Journal of Current Research in Engineering and Science
JCRES
Bi-Annual Online Journal ( ISSN: 2581 - 611X )

VOLUME:8, ISSUE:1, FEBRUARY 2025, PAPER NUMBER:28

# INTEGRATING IOT AND AI FOR AN ADVANCED INFUSION MANAGEMENT SYSTEM

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**Abstract:** In this paper, we develop an IoT-enabled dual-channel syringe pump that fulfills its intended function and integrates patient monitoring and semi-automatic adaptive infusion control, wherein decisions are made based on parameters and findings obtained from the monitoring process. Providing a syringe pump with these capabilities enhances patient safety and the efficiency of the device. Moreover, with these advanced analytics and data-driven insights, we can have personalized infusion management, remote accessibility, and real-time monitoring. To achieve this, we have proposed an IoT-based syringe pump with dual channels, sensors for the patient's vital or physical monitoring, and an ML model to keep track of his/her mental condition. Based on these insights presented on a web interface, the device is capable of making informed decisions for infusion control. Having performed extensive experiments, we have crafted an initial model for the proposed design and functionalities. This model comprises two programmable syringe drivers for infusion, monitoring capabilities for 4 physical body parameters, and a compact emotion model that achieves an impressive validation accuracy of 95%, provided the sentence length is greater than 4 to 5 words.

***Index terms:*** IoT-based Syringe Pump, Patient Monitoring, Vital Parameters, PMS, Piggyback Infusion, Web Application / Web Interface, Emotion Detection Model, Semi-Automatic, Alert System, Adaptive Infusion Control

## I. INTRODUCTION

A syringe pump is a medical device utilized for intravenous administration, delivering fluids, medications, or nutrients into a patient's circulatory system [9]. The purpose of developing and implementing this product is to provide a steady and regulated rate of infusion for critical fluids, including high-risk medications. Due to the possibility of medications having undisclosed side effects or being incompatible with a patient's body, which may result in other adverse reactions, such as fever and so forth [1]. Therefore, it is essential to monitor the patient's condition during the administration of such medications [1]. The FDA has reported several issues, including alarm errors, human factors, broken components, and other factors that result in the loss of human lives or lead to severe consequences. Incorporating new technologies, such as the Internet of Things (IoT), cloud computing, analytics, and AI and machine learning, manufacturers are revolutionizing their products. This integration aligns with the industry 4.0 era [10], implementing them into healthcare and medical devices helps us to achieve enhanced patient safety, accuracy, and efficiency. Through these advancements, we can mitigate human errors in patient care, and obtain wireless updates on the patient's vital condition, infusion details, and much more.

### A. Motivation

The motivation behind undertaking this research stems from the critical need to address the challenges faced in current healthcare systems concerning medication administration and patient safety. The potential risks associated with undisclosed side effects of medications and the human factor involved in manual monitoring necessitate a smarter, more efficient solution. The goal of this research is to bridge the gap between traditional medical devices and modern technology driven healthcare solutions.

### B. Application Scenario

Index Terms—IoT-based Syringe Pump, Patient Monitoring, Vital Parameters, PMS, Piggyback Infusion, Web Application / Web Interface, Emotion Detection Model, Semi-Automatic, Alert System, Adaptive Infusion Control.

### C. Contributions

This research paper delves into the exploration of recent advancements in the syringe pump with a focused objective of implementing innovations and ideas to enhance the efficiency, accuracy, and overall capabilities of existing medical systems. Innovative features facilitate swift response and ensure precise and secure medication administration in healthcare environments. In this context, three crucial contributions of this paper stand out.

- The paper introduces a machine learning-trained model integrated into the patient vital monitoring system, enabling real-time monitoring of a patient's mental health during the infusion process with an accuracy rate of 95
- The ML model is efficiently designed with a compact size of 45.2 MB, allowing seamless integration into existing healthcare systems, thereby contributing to enhanced patient safety and personalized care during medical treatments.
- Leveraging the patient vitals data and emotion detection capabilities, the device demonstrates autonomous decision-making abilities, promptly alerting healthcare professionals through an alert box or message system. These informed decisions include the option to halt the ongoing infusion in the event of abnormalities or adverse reactions, as well as the capability to seamlessly switch to a pre-set secondary infusion, thereby ensuring patient safety and precise medication delivery during critical situations.

