International Information and Engineering Technology Association
Advancing the World of Information and Engineering

Journal Européen des Systèmes Automatisés
Vol. 57, No. 5, October, 2024, pp. 1531-1537
Journal homepage: http://iieta.org/journals/jesa

A Smart Incubator System for Monitoring and Controlling Premature Babies' Environment Using Machine Learning

Neamet Akeel Fawzi

Computer Technique Engineering Department, Imam Al-kadhum College (IKC), Wasit 52001, Iraq

Corresponding Author Email: nemat.aqel@iku.edu.iq

https://doi.org/10.18280/jesa.570529

Received: 14 September 2024
Revised: 4 October 2024
Accepted: 14 October 2024
Available online: 28 October 2024

Keywords:
premature babies, incubator system, machine learning, IoT, healthcare

ABSTRACT

Since technology has developed at the present time and with the emergence of the problem of many deaths of premature babies for a number of reasons including the failure to monitor the child's health in a timely manner and 24 hours a day in an incubator system that provides a safer environment for the premature child. In this work, an incubator monitoring and control system has been designed and implemented including four sensors: SpO2, temperature, heartbeat, and respiratory (BPM). Two actuators have been used in this work to control the incubator's environment which are ceramic warmer and a fan. A real time dataset has been extracted from the proposed incubator designed and five machine learning where evaluated to control the incubator environment which are Linear Regression (LR), Decision Tree (DT), Nave Bayes (NB), Random Forest (RF), and Deep Neural Network (DNN). Results shows that both DT and RF obtain the best results although the other algorithms show a 100% results in five performance metrics accuracy, precision, recall, F1 score , and ROC.

1. INTRODUCTION

Premature delivery is the leading cause of death for children worldwide. More than 3,000 children under the age of five lose their lives to premature birth compilation almost every day. These days, an incubator is used to care for premature babies since they need to be in a room with a controlled temperature, similar to that of the womb. A premature infant in an incubator requires critical care. A gadget that offers a dependable and effective baby monitoring system has been invented, and it has the potential to significantly improve the care that infants receive. This gadget tracks important metrics including body temperature, heart rate, and breathe [1].

These babies will be placed in an incubator that gives them the ideal environment to thrive in the neonatal intensive care unit (NICU) in order to help them survive outside of the womb. Premature infants, sometimes referred to as preemies, are placed in an incubator that has temperature control to maintain the ideal body temperature for the infant. The premature baby may go through a number of examinations after being placed in the incubator. They are as follows: The amount of oxygen in a child's blood is measured through oxygen saturation monitoring. Baby's vital signs can be tracked by attaching sensors to their body, which can measure their body weight, blood pressure, heart rate, breathing, and temperature [2].

The Internet of Things (IoT) is now the most advanced information technology. IoT refers to internet services that are integrated with particular sensors that can be used [3-7]. Manufacturing, agriculture management, and smart city management are just a few industries where IoT is being used extensively. IoT is utilized in the healthcare industry to monitor patient health conditions through mobile web and Android applications on smartphones [8].

By evaluating real-time data on critical parameters like temperature, humidity, heart rate, and oxygen levels, machine learning can enhance the design of infant incubators. Early intervention is possible thanks to the data's ability to identify early indicators of health decline. With the help of ML models, which can automatically and dynamically alter settings based on variables like weight, gestational age, and health status, each newborn can have the ideal conditions learned. Based on past data, this technology can also forecast health outcomes [9-12].

This work aims to design a low-cost incubator for a premature baby with an integrated environment that resembles the mother's womb so that rural areas or areas with limited income can use it. The incubator provides an environment suitable for the child in terms of temperature, humidity, and oxygen. We have designed an oximeter to measure body temperature, oxygen, and heartbeat for the child's health. Five machine learning were tested and evaluated based on real time dataset obtained practically from the proposed incubator system.

The remainder of this paper follows this structure: Section two presents the related work, Section 3 outlines the methodology, Section 4 presents the proposed the incubator monitoring system design, Section 5 shows the results of the machine learning performance while conclusions are presented in Section 6.

