Grenze International Journal of Engineering and Technology, June Issue

Sustainable AI-Driven IoT Health Monitoring System with Hybrid Solar-Wind Energy for Proactive Care

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***Abstract*—Evolving surroundings presents a difficulty for continuous real-time bio sign monitoring in chronic care patients located in rural and remote areas, providing in-hospital facility ICU models. Conventional healthcare systems rely on infrequent check-ups and symptomatic emergency treatment, resulting in delayed management and unnecessary morbidities, a medical error, and otherwise avoidable complications. Furthermore, the unpredictability of energy sources in off-grid places reduces the performance and accessibility of these solutions. Therefore, we introduce an AI-Driven IoT Health Monitoring System, which utilizes a hybrid solar-wind energy arrangement in a large healthcare facility in rural areas. The system uses Body Sensor Networks (BSNs) to collect biometric data, such as heart rate, ECG, temperature, and motion, via wearable sensors. These data are processed with 90% accuracy by advanced AI algorithms such as XG-Boost, which detect irregularities and send real-time alerts to caregivers. This use of renewable energy reduces management operational expenses while ensuring performance reliability in remote places. It is modular in design, which allows for scalability applicable to both individual residences and large healthcare facilities. Merging AI, IoT, and renewable energy into one unique solution changes healthcare from a reactive to a proactive management system to improve patient outcomes, reduce costs, and ensure sustainability.**

***Index Terms*— AI, IoT, Health Monitoring, Hybrid Solar-Wind Energy, Sustainable Healthcare, Predictive Analytics.**

I. INTRODUCTION

Healthcare systems modernized in the 21st century must face several challenges, especially with regard to elderly, chronic-disease, and the underserved populations. Stressing continuous, proactive intervention to complicate issues as they arise, hamstrung by complication spurs, health monitoring in place at present is focused predominantly on intervention after a problem has matured and necessitated costly hospital admissions [1]. Furthermore, these systems still widely utilize GSM technologies, which are decidedly nefarious. The remote monitoring of patients within present healthcare practices is not there at all, which is one of the chief shortcomings of the present-day healthcare system-the absence of any real-time, continuous monitoring to catch anomalies in patients early [2]. Non predictive systems limit responses to emergencies when they are already at hand, which render them unavoidable and only amplify losses being themselves the example. An expensive mode of operation invariably means only a few can sustain access to a full range of services, especially in places with limited operability by power networks [3].

Grenze ID: 01.GIJET.11.2.599_1

Traditional healthcare systems depend on fossil fuels or other non-renewable sources of energy. This is indeed posing a challenge to sustainability efforts at the global level, not excluding health systems [4].
The proposed research outlines an AI-powered IoT-based Health Monitoring System, fed by hybrid solar-wind energy, which synergizes intelligent artificial intelligence, IoT, and green energies into one that enables real-time monitoring, anticipatory interventions, and sustainable expediency. The solution addresses crucial serious issues surrounding accessibility and environmental sustainability, which herald windows of opportunity for transformative health practices in modern-day healthcare.