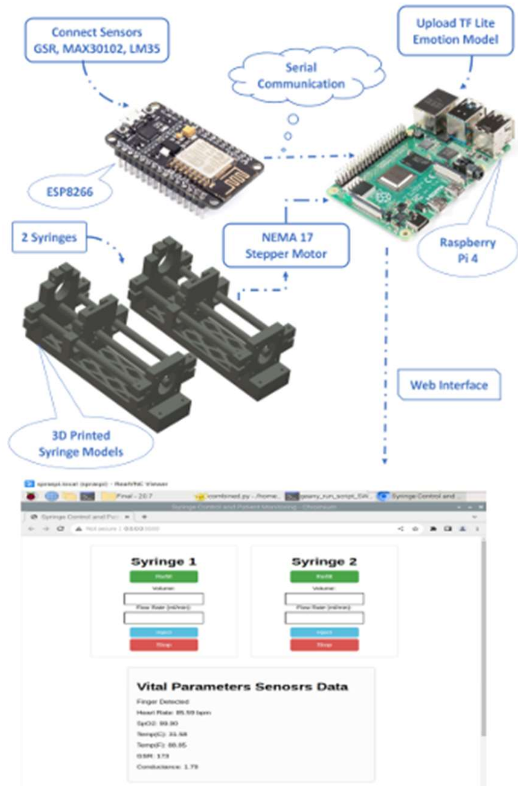


**Figure 1: Basic Architecture of the Proposed System**

## II. HISTORY & RESEARCH

The roots of syringe pumps can be traced back to as early as 1658 when Christopher Wren devised the first model to achieve a consistent and controlled infusion rate. However, due to the technical limitations of that era, its usage was restricted by the government. The advent of modern syringe pumps began in the 1950s with the introduction of the Harvard Apparatus Model 500, primarily designed for chemotherapy administration. Since then, the field has seen remarkable progress. In the 1970s, computerized syringe pumps emerged, followed by miniaturized pumps in the 1980s. Wireless connectivity was introduced in the 2000s, allowing seamless integration with electronic medical records, and in the 2010s, smart infusion pumps featuring intuitive touchscreen interfaces became prevalent. Numerous research endeavors have further expanded the capabilities of syringe pumps:

- Researchers have successfully integrated laser sensors into syringe pumps to monitor intravenous drips and provide timely alerts upon completion of infusions [12].
- Others have focused on developing web-based interfaces for remote monitoring and control of infusions, offering greater flexibility and convenience to medical professionals [10][9][7].

• Notably, the integration of patient monitoring data into the infusion process has significantly enhanced patient safety compared to traditional methods [1].

## III. METHODOLOGY

### A. Problem Statement

Current healthcare systems rely on separate and conventional syringe pumps and patient monitoring systems, resulting in limited real-time data analysis and automated decisionmaking capabilities. This lack of integration and intelligent devices poses potential inefficiencies and risks to patient care. Therefore, the primary objective of this paper is to address these limitations and enhance patient safety, optimize medication delivery, enable automated decision-making, and ultimately improve the efficiency of the syringe pump system.

### B. Proposed Solution

To address the aforementioned problem statement, we present our solution: an IoT-based Syringe pump that leverages pre-set automated decision-making capabilities, utilizing data from vital parameter sensors and an ML-trained Emotionmodel. This innovative approach aims to significantly improve patient safety by minimizing human errors and expediting response times compared to manual interventions by nurses. With continuous monitoring of patient's health and timely necessary updates to healthcare professionals through a web interface.

Key features of the proposed IoT-based Syringe pump:

• Seamless integration of vital sign sensors and the syringe pump for real-time data synchronization and analysis.

• Machine learning-driven Emotion model for emotion recognition, allowing the system to consider patients' emotional states in medication administration decisions.

• Customizable automated decision-making rules to accommodate different patient profiles and medical conditions.

### C. Preliminary

**1) Assumptions:** In this project, we assume a strong focus on data security through robust cybersecurity methods and the implementation of strong firewalls to prevent unauthorized breaches. With these security measures in place, our primary focus is on the integration of sensors, implementation of machine learning models, and utilization of edge computing. These aspects enable us to interconnect sensors and syringe pumps efficiently, collect, process, and analyze medical data in real time, and ensure responsive decision-making capabilities for medical applications.

