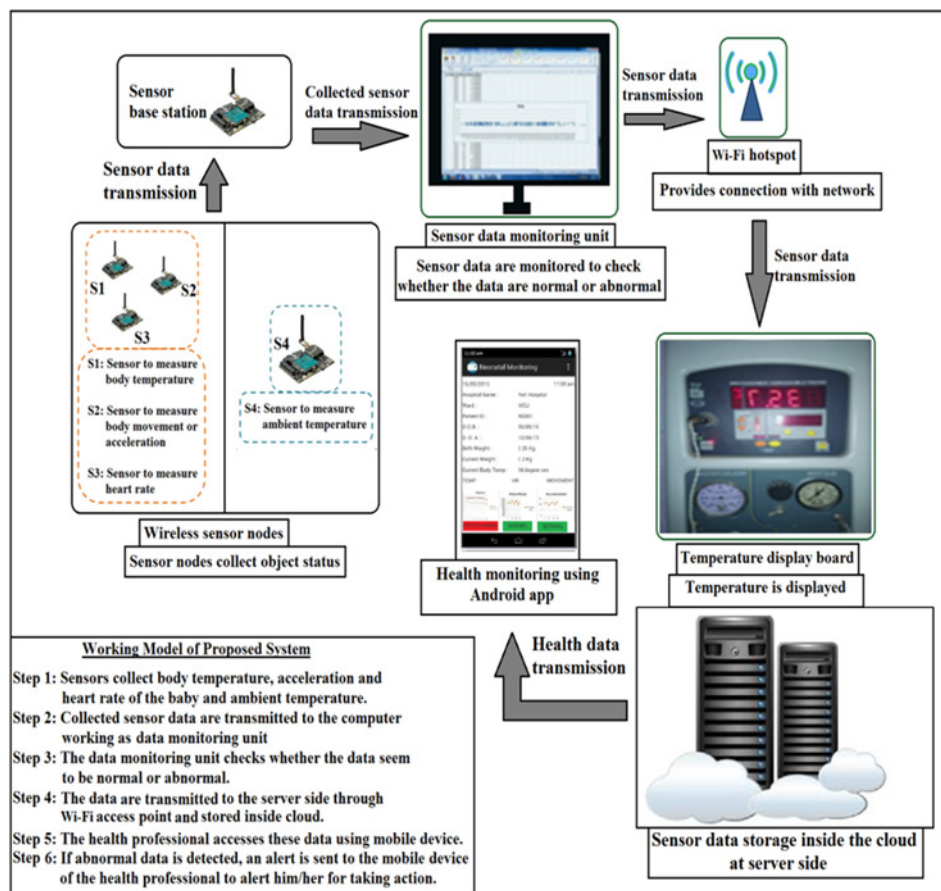


Fig. 3 Architecture and working model of our system



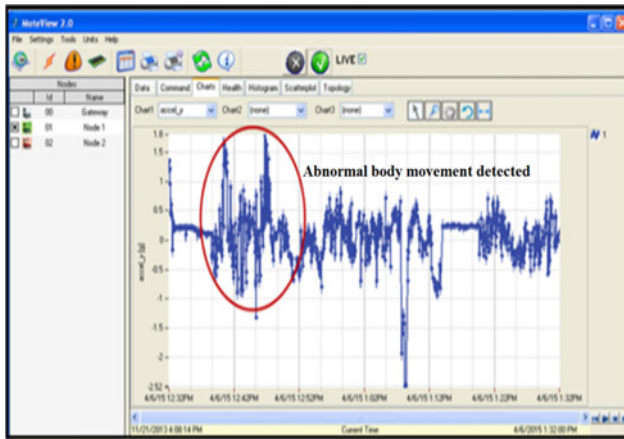


Fig. 5 Acceleration ( $m/s^2$ ) graph obtained using Motewiew software

(a) Temperature sensor (S1), acceleration sensor (S2) and heart rate measurement sensor (S3) are attached to the neonatal skin surface with a silicon non-allergic belt as shown in Fig. 2. These sensors measure the body temperature, acceleration due to body movement and heart rate of the newborn. Another temperature sensor (S4) is placed by a stand in between the baby cot and heat source of the radiant warmer. This sensor is used to sense the ambient temperature as shown in Fig. 2.

