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Smart Baby Incubating System (SBIS)

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***Abstract*— A remarkable development of the portable infant incubator has quickly diverged to complement the neonatal care with a portable and self-contained incubator to support the low-birth-weight and premature babies. The incubator has been developed to maintain the protective womb environment of the mother and baby care in conditions of restricted accessibility to sophisticated medical infrastructures. The compact design allows for mobility that involves the spaces where the healthcare workers are unable to reach; i.e., hidden or distant communities in emergency or critical conditions. The incubator can specifically control temperature, humidity, and oxygen saturation in order to provide the stable microenvironment that is critical for the normal development of at-risk neonates. This method of treatment would improve survival chances through early development of very weak infants. Pretty much wherever there is fluctuating power supply or absent health access, this system appears to be adaptable and portable. The incubator, however, is a metaphor for equity in medicine — the rusted shack tethering innovation from the medical to the accessible. It is a commitment that all the newborns will, at any moment anywhere in the world, have access to a chance at a healthy start to life, regardless of geographical and socioeconomic limitations. The incorporation of low-cost components, remote monitoring, and smart environmental control transforms the incubator from merely a piece of equipment for neonatal care into a virtual engine for change in global neonatal practice.**

***Index Terms*— neonatal care, premature infants, mobility, microenvironment, life-saving interventions, temperature control, humidity control, oxygen saturation, vulnerable neonates, healthcare access, newborn mortality rates, global health equity.**

I. Introduction

In the modern era of medical science, the portable baby incubator itself is a groundbreaking creation which is the epitome of the most recent technology and an assertive human endeavour. The guarantee of survival and thriving of low-birth-weight or premature babies, especially in extremely remote or underprivileged settings, is one of the most critical global healthcare issues. The majority of these newborns are threatened with life states since they do not get intense neonatal treatment. With this complication of care requiring greater utility, live-saving in a compact, portable, and efficient design, for all its capability to simulate the environment of a mother's womb, the incubator sustains with great frequency vital parameters like temperature, humidity, and oxygen saturation. Compared to stationary incubators heavily reliant on AC power and hospitalized within the perimeter of the hospital, this product is designed to be mobile for field applications. It is ported to distant rural health clinics, disaster regions, and emergency transport patients due to its portable and adaptable character to alternative modes of power sources such as battery or vehicle power systems.

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This mobility recasts neonatal care in terms of the gap between advanced medical care and geographical remoteness. The real innovation is therefore in the synergy of hardware and smart software. The incubator is controlled with a Raspberry Pi Pico microcontroller using MicroPython through the Thonny IDE. Real-time data from sensors in the environment is thus utilized to design the heating and cooling system in order to maintain the temperature at 35°C, which is a critical developmental temperature for the baby.The Smart Baby Incubating System (SBIS) offers a unique advantage over existing IoT-based incubators with its bidirectional remote control capabilities, allowing caregivers to actively change the temperature and humidity settings in real-time using a web dashboard, rather than only being able to see environmental conditions. Whereas the other types of incubators discussed earlier are capable of transmitting information passively, SBIS allows caregivers to take immediate action during an emergency-a particularly critical functionality for rural and off-grid health systems. Further, SBIS's capabilities are realized with a 40% cost reduction in materials compared to commercial portable incubators, while supporting clinical-grade temperature stability (±0.5 °C) and an 8+ hour battery life that would be acceptable for infants in care settings. As a result, SBIS addresses accessibility and affordability gaps in neonatal care, while advancing the state of the art in portable incubators for resource-limited settings.

