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STRESSAWAY: A DUAL-PURPOSE PORTABLE MASSAGER AND BLOOD PRESSURE MONITOR USING PNEUMATIC COMPRESSION

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Abstract
This research proposes STRESSAWAY—a cost-effective, portable health device integrating oscillometric blood pressure monitoring with therapeutic intermittent pneumatic compression (IPC). Targeted at health-conscious individuals, the device automates arm cuff inflation/deflation to simultaneously measure blood pressure and deliver compression massage therapy. Extensive literature and component-level investigations informed the system's dual-function design. The prototype, comprising an ESP32 controller, pressure sensor, air pump, and NIBP cuff, demonstrated reliable systolic/diastolic readings and noticeable muscle relaxation. The project confirms the feasibility of merging diagnostic and therapeutic functions in one unit, with future prospects for smart features like HRV tracking, app connectivity, and modular massage attachments.

Introduction
With rising levels of stress and sedentary behavior in modern lifestyles, there is a growing need for innovative solutions that address both physiological diagnostics and therapeutic recovery in one compact device. Hypertension (high blood pressure) is one of the leading chronic conditions worldwide, often undetected or poorly managed due to the absence of regular monitoring. Simultaneously, muscle fatigue, poor circulation, and stress-related muscular tension are increasing concerns, particularly among office workers, athletes, and the elderly.

Currently, individuals must use separate tools for blood pressure monitoring and massage therapy. This approach is not only costly but also inconvenient, reducing the likelihood of consistent usage. By combining these two essential functions—diagnosis and relief—into one portable system, this research aims to promote proactive health management.

The STRESSAWAY device uses the pneumatic mechanism typically found in digital BP monitors and modifies its control logic to allow repetitive inflation-deflation cycles, thereby delivering compression massage. The oscillometric method enables non-invasive, cuff-based BP measurement, while the intermittent pneumatic compression (IPC) mimics clinical-grade massage therapy. The innovation lies in hardware optimization, software switching logic, and cost-efficient component integration, making STRESSAWAY accessible, effective, and user-friendly.

Literature Review

Intermittent Pneumatic Compression (IPC) Therapy:

IPC has been extensively studied for medical applications such as Deep Vein Thrombosis (DVT) prevention, lymphedema treatment, and recovery from musculoskeletal fatigue. IPC works by applying and releasing pressure on limbs, enhancing venous return, lymphatic drainage, and localized circulation. Clinical sources including Johns Hopkins Medicine and the Cleveland Clinic recognize IPC as an effective, non-pharmacological treatment.

Blood Pressure Monitoring Devices:

Digital BP monitors utilizing the oscillometric method are standard in personal health monitoring. Brands like Omron and Beurer use automated inflation pumps and pressure sensors to calculate systolic and diastolic values from pulse oscillations. These devices are widely accepted for their ease of use, accuracy, and automation. Integrating this technology with additional functionality is a logical next step in the evolution of personal health devices.

Hybrid and Wearable Devices:

Research by Kaye et al. (2016) illustrated the feasibility of repurposing neonatal BP cuffs for therapeutic pressure delivery. Meanwhile, multifunction wellness devices, such as Thermabody and Theragun, offer heat, vibration, and pressure in a single handheld unit. Emerging trends in wearable technology have seen the convergence of diagnostic sensors (for pulse, temperature, ECG) with health-enhancing tools such as massage pads and TENS units.

Gaps Identified in Literature:

- Most IPC systems are bulky and intended for clinical use.
- Current wearable BP monitors lack therapeutic functionality.
- No existing consumer-grade product integrates oscillometric BP monitoring with programmable pneumatic massage.
- Challenges in maintaining BP accuracy while introducing cyclic inflation for massage must be addressed.

This review validates the novelty and potential impact of STRESSAWAY, which integrates both BP measurement and IPC therapy into a single compact and cost-effective system.

Methodology

The development of the STRESSAWAY device followed a comprehensive methodology covering the full design lifecycle—ranging from requirement analysis and component selection to prototype testing and optimization.

Requirement Analysis:

To define user requirements and design goals, a preliminary survey was conducted among 30 potential users including healthcare workers, working professionals, athletes, and elderly individuals. The survey responses emphasized the following key attributes:

- Portability to support frequent use at home or while traveling
- Multifunctionality to reduce the need for separate devices
- Minimal setup and operational complexity (ideally one-button control)
- Affordability within ₹2000 to ensure accessibility to lower-income groups
- Display features for real-time readings of blood pressure and massage settings

This analysis helped finalize a compact, battery-operated device offering two distinct yet related functions—BP monitoring and pneumatic massage.

Component Selection:

The hardware selection was governed by factors such as accuracy, energy efficiency, size, and compatibility with microcontroller systems.

- **Microcontroller (ESP32):** Selected for its dual-core performance, built-in wireless capabilities (Bluetooth/Wi-Fi), low power modes, and multiple analog/digital input channels.
- **Pressure Sensor (MPS2012):** A piezoresistive sensor offering accurate pressure detection in the 0–300 mmHg range, suitable for both BP readings and massage pressure detection.
- **Mini Air Pump:** A diaphragm-based pump capable of generating 0–150 mmHg pressure. Its small footprint and quiet operation make it ideal for portable applications.
- **Solenoid Valve:** Used to control the air release mechanism during deflation cycles, especially critical for accurate BP oscillation capture.
- **NIBP Cuff:** A standard upper-arm cuff compatible with adult users, capable of uniform inflation and adjustable fit.
- **Display (OLED 0.96”):** Chosen for its clarity, low power consumption, and space efficiency.
- **Buttons, regulators, MOSFETs, and battery modules** were selected to ensure circuit stability and ease of integration.

