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Design and Implementation of Arduino Based Low-Cost Ventilator Using Self Inflating Bag

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Annotation: The global demand for cost-effective and accessible medical ventilators has increased significantly, especially in response to respiratory illnesses like COVID-19. This study explores the development of a DIY ventilator using Arduino, a microcontroller-based open-source platform. The proposed system integrates sensors, motors, and control algorithms to regulate airflow and maintain respiratory parameters within clinically acceptable ranges. By leveraging low-cost components and open-source hardware, this project aims to provide an affordable alternative for resource-limited settings. The paper discusses the design, implementation, and potential limitations of the system, emphasizing the importance of safety measures, reliability, and adaptability for different patient needs. While DIY ventilators cannot replace certified medical equipment, they present an innovative approach to emergency respiratory support and biomedical engineering education.

Keywords: Low-cost ventilator. Arduino Nano. AMBU bag automation. Respiratory support. MAX30100.

1. Introduction

Mechanical ventilators play a crucial role in modern healthcare by providing respiratory support to patients suffering from severe respiratory conditions, such as acute respiratory distress

syndrome (ARDS) and complications from diseases like COVID-19. However, the high cost and limited availability of commercial ventilators pose significant challenges, especially in resource-limited settings and during global health crises.

In response to this challenge, the integration of open-source hardware and low-cost electronic components has emerged as a promising solution. This study explores the development of a DIY ventilator using Arduino, an open-source microcontroller platform known for its flexibility, affordability, and ease of use. The project aims to create a functional ventilator capable of delivering controlled airflow and monitoring essential respiratory parameters while maintaining a simple and cost-effective design.

This paper discusses the design, construction, and functionality of the proposed Arduino-based ventilator, highlighting key components such as sensors, actuators, and control algorithms. Additionally, it examines the system's limitations, safety considerations, and potential applications in emergency situations. By leveraging open-source technology, this work contributes to ongoing efforts to develop accessible and adaptable medical solutions for global healthcare challenges.

2. Components of the respiratory system

2.1 Arduino Nano

Arduino Nano is a compact microcontroller board based on the ATmega328, designed for electronics projects and embedded systems. Its small size and ease of use make it ideal for space-constrained applications. It features 14 digital input/output pins, including 6 PWM pins, and 8 analog inputs, operating at 5V. Programming is done via the Arduino IDE using a Mini USB connection. It supports UART, I2C, and SPI communication for interfacing with sensors and other components. Unlike the Arduino Uno, it lacks a DC power jack but can be powered through USB or an external 5-12V source. It is widely used in robotics, IoT applications, and automation projects. With low power consumption, it is suitable for portable devices and small-scale projects.

Fig (1): Arduino Nano.

2.2. Lcd Display20x4

The 20x4 LCD display is a liquid crystal display module that can show 20 characters per line across 4 lines, making it ideal for projects that require displaying more information at once compared to smaller LCDs (such as 16x2). It is commonly used in embedded systems, Arduino projects, and industrial applications due to its readability and ease of interfacing.

Fig (2): Lcd Display20x4.

2.3.10k Port

A 10K potentiometer (10K Pot) is a variable resistor with a resistance of 10,000 ohms (10KΩ). It is commonly used for adjusting voltage levels, controlling signal strength, and tuning circuits in electronic projects.

Fig (3): 10k Port.

2.4. Push button

A push button is a simple switch used to make or break an electrical connection when pressed. It is commonly used in electronic circuits, Arduino projects, and control systems for user input.

Fig (4): Push button.

2.5. Servo Motor (MG995)

The MG995 servo motor is a high-torque metal servo motor widely used in robotics, automation, and remote-control projects. Its durability, precision, and high torque make it suitable for applications requiring precise rotational control. It rotates at a specific angle of up to 180 degrees.

Fig (5): Servo Motor.

2.6. NodeMCU ESP8266

The ESP8266 is a low-cost Wi-Fi module with a built-in TCP/IP stack and microcontroller capability, making it ideal for IoT (Internet of Things) projects. It allows microcontrollers to connect to Wi-Fi networks and communicate with cloud services or other devices over the internet

Fig (6): ESP8266.

