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Design and Development of a Negative Pressure Wound Therapy Device

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Abstract: This study presents the design and development of a Negative Pressure Wound Therapy (NPWT) device aimed at improving the treatment of chronic wounds, particularly diabetic foot ulcers in patients with diabetes mellitus. The primary objective is to create an efficient, user-friendly, and portable wound therapy solution suitable for both clinical and home-based care. The device utilizes negative pressure to enhance blood perfusion, reduce exudate, and lower infection risk, thereby accelerating the healing process. The system is built using a NodeMCU ESP32 microcontroller, a vacuum motor pump, HX710 pressure sensor, solenoid valve, and a Nextion LCD interface. It supports three therapy modes—Continuous, Intermittent, and Dynamic—controlled by a PID algorithm to maintain stable pressure between -25 to -150 mmHg. Testing was conducted at three measurement points: battery voltage, sensor accuracy, and LCD interface functionality. Results indicate that the device performs effectively within expected operational parameters across all modes. The NPWT prototype offers a cost-effective, functional alternative for wound care management and shows promise for further development, including digital integration and broader clinical applications.

Keywords: Negative Pressure Wound Therapy, diabetic foot ulcer, portable medical device, chronic wound treatment, ESP32, PID control, wound healing technology.

INTRODUCTION

Diabetes mellitus (DM) is a chronic metabolic disorder primarily caused by genetic and lifestyle factors, characterized by inadequate insulin production or insulin resistance. This results in elevated blood glucose levels, which gradually damage various organ systems. Due to its often asymptomatic progression, DM is frequently referred to as a "silent killer" (Mursyidah et al., 2022).

One of the most serious complications of DM is diabetic foot ulcer (DFU), a chronic wound marked by open sores and potential tissue necrosis. Initially presenting as minor wounds, improper treatment can lead to infection, ulceration, and even gangrene. According to Ismiati et al. (2023), DFUs affect approximately 87% of diabetic patients, with up to 26% of adult cases resulting in lower limb amputations. This condition significantly reduces patients' quality of life and increases their dependence on family and

healthcare services. Moreover, the financial burden on individuals with DFUs is estimated to be five times higher than for diabetic patients without ulcers.

Conventional treatment methods, such as moist wound dressings, aim to maintain an optimal healing environment. However, these methods are time-consuming, often requiring up to 11 weeks for tissue granulation to occur (Aeni, 2024). Complications such as malodor, nausea during gangrenous wound care, and the prolonged healing time associated with traditional dressings highlight the need for more efficient therapeutic solutions.

Recent advancements in medical technology have introduced more effective wound management techniques. Among them, Negative Pressure Wound Therapy (NPWT), or Vacuum Assisted Closure (VAC), has emerged as a promising approach. NPWT applies controlled negative pressure ranging from -25 to -150 mmHg to promote blood circulation, reduce exudate, remove contaminants, and stimulate healthy granulation tissue formation (Kirsner et al., 2019). Clinical studies show that NPWT accelerates wound healing, reduces hospitalization time, lowers infection risks, and improves patient quality of life.

Despite these benefits, NPWT devices are often expensive, require complex equipment, and necessitate trained medical personnel. These limitations underscore the need for more accessible and cost-effective NPWT solutions, especially for outpatient and home-care settings.

This study focuses on the design and development of a compact and affordable NPWT device intended for patients with diabetic foot ulcers. It aims to offer a practical alternative that facilitates weekly wound care procedures and improves treatment adherence. The device development is inspired by a prior work by Sari (2018), which introduced a vacuum-assisted closure system using an Arduino Uno and MPX5500DP pressure sensor. Building upon that foundation, this research incorporates a NodeMCU ESP32 controller, digital sensors, and improved control logic to ensure precise pressure regulation and ease of use. Ultimately, the proposed device seeks to contribute to the advancement of wound therapy technologies that are both clinically effective and economically viable.

RESEARCH METHOD

This study employs an applied research design, specifically a design and development (rancang bangun) approach. Applied research focuses on addressing practical, real-world problems by developing tangible solutions that can be implemented directly in everyday

practice. In this case, the research aims to design and develop a Negative Pressure Wound Therapy (NPWT) device intended to support healthcare professionals—particularly nurses and medical staff—in providing more effective and efficient wound care for diabetic patients suffering from external ulcers.

The purpose of this research is to create a tool that facilitates wound management procedures in clinical settings, especially in hospitals, with an emphasis on usability, practicality, and efficiency. The prototype is expected to assist medical personnel in delivering improved patient care by minimizing the complexity of the wound treatment process. Furthermore, the outcome of this research aligns with the core goals of applied research: to produce a directly useful product that positively impacts public health and daily life through accessible and functional medical technology.