**2) Methods Used to Solve:** The proposed system employs two stepper motors to control the infusion rate, with a microprocessor providing commands to these motors. Sensors are utilized to gather data, which is then processed by a microcontroller. The processed data is sent to the microprocessor and displayed on the web interface accessible to healthcare professionals. Additionally, a USB microphone is used to capture the patient's emotions and track relevant emotional data.

Methods used in the solution:

• Utilization of edge computing for on-device data analysis to reduce latency and enhance real-time decision-making capabilities.

• Trained model used for emotion recognition with accuracy and adapt to diverse patient emotional profiles.

• Integration of audio capture to perform emotion recognition.

## IV. EXPERIMENTAL SETUP

### A. INPUTS

The system is fed with three main inputs: a pre-defined infusion table containing medication details for the pump, sensors for gathering vital data, and a microphone for voice input. Additionally, a table of potential conditions during the infusion process is provided, along with pre-set rules for the system to respond appropriately to each scenario. These rules facilitate the automation of the device, ensuring efficient and accurate management of medication infusion and patient care.

**Table 1**

Drugs Administered via Syringe Pump

| Drug | Conc. | Dosage | Type of Drug | Symptom |
|---|---|---|---|---|
| Diamorphine | /10mg | -10mg | Opioids | Pain |
| Oxycodone | 10mg/1ml | 5mg | Opioids | Pain |
| Diclofenac | 75mg/3ml | -150mg | Opioids | Pain |
| Cyclizine | 50mg/1ml | -150mg | Anti-Emetics | Nausea |
| Haloperidol | 5mg/1ml | -5mg | Anti-Emetics | Nausea, Agitation |
| Midazolam | 10mg/2ml | -10mg | Sedatives | Seizures |
| Morphine | 10mg/1ml | 1ml/hr | Sedatives | Seizures |

The basis of our work involves creating a table that includes medications administered through infusion or syringe pumps. This is an example of some of the drugs that are intended for in-patients and are given over a 24-hour period. Various symptoms may indicate that the infused medication is being rejected by the body, including cough, fever, chills, headache, itching, muscle or joint pain, nausea, rashes, shortness of breath, and swelling of hands or legs, among others. These symptoms play a crucial role in determining whether to halt the infusion and make other decisions. The sensors come into action to capture these symptoms accurately. Depending on the symptoms observed, predefined decision sets can be employed to guide the appropriate course of action. Here are several examples of potential effects that can occur during the infusion process, along with corresponding actions that can be taken to address them.

**Table 2**

Effects v/s Actions

| Adverse Effect | Vital Sign Changes | Actions |
|---|---|---|
| Infection | Inc. Temp, Inc. HR, Inc. RR | Stop infusion, administer Antibiotics |
| Allergic Reaction | Inc. Temp, Inc. HR, Dec. BP | Stop infusion, administer steroids or antihistamines |
| Fluid Overload | Inc. BP, Inc. RR, Dec. SpO_2 | Slow or Stop infusion, administer diuretics |
| Low Blood Pressure | Dec. BP, Inc. HR | Slow or stop the infusion, administer fluids or medicine to inc. BP |
| Air Embolism | Dec. BP, Inc. HR, Dec. SpO_2 | Stop infusion, place the patient in left lateral decubitus position, administer oxygen |
| Phlebitis | Redness, swelling, and tenderness at the infusion site, Inc. Temp | Stop infusion, apply warm compresses to the affected area |
| Extravasation | Swelling, redness, and pain at the infusion site, Inc. Temp | Stop infusion, administer an antidote if available, apply cold compresses to the affected area |
| Hematoma | Swelling and bruising at the infusion site, Inc. Temp | Stop infusion, apply pressure to the affected area |

Furthermore, the utilization of sensor data alongside tabular information is crucial for gaining a holistic understanding of the patient's physical and mental conditions during the infusion process. This enables the system to make well-informed decisions and take appropriate actions based on the real-time patient state. The incorporation of a speech recognition library to process audio data proves to be a valuable addition, as it facilitates the prediction of patient emotions, allowing for a more comprehensive assessment of their well-being and emotional state. The combination of diverse datasets, acquired from reputable platforms like Kaggle and Google, ensures a rich and varied set of training examples. The supplementation of each emotion class with 100 to 200 relevant keywords further enriches the dataset and helps capture subtle nuances associated with different emotions. The achieved training accuracy of 85% and validation accuracy of 95% demonstrate the effectiveness of the ML model in comprehending emotions from textual content, making it a robust tool for emotion prediction and analysis during the infusion process.