2.7. Max30100 Sensor

The MAX30100 is a pulse oximeter and heart rate sensor that combines two LEDs (infrared and red), a photodetector, and signal processing components into a single module. It is widely used in health monitoring systems, wearable devices, and Arduino projects for measuring blood oxygen levels (SpO2) and heart rate.

Fig (7): Max30100 Sensor.

2.8. 12v 2 Amp Power Supply

Fig (8): Amp Power Supply.

2.9. AMBU Bag

An Ambu bag (Bag-Valve-Mask, BVM) is a manual resuscitation device used for patients with respiratory failure or apnea. It consists of a self-inflating bag that is squeezed by hand to deliver air or oxygen to the patient. The device has a one-way valve to prevent rebreathing of exhaled air. It is used with a face mask to cover the nose and mouth or connected to an endotracheal tube. An oxygen source can be attached to increase oxygen concentration. It is commonly used in emergencies, intensive care units, and anesthesia. It helps resuscitate patients during cardiac or respiratory arrest. Proper use is essential to avoid gastric inflation or lung injury.

Fig (9): AMBU Bag.

2.10. LED

Fig (10): LED.

2.11. Zero PCB

Zero PCB is a general-purpose printed circuit board used for manually connecting electronic components during testing or development. It has a grid of copper-plated holes that allow easy soldering of wires and components without requiring a custom PCB design. It is commonly used for prototyping and experiments before final circuit manufacturing. It provides flexibility for modifications and development compared to traditional printed circuit boards. Zero PCBs are widely used in electronic projects, education, and engineering applications.

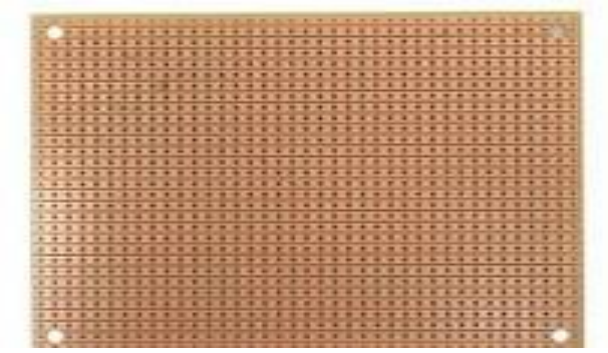


Fig (11): Zero PCB.

3. Block Diagram

- ✓ Push Button, PoT(Variable Resister), MAX30100 And DHT11 Sensor Is Input Device
- ✓ Led, Lcd (20×4 LCD Display) And Servo motor is Output Device

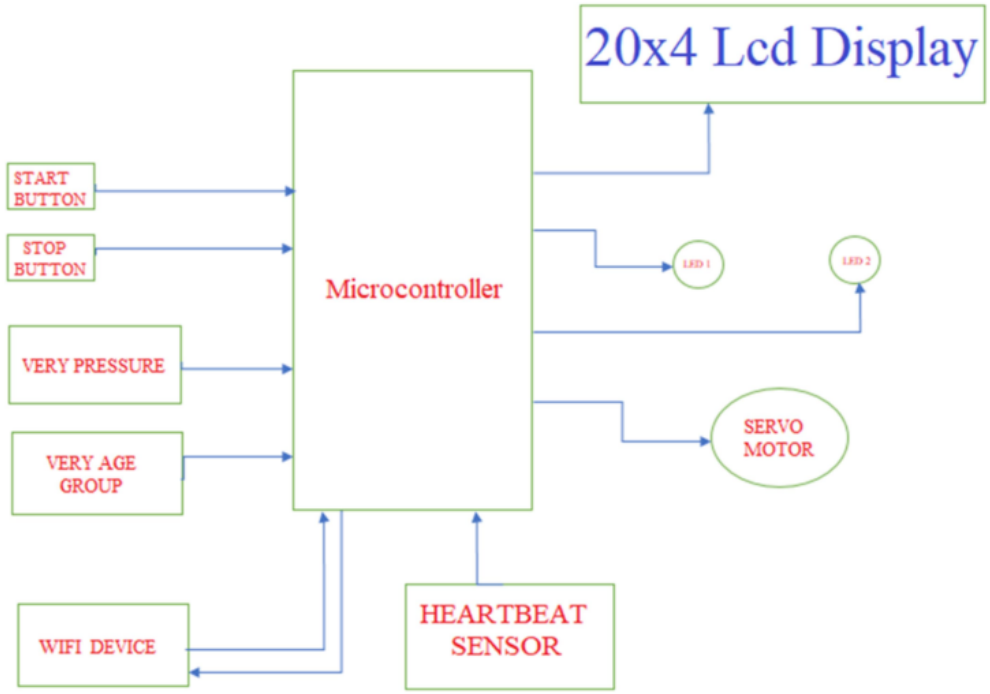


Fig (12): Block Diagram.