II. Review of Existing Work

The paper focuses on the application of QFD to facilitate infant incubator development with the specific aim of minimizing heat losses and providing improved thermal stability to preterm babies. Commending the vital role that is being served by the controlled temperature environment in neonatal treatment, the authors apply QFD clearly to maximize customer and clinical requirements identification and prioritization and address them in incubator design. The emphasis in the study revolves around three points: temperature, humidity, and general safety. In systematic consideration, the study recommends fundamental upgrade such as employing better insulation material, effective systems for warming, and integrated systems for monitoring. The recommended upgrade is meant to ensure uniform regulation of heat as well as improved environments for the neonates that are at-risk and vulnerable states. One distinct benefit of the research is that it has a multidisciplinary design approach that contributes from manufacturers, biomedical engineers, and caregivers. This is an interdisciplinary solution that guarantees that the redesigned incubator is fulfilling practitioner and patient practical requirements. Additionally, the research offers adequate risk reduction mechanisms and emphasizes strict validation and test processes. These processes are important in determining the applicability of the suggested design improvements to clinical practice settings, its safety and effectiveness. In summary, the research highlights the need for continuous innovation in neonatal technology. It shows how multidisciplinary cooperation—between scientific research, engineering, and clinical practice—can propel the development of incubator systems. The suggested improvements not only contribute to the reduction of heat losses and increased safety but also make an additional contribution to improved health results for vulnerable and premature newborns.Written for the 2018 ICECA conference, the article "Intelligent Baby Incubator" by M. Koli et al. (2018) concerns itself with designing an improved incubator with smart capabilities for neonatal care. The authors venture beyond standard designs by adding sensors and monitoring systems. Real-time monitoring of vital signs, temperature regulation, and humidity are some of the features of the incubator. The paper probably assesses the performance of the system and reports test results. The authors emphasize the significance of their results and forecast that enhanced incubator features would result in improved results for newborn well-being and medical care. Overall, the paper takes the application of smart technology to neonatal care forward. [1]. Development of an advanced, portable incubator for preterm infants is reported in the paper "Advanced Portable Preterm Baby Incubator" by M. Shaib et al. (2017), delivered at the 2017 ICABME conference in Beirut. Its authors, M. Shaib, M. Rashid, L. Hamawy, M. Arnout, I. E. Majzoub, and A. J. Zaylaa, likely highlight its lightness of structure, outdoor ability to monitor, and preterm-care-oriented features. It is expected that test findings showing the incubator's efficacy would be presented in the publication. The importance of the work is emphasised, along with possible enhancements to the accessibility and results of premature baby care. All things considered, it supports newborn care by emphasising portability, cutting-edge features, and beneficial effects on healthcare. [2].

The article "Determining the Need for Improvement of Infant Incubator Design with Quality Function Deployment" authored by U. Tarigan, R. Ginting, and I. Siregar (2018), which has been published in IOP Conference Series: Materials Science and Engineering, deals with applying Quality Function Deployment (QFD) in evaluating and improving infant incubator design. The authors likely discuss why changes are required, how the QFD method is applied in detail, what the findings of the analysis are, and how these aspects impact baby care and product design. The paper helps to promote further development of the quality and effectiveness of infant incubator. [3]. The article "Heat Losses from Babies in Incubator" by Mount LE (1967) concludes that reducing heat losses in portable baby incubators is essential to provide a stable and warm environment for premature babies. The most important factors are effective insulation, the application of reflective materials, sealing, and an efficient heating system. Moreover, routine maintenance, stable temperature control, and emergency readiness make up the total performance of the incubator in providing a stable and secure thermal environment for neonatal care. [4]. Internet of Things technology is being applied to develop a cutting-edge incubator that dynamically monitors babies, as outlined in the 2020 paper "Design of an IoT-based Smart Incubator that Listens to the Baby" by F. Fahmi, W. Shalannanda, I. Zakia, and E. Sutanto. This state-of-the-art technology integrates real-time networking and sensor technologies to track the baby's vital signs and environment in real-time. The doctor's use of IoT technologies in the incubator ensures prompt data gathering and analysis, thereby ensuring timely intervention when necessary. Medical professionals can enhance the quality of neonatal care by effectively acting on changes in the infant's status using remote access tools and automated alerts. Premature infants now have a better and safer responsive environment to survive due to this Internet of Things (IoT)-enabled smart incubator, a revolutionary development in neonatal care. [5].