## B. HARDWARE IMPLEMENTATION

The hardware implementation showcases a well-integrated setup comprising microcontrollers, sensors, motor drivers, and a 3D printed model for precise fluid delivery. The ESP8266 microcontroller serves as the central hub for data collection from sensors like the MAX30102 heart rate sensor, LM35 temperature sensor, and GSR sensor, while the Raspberry Pi 4 microprocessor handles advanced processing and emotion recognition using a pre-trained TensorFlow Lite model. The NEMA 17 stepper motor, controlled by the A4988 motor driver, ensures accurate fluid delivery, while the CD74HC4067 analog multiplexer enables seamless data Acquisition from multiple sensors. The system's ability to handle different syringe volumes and real-time emotion recognition empowers healthcare environments with intelligent and data-driven decision-making capabilities, promising safer and more personalized patient care.

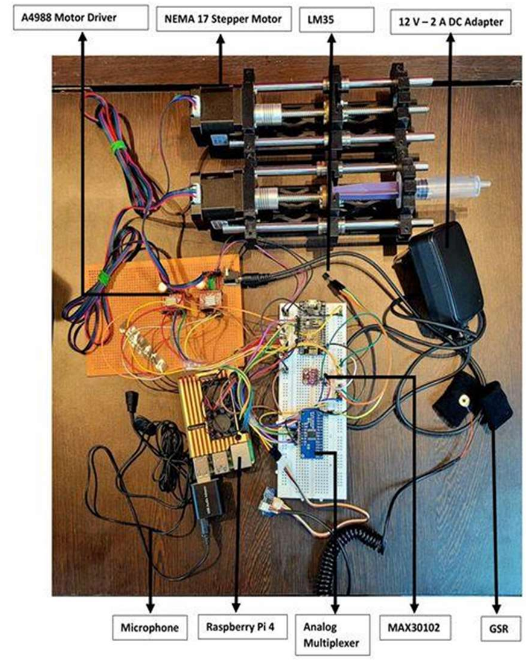


**Figure 2: Hardware Setup of the Proposed System**

Figure 3 illustrates the 3D model elements responsible for securing the syringe and motor, along with a slider designed to facilitate the discharge of fluids from the syringe. The design for these components is sourced from the online platform Thingiverse. The components are 3D printed and assembled using nuts and bolts. After attaching the motor, the syringe is placed in position, and experiments can be conducted.

The circuit diagram of the proposed system, which was created using the Fritzing app —an open-source platform designed for generating electronic circuit diagrams. The diagram effectively illustrates the interconnections between various hardware components within the system. The colors of the wires hold significant meaning.

• Red: Represents Power (5 or 12 V). 12V is used for the motor driver to run the motor, while 5V serves as the input voltage for all other sensors and a microcontroller connected to it.

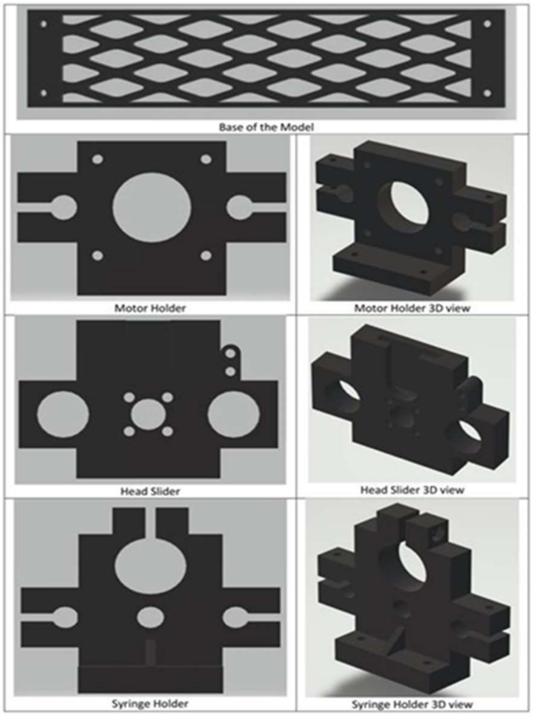


**Figure 3: Detailed breakdown view of the 3D model components**

- Black: Represents ground connections.
- Blue: Used for analog signals.
- Green: Represents I2C communication.
- Brown: Represents the binary signal sent to control the selection of the channel of the analog multiplexer.
- Gray: Represents the control sent to the A coil in the stepper motor.
- Pink: Represents the control sent to the B coil in the stepper motor.
- Orange: Direction signal for the motor drive