(b) These sensors after measuring the corresponding object status send the value to the sensor base station acting as receiver node. The receiver node sends these values to a computer working as data monitoring unit, via a data cable.

(c) The computer takes the baby's weight and age as input through software. From the computer all these data including health status are sent to the cloud at the server side through a wireless fidelity access point. Inside the cloud the data are stored and processed.

(d) The health professional accesses these data inside the cloud by using an Android application for neonatal monitoring (discussed in Section 6.2) installed inside his or her mobile phone. As the sensor data collected using WSN are stored and processed inside the cloud and the health professionals access these data using their mobile devices, our system is referred as SMCC, i.e. SMCC-based system. (e) The computer working as data monitoring unit sets the desired ambient temperature according to baby's weight and age, as presented in Table 2. Then, it is checked whether the body temperature lies in between 36.5 and 37.5 °C. It is also checked whether the ambient temperature has crossed the limit according to Table 2.

(f) In both cases, if any adverse situation occurs, the software will notify. At the same time by detecting abnormality in the data stored inside the cloud, an alert is generated into the mobile phone of the health person, so that he or she can take proper action. Hence, not only the data monitoring unit but also the mobile device is used to inform the health person to take care of the newborn when any difficulty arises. It may occur that no one is in front of the data monitoring unit. In such a case, as in our system alert is generated in the mobile phone of the health person; in case of adverse situation, the health person is automatically notified.

(g) By informing the health professional, any mechanical failure can be dealt with, e.g. if there is a sudden rise in the radiant heat

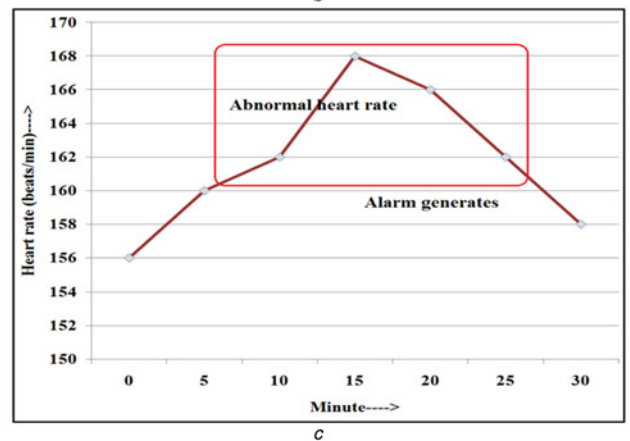
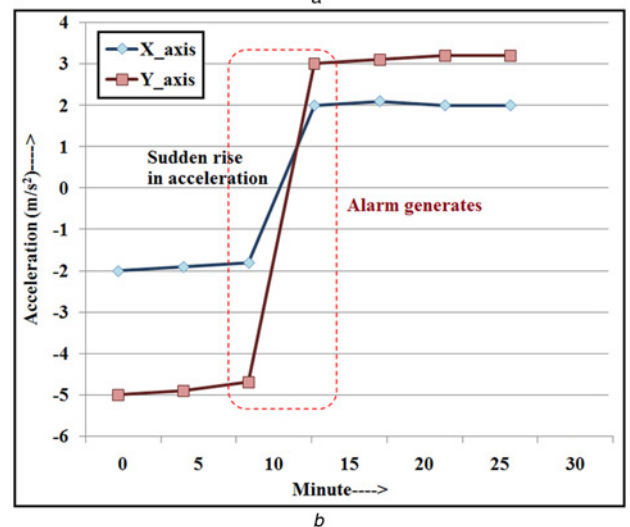
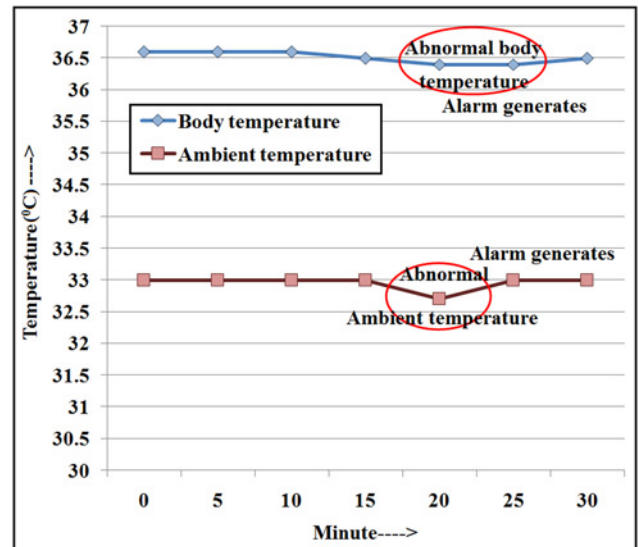