4. Circuit Diagram

Here the electrical circuit will be connected to the sensors as shown in Figure (12).

- ✓ Arduino Nano and Lcd Display and Servo motor and Leds

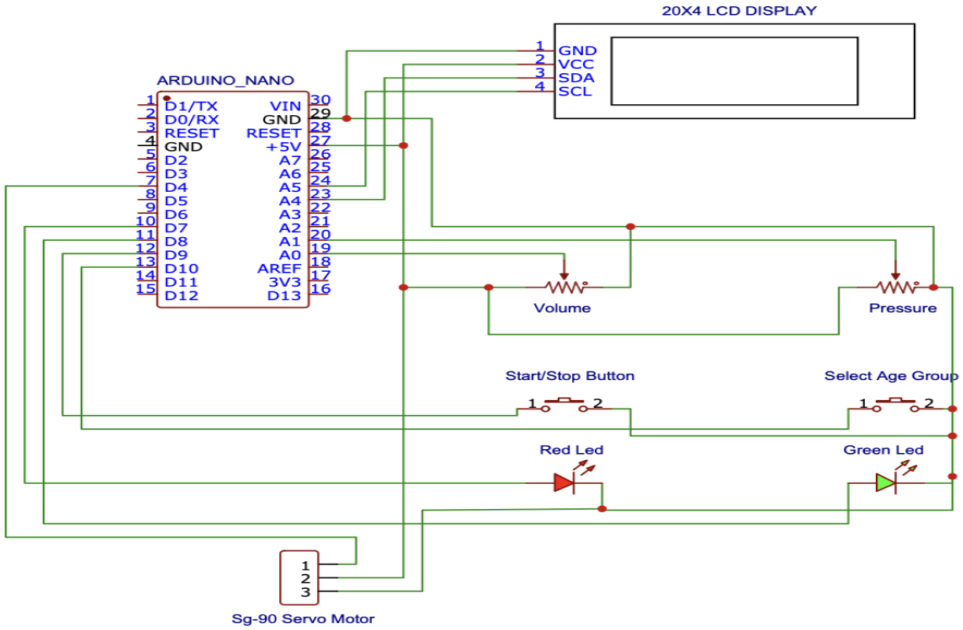


Fig (13): Circuit of Arduino Nano and Lcd Display.