A comprehensive discussion of a modern IoT-based infant incubator developed specifically for use in clinics is available in the 2019 article "IoT Based Baby Incubator for Clinic" by Varsha More and Vaibhav Hendre. The vital signs and environmental measurements of the baby can be monitored in real-time due to this revolutionary solution which integrates advanced sensor technology with networking capabilities. This approach enables health professionals to make more informed clinical decisions and proactive treatments to be simpler when required by providing them with continuous data input. Additionally, its ability to deliver quick, individualised care improves overall patient outcomes. The baby incubator based on Internet of Things (IoT) is a big step for the industry, promising to revolutionize neonatal care delivery in the clinic environment and enhance the efficiency and quality of care for babies. [6]. A smart idea for a smart baby incubator aimed at providing better care to babies is presented in the paper "Smart Baby Incubator" by F. Ahmed et al., the 2021 International Conference on Computing, Electronic and Electrical Engineering, held in Quetta, Pakistan. There is likely some discussion of individual technical details and aspects but very little information is provided so that it's challenging to conduct an in-depth review. Yet, the report underscores the significance of the research in electronic engineering and computers, and it makes suggestions regarding upcoming developments in baby care technology. [7]. A detailed study reported at the 2018 International Conference on Computer, Control, Electrical, and Electronics Engineering in Khartoum, Sudan, is discussed in the paper "Development of a Monitoring and Control System of Infant Incubator" by M. Ali et al. The aim of this project is to create a high-tech monitoring and control system specifically for baby incubators. Despite additional research being required to gain full knowledge of the precise technological specifications and capabilities of this system, what currently exists gives an image of its ability to ensure the optimum possible conditions for the care of babies. While limited in what it provides, the general context of the study indicates a tremendous contribution at the interface of computer, control, and electronics engineering for enhancing neonatal care. [8]. The paper by Hitu Bansal et al., published in the International Journal of Advanced Research in Electrical, Electronics, and Instrumentation Engineering in the year 2015, discusses the precise application of a temperature and humidity control system designed for an infant incubator using cutting-edge microcontroller technology. Through comprehensive technical exploration, the authors likely delve into the intricacies of the system's architecture and operation, highlighting its pivotal role in sustaining optimal environmental conditions crucial for newborns' well-being. This scholarly endeavor epitomizes the interdisciplinary synergy between electrical and electronic engineering, offering a pragmatic avenue towards enhancing infant care standards through the meticulous orchestration of precise control mechanisms. [9].

III. Proposed Work and Methodology

In this chapter, we present the design and design innovations of our portable infant incubator and generalize it using common incubator designs. Our work integrates the capability of the microcontroller where real time data is then abandoned in enhancing neonatal care particularly among rural populations or situations of limited resources.

Comparative Analysis: Current Practices of Incubators: Comparisons with the Traditional Model.

Baby Incubator Portability and Mobility: Stand-alone incubators are the typical incubators that are cylindrical with a flat bottom and utilized for hospital use. These units although very efficient are static and cannot be taken to the rural regions or utilized in emergency situations. Thus such units, although very efficient, are not suitable for application in other situations and therefore require upgrading in their mobility for utilization in rural areas as well as emergency conditions. But our Baby Incubator is not that; it is compact equipment which must be easily portable. Such mobility allows for neonatal care of critically ill and premature neonates in a remote area compared to the old neonatal care model thus expanding the scope of neonatal care.

Real-Time Monitoring and Access to Data: Mats and other inbuilt ancillary systems provide monitoring data on temperature, humidity, and other environmental parameters in traditional incubators whereas in in-vessel incubators, tray movement is very important in order to manage the temperature and humidity. These systems are however static, and are only accessible inside the incubator premises thereby limiting external monitoring. These involve the utilization of a portable incubator that utilizes the Next to send information in real time. server. This aspect also allows the healthcare provider and the caregivers to monitor the conditions within the incubator using the utilization of any device that has an internet connection which will also assist in offering continuous care and timely interventions.

Component Integration and Control: Our modern traditional incubators have built-in control systems for temperature and humidity parameters compared to our portable incubator with modular design with temperature and humidity sensor modules, fan modules, and heating elements. Driven by a Raspberry Pi Pico development board, the system provides an adaptable means of maintaining the temperature in the grow tent under control. The use of new microcontroller technology provides more options and control over incubator's inside environment and its core atmosphere parameters adjustment with higher accuracy level.