Fig. 6 Ambient temperature and body temperature

a Temperature (°C)

b Acceleration ( $m/s^2$ )

c Heart rate (beats/min) obtained using our wireless system

that will be instantly detected by the sensor and notified in the system to take prompt action to prevent overheating.

(h) Now, a situation may arise that the health professional cannot arrive at proper time and the temperature is required to change. For such cases, the radiant warmer operates in servo control mode to change the temperature. In this case, after generating an alert, a timer is set to 60 s. If the timer expires but the health

Table 3 Health parameter values of neonates

Health parameter	Case 1	Case 2	Case 3
Weight, g	2700	2300	2000
Age, day	1	1	1
TNE °C	33	34	34

**Table 4** Comparison between existing wired based and our SMCC-based neonatal monitoring systems

Feature	Existing wired system for neonatal monitoring		Our wireless system for neonatal monitoring	
Used type of connection	Co-axial cable, optical fibre cable		IEEE 802.15.4 protocol	
Health professional is informed through Android application	×		✓	
collected body temperature (°C) periodically	Time, min	Body	Time, min	Body
	0	36.6	0	36.6
	5	36.6	5	36.6
	10	36.6	10	36.6
	15	36.5	15	36.5
	20	36.4	20	36.4
	25	36.4	25	36.4
	30	36.5	30	36.5
collected ambient temperature (°C) periodically	Time, min	Ambient	Time, min	Ambient
	0	33	0	33
	5	33	5	33
	10	33	10	33
	15	33	15	33
	20	32.7	20	32.7
	25	33	25	33
	30	33	30	33
collected acceleration in $x$ -axis [metre per square second ( $m/s^2$ )] periodically	Time, min	$x$ -axis	Time, min	$x$ -axis
	0	-2	0	-2
	5	-1.9	5	-1.9
	10	-1.8	10	-1.8
	15	2	15	2
	20	2.1	20	2.1
	25	2	25	2
	30	2	30	2
collected acceleration in $y$ -axis ( $m/s^2$ ) periodically	Time, min	$y$ -axis	Time, min	$y$ -axis
	0	-5	0	-5
	5	-4.9	5	-4.9
	10	-4.7	10	-4.7
	15	3	15	3
	20	3.1	20	3.1
	25	3.2	25	3.2
	30	3.2	30	3.2
collected heart rate (beats/min) periodically	Time, Min	Heart rate	Time, min	Heart rate
	0	156	0	156
	5	160	5	160
	10	162	10	162
	15	168	15	168
	20	166	20	166
	25	162	25	162
	30	158	30	158
advantage of using wireless system	1. Health problem of newborn is detected using an automated system which immediately notifies the health professional through the mobile phone using Android application. By informing the health professional, immediate action can be taken to cure the baby 2. Using wireless sensor nodes free working environment is provided			

professional does not arrive, then the W-RW changes the temperature by working in servo control mode.