II. ITERATIVE SURVEY

Hammed et al., [1] investigated how traditional feature selection methods collaborate with machine learning techniques to exploit the ability to detect autism. Their investigations emphasized that the feature selection must improve the performance of the machine-learning models by selecting the best attributes from the behavioral data and physiological data. This also enhanced the interpretability of the model and accuracy of diagnosis with better ASD detection systems emerging thereafter. Singh et al., [2] explores IoT potential to enhance remote healthcare monitoring and management by facilitating real-time data exchange between patients and healthcare professionals, promoting proactive care and alleviating conventional healthcare facility strains. Ahmadet et al., [3] presents an IoT-enabled health monitoring system using various sensors and cloud-based analysis with advanced algorithms (SVM, ANN, KNN, RNN) to predict patient health, achieving high accuracy and enabling proactive care with real-time data analysis. Krishnamoorthy et al., [4] proposed to optimize communication between IoT and HBC technologies to enhance health monitoring services and the framework accommodates a variety of sensors crucial for comprehensive health assessment, including temperature, EEG, ECG, heart rate, pressure, blood glucose, oxygen saturation, respiratory rate, and blood pressure sensors. Bhubaneswar et al., [5] presented IoT-based health monitoring system with AI-powered disease prediction enables accurate and timely illness prediction, improving healthcare and preventive treatment. Thakkar et al., [6] presented the Remote Patient Monitoring System utilizes IoT devices to continuously collect patient data, enabling real-time monitoring. This proactive approach allows healthcare professionals to assess vital signs and medication adherence, facilitating early intervention and personalized care to improve health outcomes. Analia et al., [7] proposed a COVID-19 patient management system using IoT, AI, and cloud, integrating wearable devices with deep learning to monitor vital signs, predict disease progression, and augment healthcare intelligence for proactive responses to health crises. Malik et al., [8] presents anIoT-based smart healthcare system integrating sensors, wearable devices, and data analysis to provide personalized healthcare services, improving patient outcomes, reducing costs, and advancing precision medicine through real-time monitoring and predictive analytics.
Kavitha et al., [9] proposed research delves into the advancement of intelligent healthcare infrastructure by integrating hospital equipment and leveraging IoT technology to optimize healthcare workflows and focuses on the integration of data analytics, machine learning, and artificial intelligence to extract practical insights from the data produced by IoT-enabled healthcare systems. Kumar et al., [10] explores the integration of IoT in healthcare, enabling remote patient monitoring through real-time tracking of vital signs, medication adherence, and wellness metrics, promoting timely interventions and personalized care while addressing security and privacy cancer.
The existing health monitoring systems depend chiefly on GSM-based technology to transmit health-related data collected from wearable or implantable sensors. These systems are reactive and often respond to health issues only upon the development of severe symptoms. Data transmission through GSM networks is slow and prone to uncertainties and delays, especially in emergencies, which might risk timely interventions. Grid-power or disposable batteries typically supply power to these systems. This is a largely unsustainable power source, raising operational costs and becoming a problem for environmental sustainability. Frequent recharging or replacing batteries may be cumbersome, especially in those portions of the world with very sparse and inconsistent electricity supply, thereby limiting originality, scalability, and reliability. Existing systems further fail to institute any advanced AI-driven algorithms, which are a moat for predictive analysis of health and proactive care. There remains a need for such systems to become completely interoperable and integrated with IoT devices to bring real-time monitoring and data sharing. Due to these challenges, healthcare delivery systems employed remain inefficient, leaving detection of anomalies frequently feigned until they burgeon into full-blown complications. Additionally, they don't address sustainability concerns by not utilizing the renewable energy solutions proffered through solar or wind. Their environmental credentials thus discredit any legitimate truly modern and sustainable health care appraisal in that they contribute to carbon emissions and e-waste.

III. Methodology

The proposed methodology would endorse an efficient and a more sustainable integrated care system for ICU with the help of the latest technology. It is shown in Figure 1.