2. RELATED WORK

Owing to the significance of newborns' lives in incubators, researchers have concentrated on this issue, and numerous infant incubator designs have been documented in the literature. Singh et al. [13] suggested a monitoring system that used a digital thermometer and an LM35 temperature sensor to compare the readings in real time. Every five minutes, each trial used an LM35 temperature sensor and a digital thermometer to collect the data. The temperature sensor LM35, however, yielded a smaller standard deviation. Wahab and Nor [3] Created and implemented a closed-loop control system to regulate light intensity, temperature, and relative humidity. To do this, a centralized AtMega16 microcontroller will manage the data. Through a Bluetooth connection, the doctor continuously receives this data, which is updated on a regular basis by the Bluetooth receiver module. This device's sole reliance on Bluetooth for information transmission is one of its inherent limitations. Komang Alsahi et al. [14] created an incubator using Internet of Things technologies. The primary function of the prototype developer ThingSpeak is to use the Internet to provide the doctor, nurse, or family member with information about the incubator's environmental conditions.

Latif et al. [5] developed a technique to monitor a premature baby's body temperature and heart rate. The results of a humidity measurement can also be used to identify interior issues like weariness and cold. The heating element will not turn on automatically if the incubator's temperature drops because of external factors or other issues because we are unable to incorporate the capability. Shalannanda et al. [6] arranged for the temperature and humidity of the air to be measured using a DHT11 sensor that is interfaced with a microcontroller. The results were then shown on an LCD by means of the DHT11 sensor's measurements. The temperature of the incubator is raised using a heater by the researchers, who also modify the temperature to maintain the standard range of 33°C to 35°C. We use a fan to reduce the humidity levels and change the humidity settings to maintain the incubator's typical humidity range of 40% to 60%.

Madona et al. [7] utilized an Arduino Uno in conjunction with a body temperature sensor to represent biosensors; ambient temperature, humidity, and gas sensors were used to represent environment and monitoring sensors; an RFID sensor called EM-18 was included for security. An ESP8266 Wi-Fi was used to link the Arduino board to a data connection submodule. The hardware module's functions include gathering data automatically from sensors (biosensors and environmental monitoring sensors), processing it on the microcontroller board, and sending it via the Internet to a database server. The data obtained from the hardware module is stored in the PHP scripts of the database and web servers. Mohsi and Hamad [15] install an incubator so they could keep an eye on premature babies' temperatures from a distance. A contactless radar-based system has been installed to track the heart rate and respiration of the newborn patient. The temperature of both the incubator and the infant's body has been managed by means of an advanced monitoring and control system. Sensors for weight, humidity, and temperature linked via a long-distance network to a central network for the purpose of storing medical data. An inexpensive, effective newborn incubator with IoT-based remote monitoring was developed as a result of this work. The environment in this incubator stays at a specific temperature since it lacks a heat source.

Most of works in this displinary focuses on gathering the sensor values and usues simple monioring and control algorithm which results in a weak performance. This gap motivates us to use machine learning algorithm to enhance the overall performance of the proposed system.

3. PRELIMINARIES

The suggested system design makes use of a variety of sensors to gather data on the condition of the incubators and send it to the microcontroller, which decides whether to run the fun to regulate the incubators' environment to the desired state. Additionally, the data is sent to the healthcare providers via the Internet. The two components of the current work's preliminary stages are software (machine learning technique) and hardware (sensors and controller).

3.1 Hardware system design

In this work, sensors, actuators, and microcontrollers make up the hardware. The sensor portion is made up of the MAX30100, which functions as a heart rate and pulse oximeter sensor. A contactless infrared thermometer is the MLX90614 model. Respiratory sensor has been interfaced with the microcontroller and the number of breath per minute is counted. Because it has a greater humidity measurement range of 0 to 100% and an accuracy error rate of 2-5%, the DHT11 humidity sensor is chosen in the work [16, 17]. In this work, two actuators have been used: a servo motor, which runs the incubator's fan on 12 DC. Infrared radiation is also emitted by a ceramic warmer, an infrared heater, to transfer heat to a target. In this work, all system components have been powered by a switch mode power supply, and an I2C 20x4 LCD display that makes use of liquid crystals' light-modulating properties has been installed. Arduino nano has been used as the main microcontroller of the proposed incubator monitoring and control while ESP8266 module has been used as a gateway to the cloud server. Table 1 shows the sensor used in this work and its specifications in working range, power consumption, and accuracy.