(i) The body movement of the baby is detected by the acceleration sensor. If there is a sudden rise in acceleration parameter value, then it will be automatically notified in the system. Then, the health professional will take required action.

(j) The heart rate of the baby is measured by the heart rate measurement sensor. If any cardiac problem is detected, then it will be automatically notified in the system. Accordingly, the health professional will take required action. Hence, it is observed that in our system temperature, acceleration and heart rate are continuously monitored. If the temperature, acceleration or heart rate seems abnormal, the system notifies the health professional automatically through his or

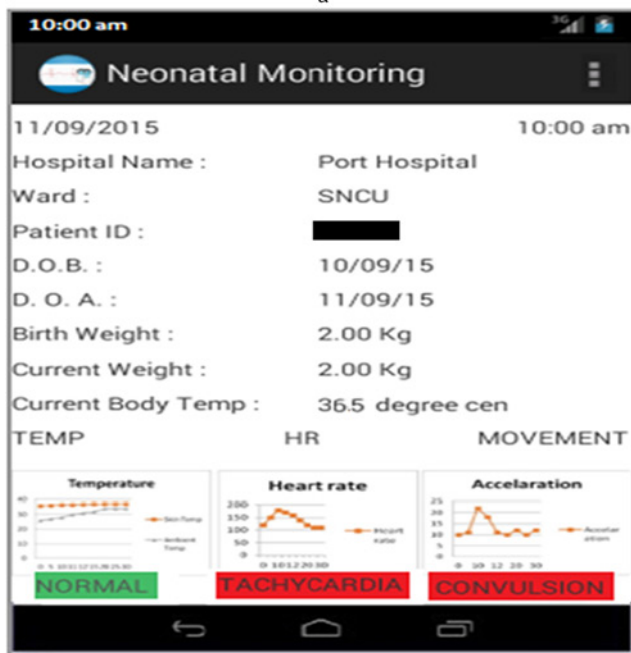
her mobile phone at anywhere anytime using the Android application. Then, the health person takes required action.

(k) Our system is based on WSN, mobile network and cloud. Message queuing telemetry transport protocol is used in the system where transport layer security and secure socket layer are used to achieve secured communication.

(l) For authentication purpose two-step checking occurs. In the first phase, the user has to provide correct user ID and password. If the provided information is correct, then biometric authentication [3, 11, 12] is used where retinal image recognition or keystroke recognition is employed to authenticate the user. This two-step verification is performed to make the system more secure as the biometric feature of each user is unique. In our previous works [3, 11, 12], the procedure



a



b

**Fig. 7** Snapshot of the application

a Hypothermia detection

b Tachycardia and convulsion detection in the Android application

of authenticating a user using biometric authentication has been discussed. The accuracy of monitoring is two digits after the decimal point. As the designed system monitors the neonates' health status in an automated way, it is referred as a smart system.

**6. Experimental analysis of our system:** In our experiment, sensor data are collected in a computer using Moteview software. The experiments have been performed in accordance with relevant guidelines and regulations. During experiment patient care has not been affected. Ethical clearance was obtained from the Institutional Ethics Committee of R.G. Kar Medical College and Hospital, Kolkata, West Bengal, India (Ethics Committee registration (ECR) number 322/Inst/WB/2013). The temperature sensor and

two-dimensional acceleration sensor are used. MTS310 is used as the sensor board and MIB520 is used as the receiver node, i.e. sensor base station. The body and ambient temperatures collected using this software are presented in Fig. 4.