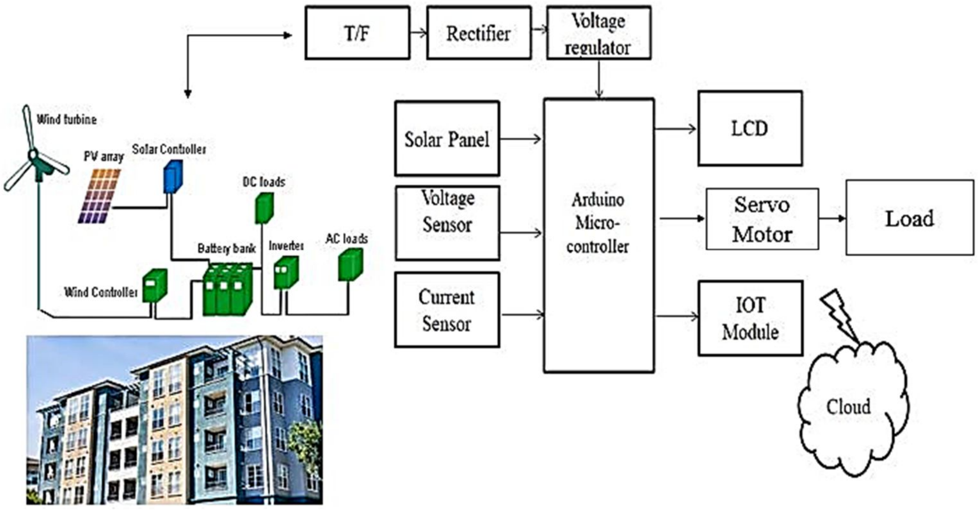

Figure 1. Hybrid Solar-Wind Energy System for Monitoring

The mother antennas surrounding hospitalized patients will establish a very secure connection to Form-factor modules. Inside the ICU, the system will monitor vital signs such as ECG, heart rate, temperature, and activity-permanent, which can be later communicated to the control unit via smart sensors. Once real-time data reaches the cloud on board IoT modules, a host of AI algorithms would analyze the collected data and look for abnormalities to notify the healthcare provider and inform him for timely decision-making. For sustainability, it is a hybrid energy solution that encompasses solar panels and wind turbines. Energy controllers manage power generation and assist in storing energy in batteries to provide uninterrupted power supply for hospital operation. A secure web interface gives doctors and nurses access to real-time patients' data all around the facility, increasing efficiency. The system shall be commercialized after effective testing and thus used as a scalable and sustainable approach in ICU healthcare delivery.

A. System Architecture

This system's development incorporates a refined strategy for energy consumption via the deployment of an Advanced Hybrid Energy Power Source, coupled with an Artificial Intelligence-Driven Health Monitoring System for ICU patients, ensuring optimal energy resource utilization and efficient healthcare service delivery.

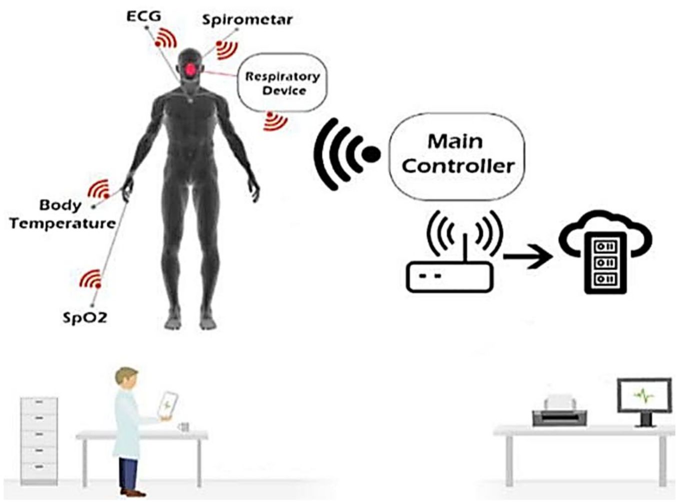

Figure 2. Structure of IOT Health Monitoring

A sequence of transformers, rectifiers, and voltage regulators manage the system's novel energy source, which integrates wind turbines and solar panels. Voltage and current measurements are conducted using sensors that transmit data to an Arduino microcontroller, which then charges batteries and displays the information on an LCD screen. An IoT module gathers real-time energy usage data and transmits it to the cloud, facilitating remote monitoring and effective management. The health monitoring system uses wearable body sensors for patients, Peter. Which enables continuous data collection for the particular patient's ECG, pulse rate, temperature, and motor activity. The acquired data is transferred to the cloud via IoT modules, while algorithms powered by artificial intelligence filter and analyze the data in real time. When these algorithms detect any irregularities, they create notifications that may be quickly viewed by physicians and other healthcare professionals via a secure web interface. This combination strategy ensures the patient's continuing functioning under ICU monitoring while also permitting the provision of sustainable energy and the integration of AI technologies. It improves patient outcomes by providing real-time information. It improves patient outcomes by providing real-time surveillance and deep patient insights using artificial intelligence while also reducing the footprint of healthcare infrastructure, making it more sustainable. The component of the proposed systems are as follows.