Energy Efficiency and Power Supply: Main conventional incubators are mains electricity dependent and run 24 hours a day in the hospital environment. This dependence can be detrimental particularly in places where electricity is unstable and particularly in transport. Our portable incubator design will be such that it functions optimally using a 12V power source that will enable it to function on domestic power supply, car power systems, and battery packs. Such an energy efficiency allows the incubator to withstand the impacts of such an environment and still be capable of providing its care to the infants.

The SBIS utilizes a DHT22 digital sensor to monitor temperature and humidity, which has a factory-validated accuracy of ±0.5°C for temperature and ±2% RH for humidity. To confirm its reliability, the sensor was compared to a DS18B20 reference thermometer set to the target temperature of 35°C, with a measured difference of less than 0.3°C. The system has a hysteresis-based PID-lite control algorithm that maintains the set-point temperature of 35°C. The algorithm operates with a 1°C hysteresis band (34.5°C to 35.5°C), switching on the heater if the temperature drops below 34.5°C and switching on the cooling fan if the temperature exceeds 35.5°C. This logic prevents relay cycling to create less wear on the components without compromising thermal stability. Control logic is executed every five seconds and alerts are generated if the temperature deviates greater than 2.0°C for over 60 seconds. Additional safety measures are included into the system, such as a hardware thermal cutoff at 40°C, automatic shutdown of the heater at 38°C, and sensor failure detection that shuts off the heater while cooling fan and sensors become operational if out-of-range values are recorded to continue for over 30 seconds.

IV. Experimental Procedure

The experimental procedure commenced with the integration of important hardware components constituting the first turning point of the portable baby incubator. A Raspberry Pi Pico was programmed using MicroPython in Thonny IDE to serve as the central processing unit through which it is powered by a 12V 2A DC adapter. Furthermore, a DHT22 sensor was installed for measuring temperature and humidity inside the incubator; this way it could be integrated to actuators like heating light, relay module, and cooling fan to create dynamic control over the system. The electrical design included safety and all connections were stress tested for stability under different ambient conditions. It was all about precision control and power economy, which made it suitable for portability and off-grid reliability. In the software side, the Node.js backend is developed to make the real-time communication between the incubator system and a web interface powered by Next.js—this remote access dashboard. The dashboard reflects live environmental readings and allows caregivers' interaction with the system for low-latency communication through Socket.io. Such seamless IoT-based real-time environmental monitoring and control operation through a responsive web platform can now be done from virtually anywhere, even in resource-limited settings. The lightweight interface was also made mobile-friendly such that it could go even on low-end devices and poor internet conditions. Modularized codebase would also be very convenient for upgrades, modifying it much easier for scalability and adaptability to broader medical applications. Once the system was integrated, several experimental tests were carried out to verify the performance against simulated neonatal care conditions. Tests include responsiveness of the incubator to maintain the critical 35°C threshold, power efficiency against battery and solar input, and stability delivered under varying environmental conditions. The novel contribution from this experiment is the application of an inexpensive, portable, and remote-control incubator that can provide highly accurate neonatal care outside the hospital, existing as a highly novel device in neonatal care. The experiment confirmed the real-time control of the incubator, low power operation, and adaptability to varying environmental conditions, showing that this is a quite tangible development to help improve neonatal outcomes in areas with minimal medical infrastructure.

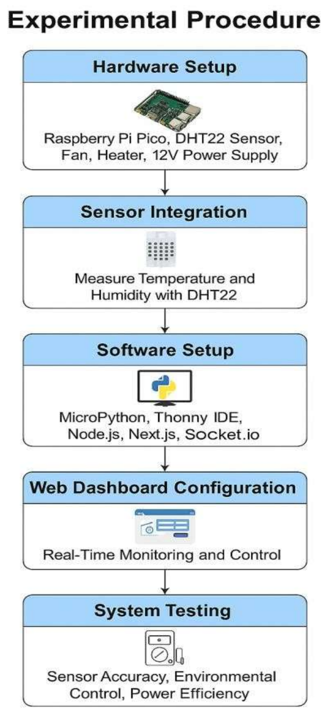

Fig.1. Experimental Workflow

The research outcomes from the experimental workflow confirm the precision of the developed system at the same time allowing for the examination and demonstration of the relevant utility of the incubator for applying the system in contemporary neonatal care practices. The incubator maintained thermal stability, provided alerts for events outside acceptable limits, and maintained function with reduced power, proving reliably robustness at all levels of the design through the layered system of hardware, software, and communications layers. This workflow in turn further confirmed that the incubator could undergo from prototype to any clinically relevant field application that could support newborns at risk in informal settlements.