Circuit Design & Simulation:

The electronic circuit was designed using Proteus software. Key aspects included:

- Use of MOSFETs to control high-current loads from the air pump and solenoid valve
- Voltage regulation circuitry for stable 3.3V and 5V supply rails
- Overcurrent protection for battery and pump circuits
- LCD interfacing using I2C protocol to reduce GPIO usage

Simulations were conducted to test the timing cycles of massage and BP mode. Special attention was paid to ensure the pressure sensor data acquisition frequency matched the requirement for oscillometric waveform analysis.

Software Development:

Firmware was developed in Arduino IDE with the following software architecture:

- **BP Mode Routine:** Includes pump activation, pressure ramp-up, data sampling, oscillation detection, and systolic/diastolic value estimation using envelope peak detection.
- **Massage Mode Routine:** A separate loop triggers timed inflation-deflation cycles, modifiable via user input.

- **Mode Switching Logic:** Allows safe transition between modes with auto-reset and default pressure release for safety.
- **OLED UI Module:** Displays current mode, BP readings, and massage cycle status.
- **Battery Monitor Function:** Measures battery voltage and alerts if low.

Interrupts and timers were used for precise timing control, and debounce logic was implemented for input stability.

Prototype Fabrication:

A custom enclosure was designed in Fusion 360, optimizing internal component arrangement for airflow and cooling. The device was 3D printed in PLA plastic for its lightweight and durable properties. PCB was fabricated using UV etching and verified using continuity tests. Components were soldered with lead-free solder for health and environmental safety.

The user interface includes:

- A single-mode selector button
- Two pressure adjustment buttons
- A start/stop button
- OLED screen and status LED

Testing & Calibration:

- **Accuracy Testing:** BP readings were validated against a calibrated mercury sphygmomanometer and a clinical Omron BP monitor. Three trials per user were averaged.
- **Massage Effectiveness:** Pressure delivery was evaluated using a calibrated pressure gauge. 10 volunteers were asked to rate comfort, perceived relaxation, and pain relief on a scale of 1–5.
- **Power Testing:** Battery life was tested under continuous use in both modes. Charging time was also measured.
- **Thermal Tests:** Ensured no overheating occurred in the pump or valve over a 15-minute cycle.
- **Safety Protocols:** Automatic release logic was tested in overpressure conditions (set at >160 mmHg).

This methodology ensured not only the technical viability of STRESSAWAY but also its ergonomic comfort, user satisfaction, and safety for everyday usage.

Results and Analysis

The performance of the STRESSAWAY prototype was evaluated through a combination of technical testing and user-centered feedback. Key findings include:

Blood Pressure Measurement Accuracy:

- 10 individuals were tested using both STRESSAWAY and a clinically validated Omron BP monitor.
- STRESSAWAY showed an average error of ±3.5 mmHg for systolic and ±2.8 mmHg for diastolic values.
- The standard deviation in readings was within 4 mmHg, which aligns with IEC 80601-2-30 compliance for home BP monitors.

Massage Comfort and Effectiveness:

- Volunteers experienced the massage mode at three preset pressure cycles (30 mmHg, 40 mmHg, 50 mmHg).
- 80% of users reported muscle relaxation and comfort.
- 70% preferred moderate-pressure cycles, especially for post-work or long sitting hours.
- No thermal discomfort or pain was reported.

Power Performance:

- Powered by a 3.7V, 2200mAh lithium-ion battery.
- Average operation time per charge: 2.4 hours in massage mode, 3 hours in BP mode.
- Full recharge time: 90 minutes.

Interface Usability:

- OLED display visibility rated 4.7/5 by users.
- One-touch mode switch appreciated for simplicity.
- No software crashes or interface lag during tests.

Limitations Observed:

- The arm cuff is not optimal for users with very large or small arms.
- Audible pump noise during inflation was mildly distracting for 20% of users.

Cost Estimation

Component	**Cost (INR)**
ESP32 Microcontroller	350
Pressure Sensor (MPS2012)	250
Mini Air Pump	150
Solenoid Valve	150
OLED Display	120
Battery + Charging Module	100
NIBP Cuff + Tubing	180
3D Printed Case	120
Miscellaneous	500
Total	**1920**

This total manufacturing cost suggests strong potential for commercialization under ₹2500 retail price, making it competitive with single-function BP monitors.

Advantages and Limitations

Advantages:

- Combines two health functions into one compact device.
- Affordable and accessible, especially for low-income or rural users.
- Fully non-invasive and safe to operate.
- Modular design allows future expansion (e.g., Bluetooth, mobile apps).

Limitations:

- Currently supports only arm cuffs; calf/leg support not yet implemented.
- Massage function is limited to low-to-moderate compression levels.
- Lacks real-time mobile connectivity in current version.
- Not yet certified for medical use under regulatory standards.

Conclusion and Future Scope

The STRESSAWAY prototype successfully demonstrated the integration of a diagnostic (BP monitoring) and therapeutic (pneumatic massage) tool into a single, cost-effective, and portable device. Performance testing confirmed its reliability in capturing accurate blood pressure readings and delivering user-comfortable compression therapy.

The project fills a notable gap in the current health device market, especially for at-home and on-the-go users. The potential to support preventive care, stress management, and muscle recovery in one unit makes STRESSAWAY especially relevant for aging populations, professionals, and patients managing hypertension or circulatory concerns.

Future enhancements may include:

- Bluetooth connectivity and smartphone app integration for data tracking.
- HRV and temperature sensing for advanced diagnostics.
- Modular cuff designs for use on legs and forearms.
- Voice-based feedback and digital assistant integration.
- Clinical trials and certification for hospital-grade use.

With further development, STRESSAWAY can be positioned not just as a consumer gadget but as a medically relevant smart health assistant.

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