The acceleration graph is shown in Fig. 5. If the temperature is high or low, an alarm is generated in the health professional's mobile phone to alert him or her for taking initiative. The normal ambient temperature varies from 32 to 35 °C depending on the age and weight of neonates as per Table 2. For sudden quick movement, acceleration is very high and abnormal body movement is detected as shown in Fig. 5. Then, necessary step is taken by the medical professional. An alarm is generated at this time to alert health professional, so that prompt action can be taken by the doctor.

6.1. Case study: Three cases presented in Table 3 are considered in our experiment. During experiment patient care has not been affected and patient privacy is preserved:

(a) *Case 1:* A 2700 g newborn is put under our W-RW, i.e. W-RW for next 30 min without affecting patient care. The ambient temperature and body temperature are collected and presented in Fig. 6a and Table 4. Fig. 6a shows that when the body temperature goes beyond the normal range, alarm is generated in our wireless system. At the same time, the health professional gets informed through the Android application in his or her mobile phone in case of our system.

(b) *Case 2:* Acceleration sensor is attached with a 2300 g newborn for next 30 min to collect the corresponding data without affecting patient care. The collected data are shown in Fig. 6b and Table 4. During observation period, at around 10 min there is a sudden rise in the acceleration. It is detected by our system and alarm is generated as shown in Fig. 6b. Consequently, the health professional gets informed through the Android application in his or her mobile phone for taking prompt action.

(c) *Case 3:* Heart rate measurement sensor is attached with a 2000 g newborn for next 30 min to collect the corresponding data without affecting patient care. The collected data are shown in Fig. 6c and Table 4. It is shown in Fig. 6c that when the data seem abnormal (exceeds 160 beats/min) the alarm is generated in our system. This abnormal increase in heart rate indicates tachycardia. At the same time, the health professional is informed through the Android application in his or her mobile phone. When heart rate of a newborn becomes abnormal and body movement is also abnormal, then convulsion is suspected.

6.2. Android application for neonatal monitoring: An Android application Neonatal Monitoring is designed in our MCC [11, 12] laboratory. This application will alert the treating physician or other health professional instantaneously about any change in the health parameter above or below the preset point through their mobile devices. In our experiment patient care has not been affected and patient privacy is preserved. A snapshot of the application is given in Fig. 7. Doctors can control various NICU parameters remotely as and when required with full access control. Nurses have limited access to control the parameters of NICU. Parents can only monitor the condition of neonates with no access control but they can inform the doctors and nurses if any problem is suspected. As observed from Fig. 7a, body temperature of the baby indicates hypothermia whereas the heart rate and acceleration denoting the body movement of the baby are normal. As the system notifies that hypothermia has occurred, the health professional takes proper action to cure the baby. Fig. 7b shows that the heart rate and acceleration of the newborn are abnormal. Abnormal heart rate is showing tachycardia. As sudden acceleration has occurred, it means body movement of the baby is abnormal. As heart rate as well as body movement both are abnormal, convulsion is suspected. In this way using the Android

application Neonatal Monitoring, the health professional is automatically notified by the system when severe case arises, so that the health person can take required action to solve the problem.

6.3. Comparison between our SMCC-based neonatal monitoring and existing wired neonatal monitoring systems: Table 4 shows the advantage of using wireless system with respect to the traditional wired system. Our SMCC-based system has used IEEE 802.15.4 protocol. The experimental data collected using wired system and our wireless system are presented in Table 4. It is observed that same information is obtained in our wireless system as the wired system but the wires are not used and a free working environment is offered to the medical person. This is the advantage of using our wireless system.

**7. Conclusion:** In this Letter, an automated system is designed for neonatal monitoring using SMCC. Use of wireless sensors in this system reduces the overhead associated with wired connection of the existing systems. Our system automatically can detect hypothermia, hyperthermia, abnormal body movement and cardiac problem and inform the health persons through mobile devices anywhere anytime using an Android application. The health data storage and access take place inside the cloud. By immediately informing the health professional in adverse case, probability of cure is increased and better quality of life is provided.

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