✓ ESP8266NodeMCU and Max30100 and DHT11

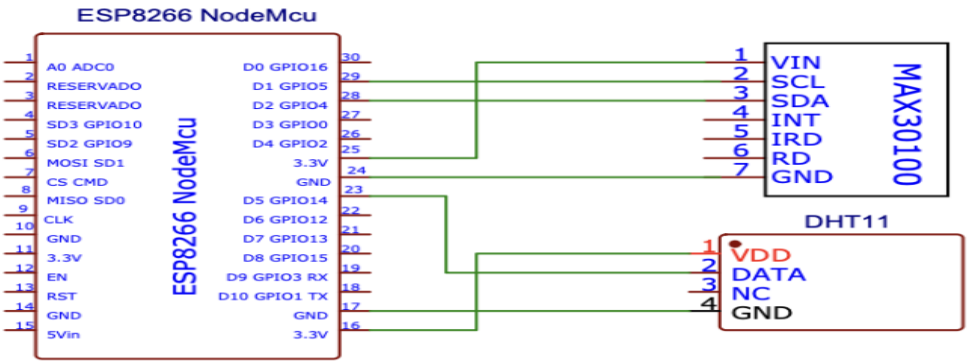
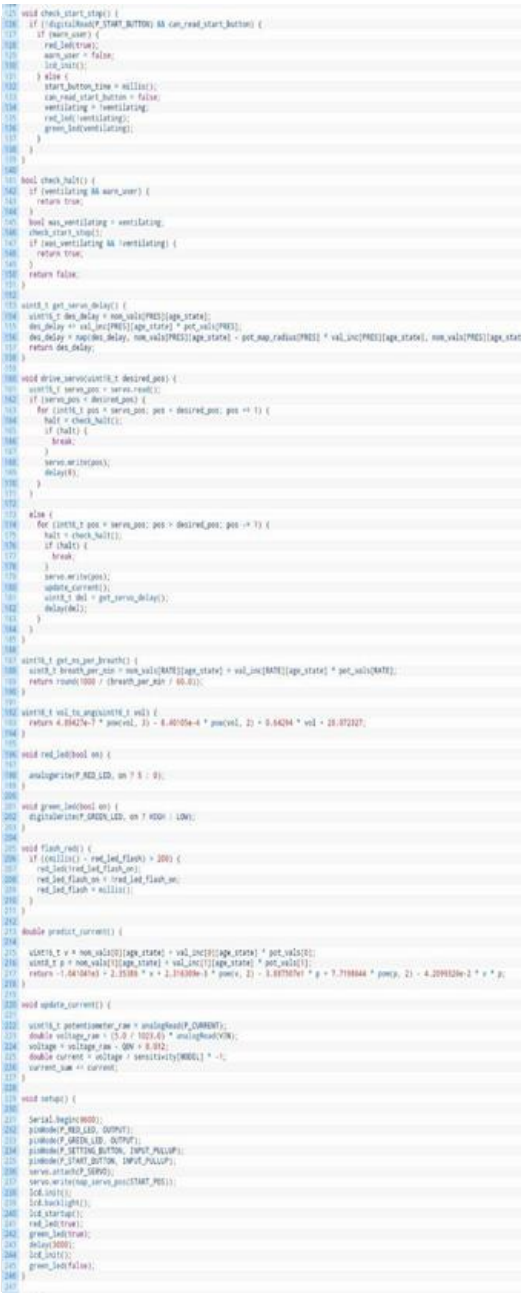


Fig (14): Circuit of ESP8266NodeMCU and Max30100 and DHT11.

5. Source Code/Program



```
void loop() {
  if (!can_read_age_button && millis() - age_button_time >= 500) {
    can_read_age_button = true;
  }
  if (!can_read_start_button && millis() - start_button_time >= 500) {
    can_read_start_button = true;
  }

  if (!warn_user) {
    if (!ventilating) {
      check_age_setting();
    }
    check_pot_vals();
  }

  if (halt) {
    compression_state = 0;
    ventilating = false;
    drive_servo(map_servo_pos(START_POS));
    release_time = millis();
  }
  halt = check_halt();

  if (warn_user) {
    flash_red();
  }

  if (ventilating) {
    uint16_t ms_per_breath = get_ms_per_breath();
    int16_t post_breath_delay = ms_per_breath - base_delays[age_state];
    if (post_breath_delay < 0) {
      post_breath_delay = 1000;
    }

    if (time_to_squeeze && !compression_state) {
      compression_state = 1;
      uint16_t des_vol = nom_vals[VOL][age_state];
      des_vol += val_inc[VOL][age_state] * pot_vals[VOL];
      uint16_t dest = vol_to_ang(des_vol);
      if (age_state == 0) {

        dest = map(dest, 193, 208, 180, 250);
      }
      drive_servo(map_servo_pos(dest));
      squeeze_time = millis();
    } else if (time_to_release && compression_state) {

      if (current_sum >= predict_current() * 1.2 && age_state == 0) {
        halt = true;
        green_led(false);
        warn_user = true;

      } else {
        compression_state = 0;
        drive_servo(map_servo_pos(START_POS));
        release_time = millis();
      }
      current_sum = 0;
    }

    if (compression_state) {
      update_current();
    }

    time_to_squeeze = millis() - release_time > post_breath_delay;
    time_to_release = millis() - squeeze_time > base_delays[age_state];
  }
}
```

Fig (15): Source Code/Program

6. Working principle

The operation of the proposed low-cost ventilator is based on a combination of mechanical actuation and sensor-based monitoring, all controlled by an Arduino Nano microcontroller. The main function of the device is to provide basic mechanical ventilation by compressing an AMBU bag using a servo motor, while simultaneously monitoring patient vital signs.