Table 1. Incubator sensors specifications

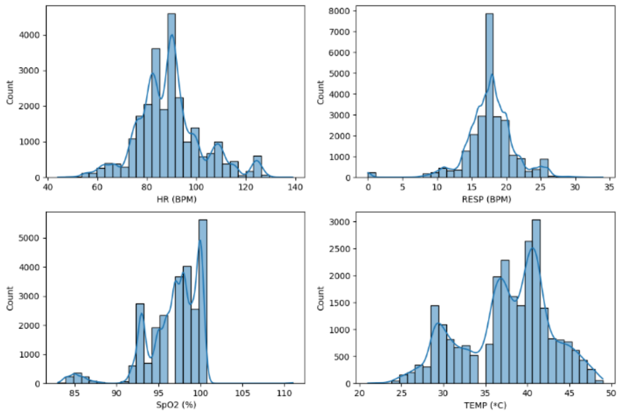
Sensor	Range	Current/voltage	Accuracy
DHT11	20% to 90% 0°C to 50°C	0.3mA/3.5V	±1°C and ±1%
mlx90614	-40 to +125	0.3mA/3.5V	0.5°C
Max30100	0-100% (Oxygen rate)	20mA/1.8V to 3.3V	13-bit

3.2 Dataset collection

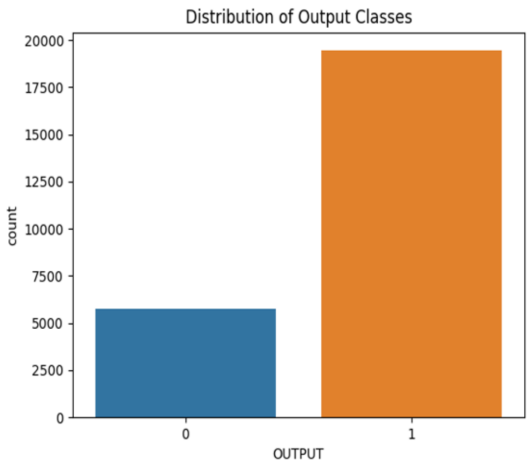
The dataset was gathered in real time from the hardware sensors covered in the preceding section. The heartbeat, breathing rate, SpO2, and body temperature are the four features that have been used. With roughly 25,000 samples, a one-second sampling time was used. There are two output status classes—normal and abnormal—that are binary classes. The dataset's features are displayed in Table 2. The dataset features—heart rate (HR), SpO2, temperature, and breathing rate (BPM)—are represented histographically in Figure 1(a) histogram is a tool used to display the distribution of numerical data of a given class and provides an early sense of feature effectiveness. The distribution of the binary classes representing normal and pathological state is depicted in Figure 1(b). The dataset has been collected for different sets each about one hour for different period of the day and night. Some samples of the dataset were intentialy put in abnormal condition to simulate the failure states.

Table 2. Custom dataset features

	Unnamed: 0	Time (s)	HR (BPM)	RESP (BPM)	SpO2 (%)	TEMP (*C)	OUTPUT
0	0	0	94.0	21.0	97.0	36.2	Normal
1	1	1	94.0	25.0	97.0	36.2	Normal
2	2	2	101.0	25.0	93.0	38.0	Abnormal
3	3	3	55.0	11.0	100.0	35.0	Abnormal
4	4	4	93.0	26.0	95.0	37.0	Normal
…	…	…	…	…	…	…	…
25488	476	476	56.0	12.0	101.0	33.0	Abnormal
25489	477	477	94.0	25.0	98.0	36.4	Normal
25490	478	478	94.0	21.0	97.0	36.2	Normal
25491	479	479	93.0	27.0	95.0	37.0	Normal
25492	480	480	102.0	25.0	92.0	37.0	Abnormal



(a) Feature histogram



(b) Binary classes distribution

Figure 1. Dataset features

3.3 Machine learning algorithms

It is an area of artificial intelligence where systems use data to learn, spot patterns, and make judgments with minimal help from humans. Machine learning algorithms are used to construct mathematical models; these algorithms are dependent on a training dataset. On the basis of fresh facts, these models are then utilized to forecast or decide. This work examined four supervised machine learning algorithms: DT, RF, LR, Naive Bayes, and DNN, NB [18-20].