B. Sensor

A wearable sensing module monitors key health metrics such as ECG, heart rate, body temperature, and movement. These sensors aim to track health over the long run, providing real-time updates from users. The team developed the sensors to provide accurate and trustworthy reading of a patient's state. The module also pairs with a microcontroller that processes the data and sends it to cloud storage for thorough analysis and secure storage.

C. Data Pre-processing

The data processing module collects raw data from the sensor module via the microcontroller within no time, thus sending the data to the cloud. However, filtering, encoding, and compressing the data into small packets provide a performance gain in data transfer across the network. The output is almost singularly when the signals from the sensor become, to start with, information sent downstream for processing and evaluation for AI purposes. This technology maintains a continuous stream of data with no latency and enables real-time health monitoring and the first step in anomaly detection.

D. AI filter

The AI Filter Module applies advanced artificial intelligence algorithms for the analysis of health data from sensors. It filters and processes that data in real-time, breaking down it into patterns, citing anomalies with utmost precision. This module will increase the credibility of such a monitoring system by reducing the number of false positives and ensuring reliable detection of anomalies. It functions in the cloud or local processing unit for speedy decision-making in cases of emergency alerts. The AI filter processes these health insights, enabling information-based proactive care and timely medical intervention.

E. Renewable Energy

The renewable energy promises a continuous source of power for the system also through solar panels and wind turbines. These are able to easily harness, store and convert renewable energy into electricity, thus reducing dependence on conventional sources of energy. This module is designed to increase energy efficiency and provide uninterrupted power supply especially in the remote areas. The module is ecologically conscious and operates on clean energy to ensure the reliability and sustainability of the health monitoring system

F. User Interface

The user interface module presents a safe and friendly platform for real-time access to the patient's health information. It is oriented towards healthcare professionals and caregivers and displays vital signs, trends, and alarms on user-friendly dashboards, accessed via smartphones, tablets, or desktops. This module assures data privacy via encryption and safe authentication. The module allows users to record the health status of their patients, analyze past data, and act promptly against abnormal situations. The interface is very flexible, allowing customizable graphics and notifications to help one in making informed decisions with respect to healthcare management.

G. Alert

Whenever any deviation is detected from expected values in patient health data, the Alert Module sends out a timely notification to the user. Through AI analysis and real-time monitoring, the Alert Module identifies urgent health circumstances and alerts caregivers and healthcare professionals through SMS, email, or notifications. Depending on the need, it also provides information about the irregularity and location of the patient for takedown.

H. Sensor Data Acquisition Models

Heart Rate (HR) Calculation from PPG (Photoplethysmogram) Sensor. The heart rate is estimated based on peak detection in the PPG signal is shown in equation (1).

$$HR = \frac{60 \times f_s}{N} \tag{1}$$

Where:

- fs = Sampling frequency (Hz)
- N = Number of samples between successive peaks

I. Blood Pressure (BP) Estimation using Pulse Transit Time (PTT)

The blood pressure can be estimated using the pulse transit time method is shown in equation (2).

$$BP = k_1 + k_2 PTT^{-1} \tag{2}$$

Where:

- PTT = Time difference between ECG R-wave and corresponding PPG peak
- k_1, k_2 = Calibration constants

J. Oxygen Saturation (SpO_2) Estimation

Using red and infrared light absorption from a pulse oximeter is shown in equation (3).

$$SPO_2 = A - B \times \left(\frac{R}{IR}\right) \tag{3}$$

Where:

- R = Red light absorption
- IR = Infrared light absorption
- A, B = Empirical coefficients

K. Wireless Data Transmission (IoT Communication Model)

For transmitting health data over Wi-Fi/Bluetooth/5G, the required Signal-to-Noise Ratio (SNR) is given in equation (4).

$$SNR = \frac{P_{signal}}{P_{noise}} \tag{4}$$

K. Data transmission rate (Shannon Capacity)

For transmitting health data over Wi-Fi/Bluetooth/5G, the required Signal-to-Noise Ratio (SNR) is given in equation (5).

$$C = Blog_2(1 + SNR) \tag{5}$$

Where:

- B = Bandwidth (Hz)
- C = Channel capacity (bits per second)

Figure 3 is the visual representation of AI-driven IoT health monitoring system powered by hybrid solar-wind energy. It is described as follows.