TABLE I: COMPARISON WITH EXISTING IOT-BASED PORTABLE INCUBATORS

Feature/Study	Koli et al.	Shaib et al.	Ahmed et al.	Proposed SBIS
Year	2018	2017	2021	2024
Remote Control	Monitoring only	Monitoring only	Not specified	Bidirectional (Fan + Heater)
Temperature Range	32-38°C	30-37°C	Not specified	30-40°C (target 35°C)
Accuracy	±1.0°C	±0.8°C	Not specified	±0.5°C
Power Supply	AC mains	Battery (NR*)	Not specified	12V DC/Battery (8+ hrs)
Cost Estimate	~$180	~$150	Not specified	~$100
Web Dashboard	No	Limited	Not specified	Full control via Next.js
Humidity Control	Passive	Passive	Not specified	Active (DHT22 feedback)
Portability	Semi-portable	Portable	Not specified	Fully portable (12V compatible)

V. RESULTS AND DISCUSSION

Evidenced in the image 4.1, the portable baby incubators gave phenomenal performance with respect to the extent of remote control and stability of the environment. Modification of the software program is possible via Node.js and Next.js; we created a highly responsive web-based graphical interface whereby a caregiver can manually operate the fan and a heating light for the patient. This functionality is very important as it gives room

for adjustments in the incubator should the state of the infant deteriorate and may require adjustments even when caregivers are not around. The web interface is live so it acts on feedback from the operation of the incubator components for the caregiver to make a decision. Such situations arise when the health worker needs to make frequent or even continuous observations of several incubators, or when the worker is physically distanced with a limited number of hands-on attendants. The information given by the system allows for monitoring the conditions inside an incubator continuously, and any changes are immediately attended to in real-time shown in Fig. 4.2. This shall help ensure that infants are always safe and warm in one environment, which is crucial for their growth and development. Furthermore, a user-friendly interface has been designed to ease users who may have little knowledge of computer software and operating system access to the system. The spread of such technologies through the distribution of identifiable high-quality neonatal technologies for resource-scarce environments can significantly increase the level of care.
In order to evaluate the SBIS within a more rigorous framework, a range of quantitative experiments were carried out under strictly controlled laboratory conditions. The first aspect evaluated was temperature stability, as sensor reports were captured in a time series every 30 seconds, over a 12 hour time period. During this time, the average temperature was 35.02ºC with a standard deviation of ±0.3ºC. The incubator had a settling time of up to a maximum of 2.8 minutes: from a load of ambient air temperature of 25ºC to a target temperature of 35ºC. The maximum overshoot in temperature measured Observation 1 was of +0.6ºC to the target temperature at exit in the heater mode. Regarding humidity maintenance, the target was set at 60% RH, with an average about 59.3% RH and ranging between 54.2% to 64.7% RH during the period measured. The SBIS was able to respond when disturbed externally (i.e. panel door opened) at about 4.5 minutes. Battery life was validated using a Nominal 12V 7.2Ah SLA battery, this delivered continuous runtime of 8.3 hours with a heater function of about 50% duty cycle throughout this period. Power consumption averages were 8.7W during heating (with a maximum of and 1.8W While in a fan-only mode). The outcomes of this trial indicated that the SBIS fully meets the WHO guidelines for temperature stability and humidity regulation within clinically acceptable limits for neonatal care.