The proposed DNN model's hyperparameter used in this work is described in Table 3 where the model is consists of 5 layers, the input layer size is the same size of the input features while the output layer is the same size for each dataset number of class.

Table 3. Hyperparameter for the DNN model

Parameter Name	Value
Hidden node in model	50
Batch size	64
Epoch	300
Loss function	Categorical cross entropy
Activation function	Relu, SoftMax (in output layer)
Optimizer	Adam

4. PROPOSED SYSTEM DESIGN

The proposed incubator monitoring and control has been designed to control the environment of the incubator for premature babies based on machine learning approach. The proposed system consists of three layers:

Sensor and actuator layer: this layer implies temperature, humidity, oximeter, and heart beat sensors. Actuators like servomotor to control the speed of a fan and a ceramic warmer to increase the incubator temperature if required. An I2C 20×4 LCD display has been used to show the different vital signs of the premature baby held in the incubator.

Communication layer: three different communication protocols have been used in this work. The first protocol is the I2C which have two lines only serial data (SDA) and serial clock (SCL) where all sensors and the display have connected. The second protocol is the universal asynchronous receiver-transmitter (UART) protocol which has been used in communication between the Arduino and ESP8266 module. Finally, a WiFi protocol is used to connect the ESP8266 to the cloud server through the Internet.

Application layer: an open source Blynk app has been used to display the vital signs of the baby and also give the healthcare provider the ability to control the incubator remotely and continuously.

Figure 2 illustrates the proposed system design while Figure 3 shows the implementation of the proposed incubator. We designed the work to assist both the premature baby and the observer. It consists of two systems: the first one monitors the premature baby's condition, enabling the observer to be aware of any effects on the baby at anytime, anywhere. It also uses comfortable and harmless sensors for the premature baby. The second system tailors the environment to the baby's needs. The premature baby incubator's size height 55, width 50, go down 40. For construction, we used white MOV type wood and 3 mm transparent glass. On the first side, we installed a box to house the sensors for the second system, and on the second side, we installed a fan to facilitate air exit. Inside, we install a ceramic heater, moisture and heat sensors, a nipper for measuring the premature baby's vital signs, and the sensors from the first system. The front side features an openable door with two openings to facilitate the child's exit and entry into the incubator. The following figure shows the shape of the incubator and its aspects. Algorithm 1 shows the proposed software design for monitoring and control of the incubator system based on machine learning approach.

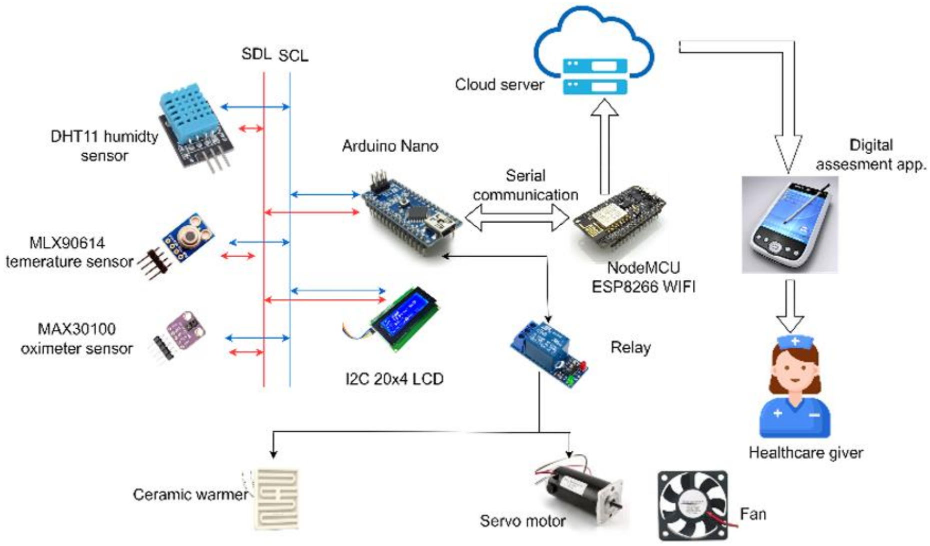


Figure 2. Schematic diagram for the proposed incubator monitoring and control system