L. Mointoring Status

Power Generation over 24 hours shows the contribution of solar (orange) and wind (blue) energy. Solar peaks at midday, while wind fluctuates throughout the day. Health monitoring trends displays variations in heart rate (red), blood pressure (green), and SpO_2 (purple) over time. These trends can help in AI-driven anomaly detection.

M. Analysis

Healthcare systems worldwide are evolving to address the growing demand for efficient and sustainable healthcare solutions. Traditional health monitoring methods face challenges such as accessibility, reliability, and affordability. The convergence of AI and IoT has opened new avenues in remote health monitoring by offering real-time health tracking and predictive analysis. However, energy constraints limit the efficiency and reliability of these systems, particularly in rural areas. This paper explores an AI-driven IoT health monitoring system powered by hybrid solar-wind energy, ensuring sustainability and reliability.

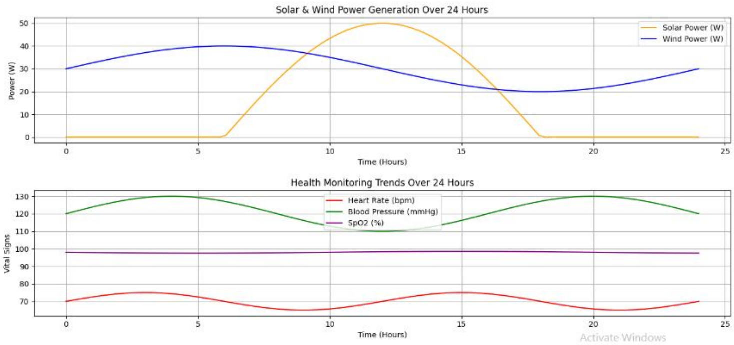

Figure 3. Power Generation

C. IoT-Enabled Wearable Devices

Sensors integrated into wearable devices continuously collect health metrics such as heart rate, blood pressure, oxygen levels, and body temperature.

D. AI-Driven Analytics

Machine learning algorithms process and analyze the collected data to detect abnormalities and predict potential health risks.

E. Hybrid Solar-Wind Energy Source

A combination of solar panels and wind turbines ensures uninterrupted power supply, making the system sustainable and independent of traditional electricity sources.

IV. Simulation

The simulation details are as follows.

A. AI-Driven Health Monitoring

AI plays a crucial role in the proposed system by analysing large volumes of health data, identifying patterns, and predicting health conditions. The system incorporates:

B. Predictive Analytics & Automated Alerts

AI models forecast potential health issues based on historical and real-time data. Patients and healthcare providers receive instant alerts for abnormal health conditions. AI suggests lifestyle and medical interventions tailored to individual needs.

C. Hybrid Solar-Wind Energy System

A hybrid solar-wind system is implemented to ensure uninterrupted power supply. Key features include the following and are shown in Figure 4.

- Solar Panels: Harness sunlight to generate electricity during the day.
- Wind Turbines: Generate power from wind energy, particularly useful during cloudy or nighttime conditions.
- Energy Storage System: A battery backup stores excess energy for use during low generation periods.

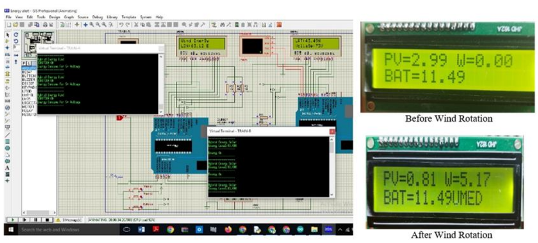

Figure 4. Arduino Simulations of Hybrid Solar-Wind Energies Monitoring System

TABLE I. HYBRID ACCESS MODEL FOR HEALTH CARE SYSTEM

Hybrid Access	Hybrid Access Model for Health Care System		
	Resources Models	**Approach**	**Medical System**
Value	Devies Model	Values	Results
Wearable Sensors	Smart IoT Devices	Continuous Data	Real-time Monitoring
AI Algorithms	Machine Learning	Predictive Models	Accurate Health Alerts
Energy Source	Solar-Wind Hybrid	Renewable Energy	24/7 Power Supply
Healthcare Access	Remote Monitoring	Global Coverage	Improved Accessibility
Cost Efficiency	Sustainable Model	Lower Expenses	Affordable Healthcare