The core working mechanism is as follows:

1. Mechanical Ventilation Process:

A high-torque servo motor (MG995) is connected to a mechanical arm that periodically compresses the AMBU bag. The frequency and duration of the compression cycles simulate inhalation and exhalation, with the breathing rate adjustable through a 10k potentiometer connected to the Arduino.

2. Sensor Integration:

The MAX30100 sensor continuously measures SpO2 levels and heart rate by detecting infrared light absorption through the fingertip. These readings are processed by the Arduino and displayed on a 20x4 LCD screen.

The DHT11 sensor monitors ambient temperature, providing insight into the surrounding environment that may affect patient stability.

3. Control and Display:

The Arduino Nano receives input from the sensors and potentiometer, processes the data, and sends commands to the servo motor accordingly. The LCD screen presents real-time information

including oxygen saturation, heart rate, temperature, and system status.

4. Wireless Communication (Optional):

An ESP8266 Wi-Fi module can be integrated to allow for remote monitoring or future cloud connectivity, although in the current prototype, this feature is optional and not fully implemented.

The entire circuit is assembled on a Zero PCB for testing, with power supplied through a 5V regulated source. The design emphasizes simplicity, affordability, and modularity, allowing easy modifications or upgrades.

This working model demonstrates a practical application of embedded systems in biomedical engineering and showcases how basic electronic components can be used to simulate a life-supporting function in emergency or low-resource contexts.

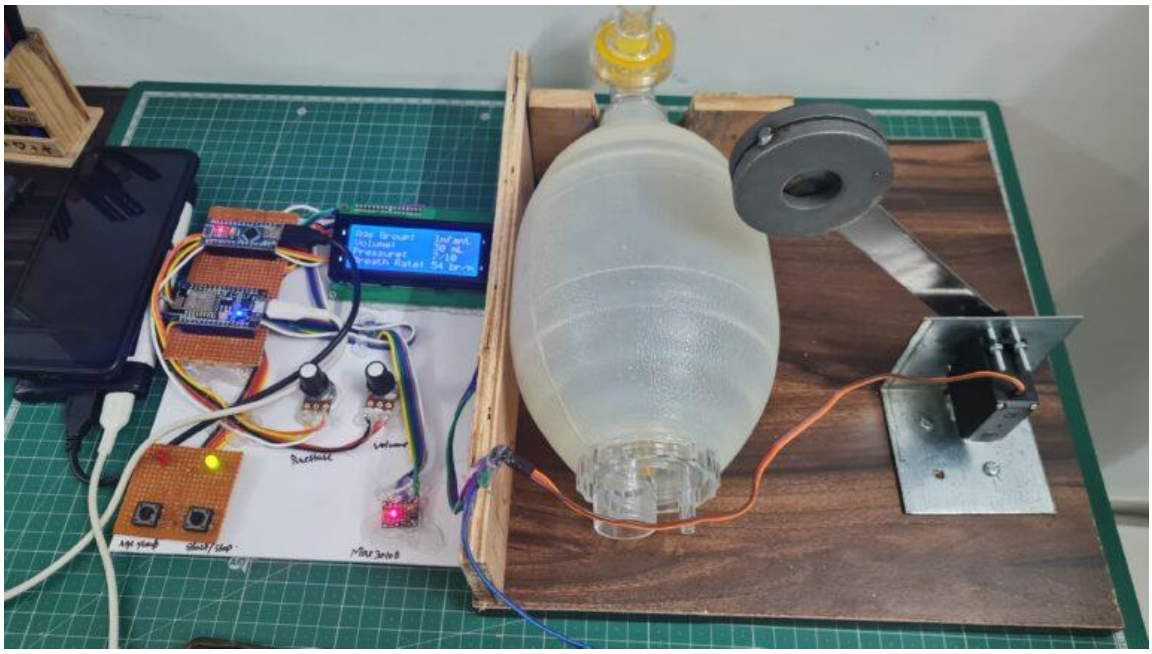


Fig (16): Final work and operating principle

6. Results

A low-cost prototype ventilator was successfully developed using the Arduino platform, integrating multiple electronic components to control airflow and monitor patient vital signs. Initial testing results demonstrated the ability to generate consistent mechanical ventilation through the compression of an AMBU bag using a high-torque servo motor (MG995), with adjustable breathing rates controlled via a 10k potentiometer.