Figure 3. The front part of the incubator

Algorithim 1: Monitoring and control the incubator

```
Input: Sensor values
Output: control the fun speed, control the ceramic warmer heater

# Initialize sensors
initialize temperature_sensor
initialize humidity_sensor
initialize spo2_sensor

# Define control systems (e.g., heater, humidifier, oxygen system)
initialize heater
initialize humidifier
initialize oxygen_system

# Load pre-trained machine learning model for optimal conditions
model = load_model("incubator_control_model")

# Define the desired set points for temperature, humidity, and SpO2 (can be learned by the model)
setpoint_temperature = 37.0    # Example: 37°C for temperature
setpoint_humidity = 60.0       # Example: 60% relative humidity
setpoint_spo2 = 95.0           # Example: 95% oxygen saturation

# Main loop to monitor and control incubator environment
while incubator_is_running:

   # Step 1: Read sensor data
   current_temperature = temperature_sensor.read()
   current_humidity = humidity_sensor.read()
   current_spo2 = spo2_sensor.read()

   # Step 2: Combine sensor readings into a feature set
   sensor_data = [current_temperature, current_humidity, current_spo2]

   # Step 3: Predict optimal control actions using the machine learning model
   control_actions = model.predict(sensor_data)

   # Step 4: Control incubator environment based on model's prediction
   # Adjust temperature
   if control_actions["temperature_action"] == "increase":
      heater.turn_on()
   elif control_actions["temperature_action"] == "decrease":
      heater.turn_off()

   # Adjust fun
```

```
    if control_actions["humidity_action"] == "increase":
        humidifier.turn_on()
    elif control_actions["humidity_action"] == "decrease":
        humidifier.turn_off()

    # Adjust SpO2
    if control_actions["spo2_action"] == "increase":
        oxygen_system.increase()
    elif control_actions["spo2_action"] == "decrease":
        oxygen_system.decrease()

    # Step 5: Log the sensor readings and actions taken (for
analysis and further training)
    log_data(sensor_data, control_actions)

    # Wait for the next monitoring cycle (e.g., 1 second)
    sleep(1)

# End of monitoring loop
```

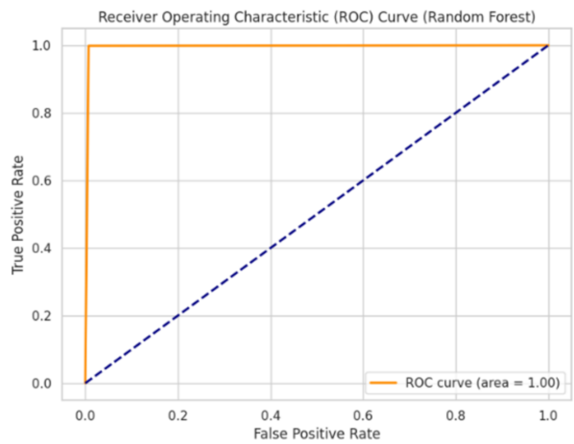
5. RESULT AND DISCUSSION

In this work, five different machine learning have been tested to control the environment of the incubator which are LR, DT, RF, NB and DNN. The performance of the algorithms have been evaluated on the previously achieved real time dataset. Table 4 shows the various algorithm results based on five metrics which are accuracy, precision, recall, F1 score, and ROC. The evaluation of the different models for the unseened data was close to those obtained in the training phase which indicates that the proposed algorithm doesn't has an overfitting problem.

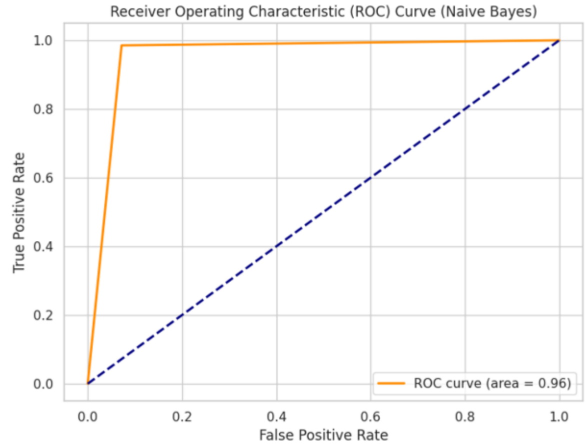
Table 4. Test results of the machine learning algorithms