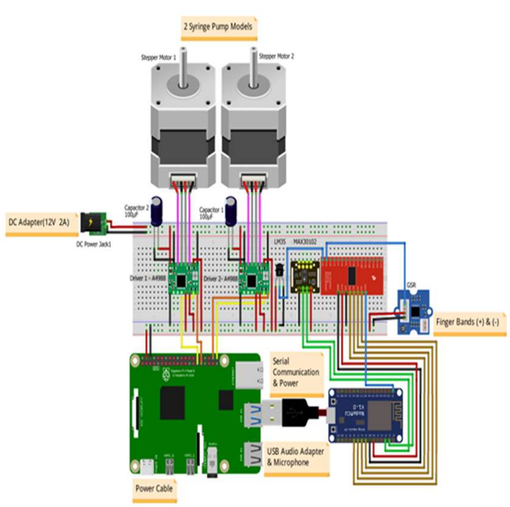


**Figure 3: Circuit Diagram for the proposed system**

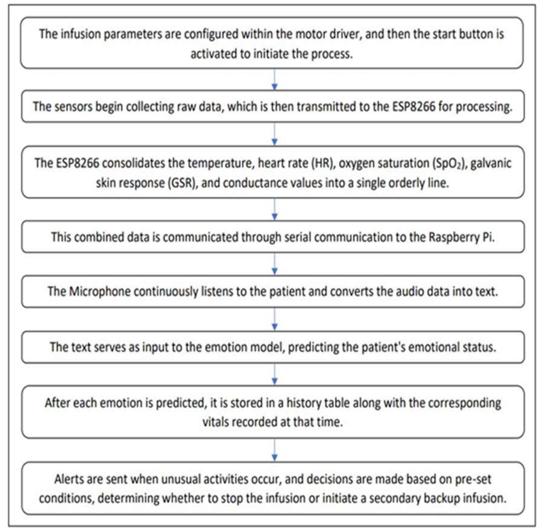


**Figure 4: Process flow of the overall system**

**C. OUTPUTS**

The setup provides essential patient data, emotional status, and infusion parameters. These are recorded in a history table whenever emotions are detected, focusing on four specific emotions: happy, sad, anxious, and neutral. This simplified classification allows for efficient patient monitoring and targeted treatment when necessary. The sensor outputs consist of the following:

- **Temperature** The body temperature is sensed and recorded in both degrees Celsius and Fahrenheit. Measurement is taken at the fingertip for the demonstration.
- **Heart Rate** Also known as pulse rate, the heart rate is measured and expressed as BPM (Beats per Minute). The microcontroller is programmed to alert in cases of tachycardia, which is a high heart rate defined as above 100 BPM at rest, and bradycardia, a low heart rate defined as below 60 BPM at rest.
- **SpO2** (Blood Oxygen Saturation) SpO2 refers to peripheral capillary oxygen saturation, a measure of the oxygen-carrying capacity of hemoglobin in the blood. It is expressed as a percentage and represents the level of oxygen saturation in the bloodstream. Monitoring SpO2 is critical in assessing the respiratory and cardiovascular health of patients, particularly during infusions and other medical procedures.
- **GSR** (Galvanic Skin Response) GSR, also known as electrodermal activity (EDA) or skin conductance, is a measure of the electrical conductance of the skin, which changes in response to emotional arousal and sweating. It is often used as an indicator of emotional and physiological responses to stimuli.
- **Human Skin Conductance** It is the ability of the skin to conduct electricity. It is closely related to GSR and is measured to assess the level of emotional arousal and stress experienced by an individual. Changes in skin conductance can indicate variations in emotional states.