The MAX30100 sensor was employed to measure heart rate and blood oxygen saturation (SpO2), providing reasonably accurate readings suitable for educational or home-based applications, and displayed clearly on a 20x4 LCD screen. The DHT11 sensor was used to monitor ambient temperature, supporting overall environmental assessment for patient safety.

The servo motor effectively compressed the AMBU bag at a consistent rhythm, and the system allowed for manual adjustment of respiratory rate. The ESP8266 module enabled wireless connectivity, laying the groundwork for potential future integration with cloud platforms or remote monitoring interfaces.

Circuit integration was achieved using an Arduino Nano and a Zero PCB board. All components worked harmoniously, and the system completed a full respiratory cycle within the expected parameters.

Despite the functional success of the prototype, some limitations were observed. These include

the reliance on manual control for breathing rate and the absence of a closed-loop feedback mechanism for dynamic regulation of air volume or pressure, which are critical for clinically approved medical devices.

7. Discussion

The results of this study indicate the feasibility of developing a low-cost mechanical ventilator using commercially available components and the open-source Arduino platform. This aligns with the study's hypothesis that simple technical solutions can help meet healthcare demands, especially in resource-limited settings or during public health emergencies such as the COVID-19 pandemic.

The project highlights the importance of integrating hardware (sensors and actuators) with software (Arduino-based control logic) to deliver functional performance. While simple, the system was capable of performing essential tasks such as mechanical ventilation and vital sign monitoring (SpO2, heart rate, temperature), demonstrating its potential as a practical educational tool in biomedical engineering.

However, several technical and clinical challenges were identified that must be addressed before considering the system for real-world medical use. The lack of essential safety features—such as protection against over-ventilation and pressure monitoring—as well as the absence of calibration procedures, may compromise the reliability of patient data.

In practical terms, the system could be useful as a training platform for engineering students or as a prototype for further development in collaboration with healthcare professionals. Future enhancements could include the use of artificial intelligence to adjust ventilation based on patient data, and the refinement of the mechanical structure for more robust performance.

8. Future Work

Based on the outcomes of this project and the recognized technical limitations of the prototype, several future directions are proposed to enhance and develop the performance of the Arduino-based ventilator system:

1. Integration of a Closed-Loop System:

To ensure accurate and stable ventilation, it is essential to incorporate pressure and tidal volume sensors connected to a dynamic control system capable of adjusting motor speed and actuation angle in real time based on the patient’s physiological needs.

2. Enhancing Safety and Reliability:

The system should include audible and visual alarms to alert users in cases of malfunction, such as low oxygen saturation, sensor failure, or power loss. A backup battery system should also be integrated to ensure uninterrupted operation during emergencies.

3. Advanced Mechanical Design:

Improving the mechanical actuation of the AMBU bag is recommended by utilizing more robust mechanisms such as linear actuators or lever-based systems, which offer greater durability and consistent performance compared to basic servo motors.

4. Networking and Digital Integration:

The ESP8266 module can be further utilized for real-time data transmission to healthcare providers or cloud platforms. This allows remote patient monitoring and opens the possibility for advanced data analysis using artificial intelligence tools.

5. Improved User Interface:

Developing a more interactive graphical interface is encouraged, either through a larger LCD screen or a mobile application, to allow real-time visualization of patient data and easier control

of system parameters.

6. Clinical Validation and Bio-Simulation:

Future work should include validation of the ventilator's effectiveness using lung simulation models and testing in an educational medical environment under the supervision of healthcare professionals prior to any potential clinical application.

7. Compliance with International Standards:

Aligning the system with international ventilator standards (such as ISO and FDA guidelines) is vital. Adapting the design to meet some of these requirements would increase its potential for adoption in localized medical device manufacturing initiatives.

9. Conclusion

Creating an economical ventilator that incorporates temperature monitoring, breaths per minute (BPM), and oximeter functions using Arduino offers a cost-effective option for emergency situations where conventional medical equipment may be unavailable. Nevertheless, it is important to emphasize that this DIY ventilator is intended solely as a temporary measure and should not serve as a substitute for professionally designed and validated medical devices. Prior to utilizing such a DIY ventilator in a healthcare environment, it is vital to seek advice from medical professionals and adhere to local regulations and guidelines.

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