Algorithm	Accuracy	Precision	Recall	F1 Score	ROC
LR	0.98	0.99	0.98	0.98	0.97
NB	0.97	0.98	0.99	0.98	0.96
DT	1.00	1.00	1.00	1.00	1.00
RF	1.00	1.00	1.00	1.00	1.00
DNN	0.99	1.00	0.99	0.99	0.99

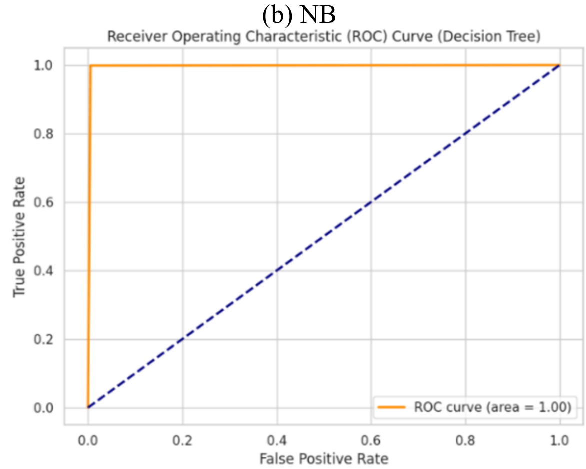
Figures 4(a)-(e) shows the different algorithm ROC curve which is an evaluation metric used for binary classification. ROC is a probability curve that depicts the FPR (rate of false positives) on the x-axis against the TPR (rate of true positives) on the y-axis.