The ML model plays an important role in predicting patient emotions based on audio inputs that are converted into textual inputs, while the integrated sensors continuously collect vital data such as body temperature, heart rate, GSR (Galvanic Skin Response), and SpO2 (Blood Oxygen Saturation). This information is collected to create a comprehensive history table, enabling the system to track and monitor the patient's physical and mental health during infusion. These efforts result in a final output that provides a concise yet detailed overview of each infusion session, offering valuable insights into the patient's emotional state, physiological responses, and overall well-being.

## V. RESULTS

The system's web interface offers real-time access to live sensor data, infusion progress, and patient vitals, enabling medical personnel to closely monitor the infusion process and the patient's health status. The emotion prediction section provides valuable insights into the user's emotional response during the system's operation. The successful integration of diverse functionalities and the user-friendly web interface showcases the system's potential for practical implementation and positive impact in healthcare settings, empowering medical professionals with efficient infusion control and valuable emotional monitoring capabilities.

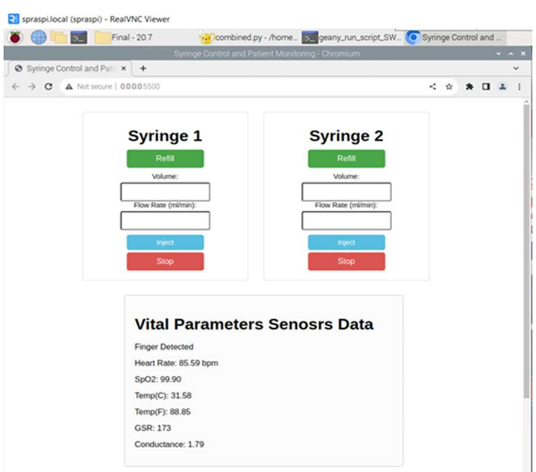


**Figure 5: Web interface displays live sensor data and infusion progress during operation.**

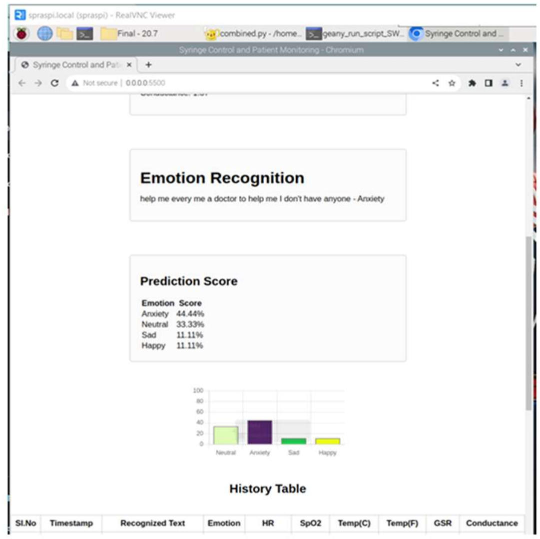


**Figure 6: The web page section for emotion prediction, obtained through the analysis of audio inputs.**

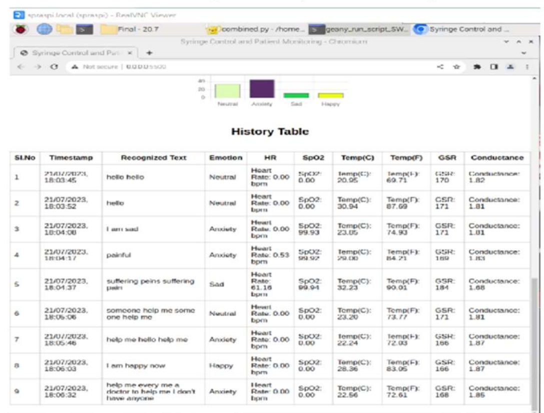


**Figure 6: The history table includes both the patient's vitals and emotional status data during the infusion process.**


**Figure 6: Alert message triggered during the infusion process.**

## VI. CONCLUSION

In conclusion, this research introduces an innovative IoT-enabled dual-channel syringe pump that integrates patient monitoring and informed automatic adaptive infusion control. The system's advanced analytics and data-driven insights enable personalized infusion management and real-time monitoring, while the compact emotion detection model enhances mental health monitoring during infusions. With autonomous decision-making capabilities, the device ensures precise medication delivery and patient safety. The syringe pump represents a significant advancement in healthcare technology, offering a smart and efficient solution for critical care settings, validated by promising experimental results.

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