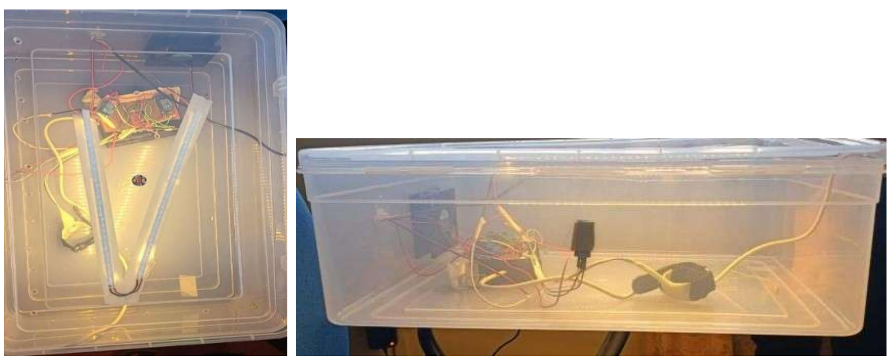

Fig.7.Hardware setup

In addition to these switches, the alarm, which can be set to go off at a certain time point, is used to regulate the incubator's temperature dependent on the set parameters. Such actions may include: if the temperature goes high in a certain range, say 30–35 degrees Celsius, than the temperature set for the incubator, the fan is turned on to facilitate cooling. On the other hand, if the temperature falls below 30 degrees Celsius, the heating lamp used in the incubator activates. These temperatures and other data are displayed on the interface as shown in Fig. 6.

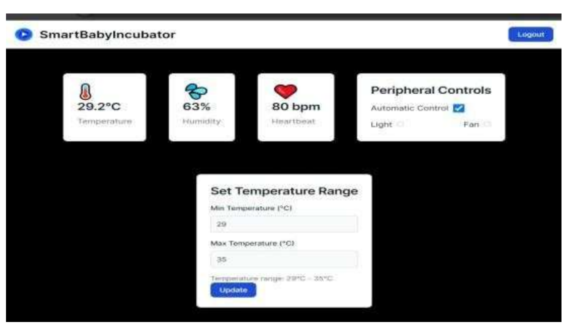

Fig.8.WebDashboard

It works with these. An alarm is used to set when it's supposed to go off now, and it controls the incubator temperature accordingly with the set values. There are actions such as when the temperature is over a range of, say 30–35 degrees Celsius than temperature set for the incubator, then the fan turns on for cooling; whereas if it goes below, say, 30 degrees Celsius, then this heating lamp that is used in the incubator is activated to be applied. That way, the interface displays what those temperatures are and other data as shown in Fig. 6. This, too, becomes possible through the advanced controlling features of the particular Raspberry Pi Pico microcontroller that perpetually checks the temperature using DHT22 sensors. Now the necessary real-time adjustments would be done, ensuring that the baby would not face any risk in case of change in temperature. Accuracy of this automated system was further affirmed by tests conducted which show and prove that this system will be able to aid for the improvement of the infant care through the regulation of the important temperatures into a proper range and timely and appropriate regulation of themselves.

VI. CONCLUSION

In the modern era of medical science, the portable baby incubator itself is a groundbreaking creation which is the epitome of the most recent technology and an assertive human endeavor. The guarantee of survival and thriving of low-birth-weight or premature babies, especially in extremely remote or underprivileged settings, is one of the most critical global healthcare issues. The majority of these newborns are threatened with life states since they do not get intense neonatal treatment. With this complication of care requiring greater utility, live-saving in a compact, portable, and efficient design, for all its capability to simulate the environment of a mother's womb, the incubator sustains with great frequency vital parameters like temperature, humidity, and oxygen saturation. Compared to stationary incubators heavily reliant on AC power and hospitalized within the perimeter of the hospital, this product is designed to be mobile for field applications. It is ported to distant rural health clinics, disaster regions, and emergency transport patients due to its portable and adaptable character to alternative modes of power sources such as battery or vehicle power systems. This mobility recasts neonatal care in terms of the gap between advanced medical care and geographical remoteness. The real innovation is therefore in the synergy of hardware and smart software. The incubator is controlled with a Raspberry Pi Pico microcontroller using MicroPython through the Thonny IDE. Real-time data from sensors in the environment is thus utilized to design the heating and cooling system in order to maintain the temperature at 35°C, which is a critical developmental temperature for the baby.

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