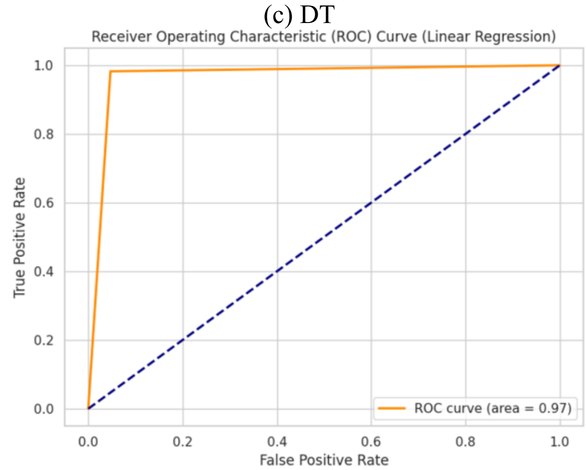
(a) RF



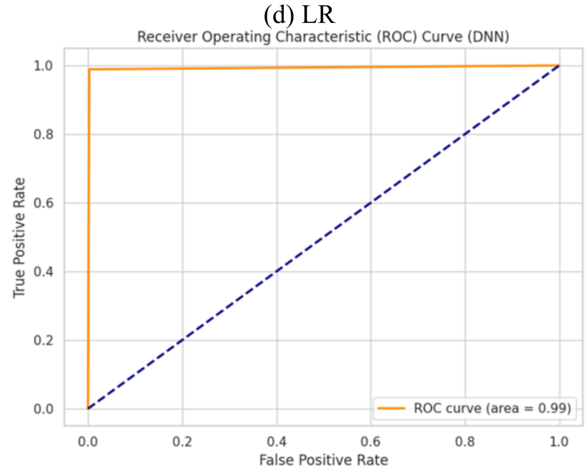
(b) NB



(c) DT



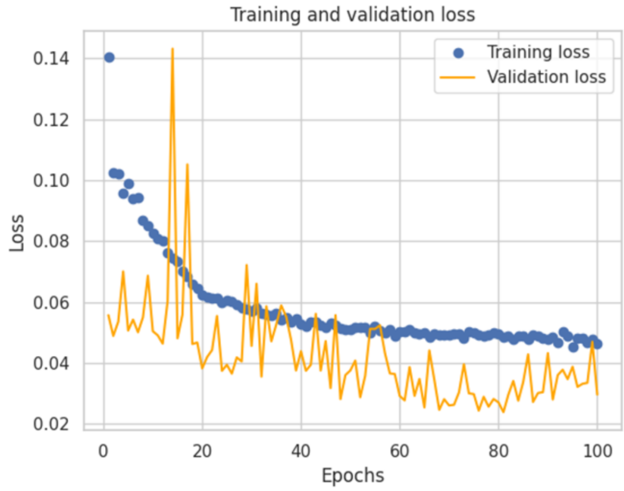
(d) LR



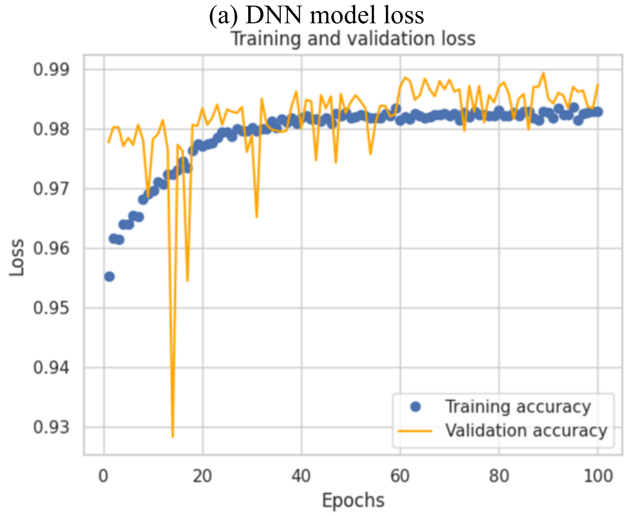
(e) DNN

Figure 4. ROC curve for the different machine learning algorithms

Figures 5(a) and (b) show the performance of the training process of the deep neural network for two metrics accuracy and loss where it could be shown that the performance is well against over and under fitting.



(a) DNN model loss



(b) DNN model accuracy

Figure 5. DNN model training performance

6. CONCLUSIONS

Development in the field of health care, particularly for premature infants, has become rare, and the quality of health services for these infants has recently declined. This includes a lack of systematic monitoring of the child's health condition and the provision of a suitable environment for the infants. Other factors contribute to the recurring deaths of premature babies. In this paper, we developed an incubator using IOT technology, and subsequent results validated its ability to assist the observer, such as a nurse or doctor, in monitoring the health condition of the premature infant. At any time. Therefore, the observer has the ability to monitor multiple premature babies and identify any changes in their health condition. In brief, the observer adjusts the incubator settings and knows what the incubator's temperature and humidity are, and then he sets an oximeter for the child to monitor the child's health. The results then emerge, enabling the observer to understand the current state of the premature baby's health, including changes in temperature, oxygen level, and heartbeat. In addition to that, the incubator system works to provide a safe environment for the child, including ventilation of the incubator, temperature, and humidity levels. For future work, more sensors should be added and also a network of incubators should be done to provid the healthcare givers a more details about all incubators inside and ouside environment.

REFERENCES

[1] Karthick, R., Rinoj, B., Kumar, T.V., Prabaharan, A.M., Selvaprasanth, P. (2019). Automated health monitoring system for premature fetus. Asian Journal of Applied Science and Technology, 3: 17-23.

[2] Suthagar, S., Mageshkumar, G., Tamilselvan, K.S., (2022). Baby incubator monitoring system using global system for mobile. Jurnal Kejuruteraan, 35(4): 899-904. https://doi.org/10.17576/jkukm-2022-34(5)-17

[3] Wahab, M.A., Nor, D.M. (2021). Safety and health monitoring system for baby incubator using IoT. Evolution in Electrical and Electronic Engineering, 2(2): 256-264.

[4] Martínez, A.W., Cáceres, F.D.L., Martínez, K.F. (2023). IoT-based neonatal incubator monitoring system. In 2023 IEEE Latin American Electron Devices Conference (LAEDC), Puebla, Mexico, pp. 1-5. https://doi.org/10.1109/LAEDC58183.2023.10209121

[5] Latif, A., Widodo, H.A., Atmoko, R.A., Phong, T.N., Helmy, E.T. (2021). Temperature and humidity controlling system for baby incubator. Journal of Robotics and Control (JRC), 2(3): 190-193. https://doi.org/10.18196/jrc.2376

[6] Shalannanda, W., Zakia, I., Sutanto, E., Fahmi, F. (2020,). Design of hardware module of IoT-based infant incubator monitoring system. In 2020 6th International Conference on Wireless and Telematics (ICWT), Yogyakarta, Indonesia, pp. 1-6. https://doi.org/10.1109/ICWT50448.2020.9243665