The integration of AI and IoT with a hybrid solar-wind energy system presents a groundbreaking solution for sustainable and proactive healthcare. As shown in Table I, the proposed approach ensures continuous health monitoring, timely medical interventions, and accessibility to healthcare services, particularly in remote regions. By leveraging renewable energy, the system contributes to environmental sustainability while providing cost-effective and reliable healthcare solutions.

V. CONCLUSION

During these days, real-time patient monitoring, predictive analytics powered by artificial intelligence, and renewable energy in healthcare is expected to revolutionize the industry. Continuous health monitoring can lead to early detection of diseases and alert for attendant emergencies and can thus reduce the burden on the hospital systems. The work improves sustainability, making the hybrid solar-wind energy system suitable for use in remote and off-the-grid health centers. Edge the security of block chain, and telemedicine will strengthen this efficacy with guaranteed safety and effortless access to citizen health in future events. Smart health plus green energy goes for a bright future, healthier and sustainable health ecosystem.

REFERENCES

[1] UN, “World Population Aging 2013,” 2013, pp. 8–10.

[2] R. Weinstein, “RFID: A technical overview and its application to the enterprise,” IEEE IT Prof., vol. 7, no. 3, pp. 27–33, May/Jun. 2005.

[3] P. Gope, T. Hwang, “Untraceable Sensor Movement in Distributed IoT Infrastructure,” IEEE Sensors Journal, Vol. 15 (9), pp. 5340 – 5348, 2015.

[4] P. Gope, T. Hwang, “A Realistic Lightweight Authentication Protocol Preserving Strong Anonymity for Securing RFID System,” Computers & Security (Elsevier Journal), Vol. 55, pp. 271–280, 2015.

[5] P. Kumar, and H. Lee, “Security Issues in Healthcare Applications Using Wireless Medical Sensor Networks: A Survey.” Sensors (Basel, Switzerland) 12.1 (2012): pp. 55–91.

[6] D. Malan, T. F. Jones, M. Welsh’s. Moulton, "Code Blue: An Ad Hoc Sensor Network Infrastructure For Emergency Medical Care," Proceedings of the MobiSys 2004 Workshop Applications of Mobile Embedded Systems (WAMES 2004); Boston, MA, USA. 6–9 June 2004.

[7] K. Lorenz, D. J. Malan, T. R. F. Fulford-Jones, A. Nawoj, A. Clavel, V. Shayder, G. Mainland, M. Welsh, "Sensor Networks for Emergency Response: Challenges and Opportunities", Pervas. Comput. vol.3, pp.16–23, 2004.

[8] A. Wood, G. Virone, T. Doan, Q. Cao, L. Salvo, Y. Wu, L. Fang, Z. He, S. Lin, J. Stankovic, "ALARM-NET: Wireless Sensor Networks for Assisted-Living and Residential Monitoring," Department of Computer Science, University of Virginia; Charlottesville, VA, USA: 2006. Technical Report CS-2006-01.

[9] S. Pai, M. Meingast, T. Roosta, S. Bermudez, S. Wicker, D. K. Mulligan, S. Sastry, "Confidentiality in Sensor Networks: Transactional Information," IEEE Security and Privacy Magazine. 2008

[10] J.W.P. Ng, B.P.L Lo, O. Wells, M. Sloman, N. Peters, A. Darzi, C. Toumazou, G. Yang, "Ubiquitous Monitoring Environment for Wearable and Implantable Sensors (UbiMon)," Proceedings of 6th International Conference on Ubiquitous Computing (UbiComp’04); Nottingham, UK. 7–14 September 2014.