[7] Madona, E., Yulastri, Y., Putra, R., Anggara, N., Wardhani, A. (2023). Monitoring system for premature baby weight and incubator temperature using telegram messanger with smart notificaton. JECCOM: International Journal of Electronics Engineering and Applied Science, 1(1): 34-40. https://doi.org/10.30630/jeccom.1.1.34-40.2023

[8] Najib, S.M., Hassan, N.B., Rahim, N., Ab Wahab, N. (2019). Intelligent neonatal monitoring system based on android application using multi sensors. In 2019 IEEE 9th Symposium on Computer Applications & Industrial Electronics (ISCAIE), Malaysia, pp. 131-135. https://doi.org/10.1109/ISCAIE.2019.8743867

[9] Ali, M., Abdelwahab, M., Awadekreim, S., Abdalla, S. (2018). Development of a monitoring and control system of infant incubator. In 2018 International Conference on Computer, Control, Electrical, and Electronics Engineering (ICCCEEE), Khartoum, Sudan, pp. 1-4. https://doi.org/10.1109/ICCCEEE.2018.8515785

[10] Weber, R., Cabon, S., Simon, A., Poree, F., Carrault, G. (2021). Preterm newborn presence detection in incubator and open bed using deep transfer learning. IEEE Journal of Biomedical and Health Informatics, 25(5): 1419-1428. https://doi.org/10.1109/JBHI.2021.3062617

[11] Evstatiev, B., Evstatieva, N. (2022). Conceptual model of a system for controlling the process of egg-hatching in incubators. In 2022 IEEE 28th International Symposium for Design and Technology in Electronic Packaging

(SIITME), Bucharest, Romania, pp. 17-22. https://doi.org/10.1109/SIITME56728.2022.9988185

[12] Amoshie, D.A., Nyazenga, M.D., Rosca, E.V. (2024,). Automated black soldier fly incubator using internet-of-things and computer vision. In 2024 International Conference on Artificial Intelligence, Computer, Data Sciences and Applications (ACDSA), Victoria, Seychelles, pp. 1-6. https://doi.org/10.1109/ACDSA59508.2024.10467464

[13] Singh, A.K., Leela, M., Jeevitha, R., Mirudhularani, R., Vigneswari, S. (2023). Incubator for home-based baby care using IoT. Journal of Biomedical Engineering, 10(1): 1-7. https://doi.org/10.12691/jbet-10-1-1

[14] Komang Alsahi, Q.N., Marhoon, A.F., Hamad, A.H. (2020). Remote Patient Healthcare surveillance system based real-time vital signs. Al-Khwarizmi Engineering Journal, 16(4): 41-51. https://doi.org/10.22153/kej.2020.10.003

[15] Mohsin, M.A., Hamad, A.H. (2022). Performance evaluation of SDN DDoS attack detection and mitigation based random forest and K-nearest neighbors machine learning algorithms. Revue d'Intelligence Artificielle, 36(2): 233-240. https://doi.org/10.18280/ria.360207

[16] Mohammed, N.A., Abdulateef, O.F., Hamad, A.H. (2023). An IoT and machine learning-based predictive maintenance system for electrical motors. Journal Européen des Systèmes Automatisés, 56(4): 651-656. https://doi.org/10.18280/jesa.560414

[17] Jasim, F.M., Al-Isawi, M., Hamad, A.H. (2022). Guidance the wall painting robot based on a vision system. Journal Européen des Systèmes Automatisés, 55(6): 793-802. https://doi.org/10.18280/jesa.550612

[18] Obaid, M.H., Hamad, A.H. (2023). Deep learning approach for oil pipeline leakage detection using image-based edge detection techniques. Journal Européen des Systèmes Automatisés, 56(4): 663-673. https://doi.org/10.18280/jesa.560416

[19] Ali, F.I., Ali, T.E., Hamad, A.H. (2022). Telemedicine framework in COVID-19 pandemic. In 2nd 2022 International Conference on Engineering and Emerging Technologies (ICEET), Kuala Lumpur, Malaysia, pp. 1-8. https://doi.org/10.1109/ICEET56468.2022.10007389

[20] Mohammed, N.A., Abdulateef, O.F., Hamad, A.H., Abdullah, O.I.. (2024). Performance analysis of different machine learning algorithms for predictive maintenance. Al-Khwarizmi Engineering Journal, 20(2): 26-38.