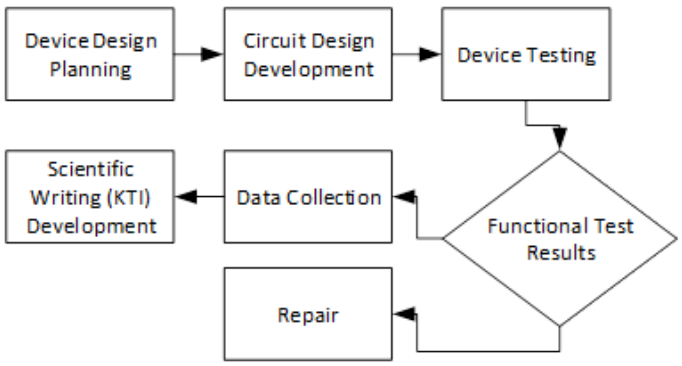

Figure 1. Flowchart for Making Tools

Block Diagram

The block diagram provides a conceptual overview of the hardware configuration used in the NPWT device. The system is powered by a 7.4V 2S Li-ion battery connected to a charging module. The core control is managed by a NodeMCU ESP32 microcontroller, which regulates the operation of key components:

- Vacuum motor pump: generates negative pressure.
- Solenoid valve (5V, 1.5 mm opening): regulates airflow and pressure release.
- MEMS pressure sensor XGZP101: measures negative pressure.
- Nextion 3.5” LCD: provides user interface and real-time pressure display.

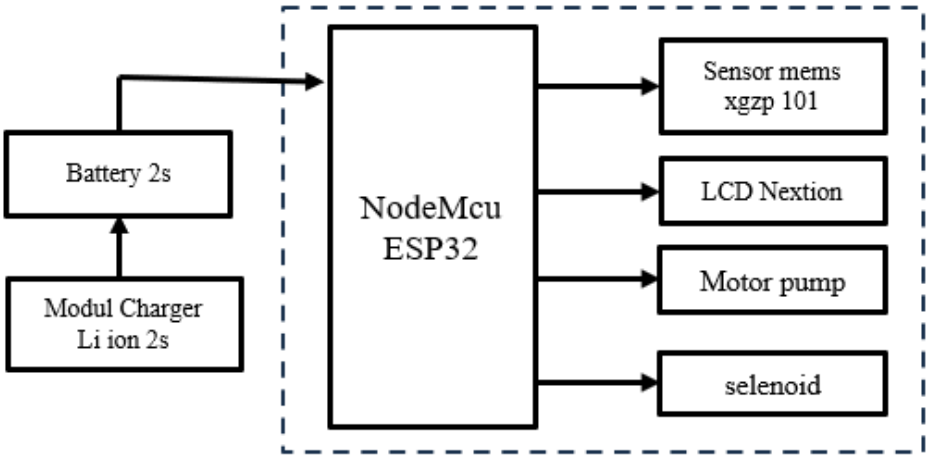

Figure 2. Block Diagram of the NPWT Device

Hardware Design

Hardware Planning

The hardware is designed to produce and regulate stable negative pressure (50–150 mmHg), depending on the selected therapy mode. It ensures operational safety, portability, and user convenience, with the ESP32 microcontroller handling real-time control logic and monitoring.

Physical Design

The physical layout of the NPWT device is compact and structured for bedside use. The main enclosure accommodates the microcontroller, motor pump, sensor, valve, battery, and user interface.

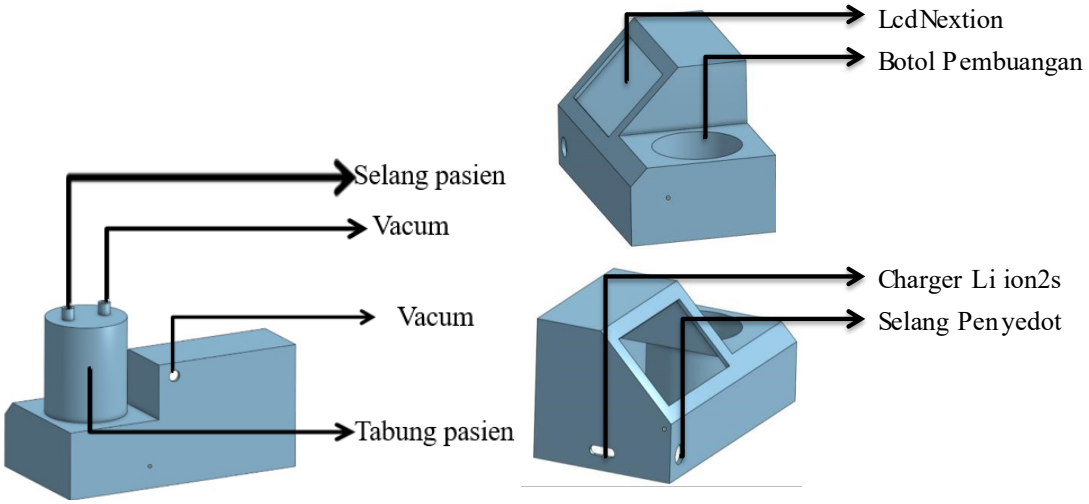

Figure 3. Physical Design Layout

Wiring Diagram

The wiring diagram represents the electrical connection between components:

- TP1: Battery circuit
- TP2: Pressure sensor circuit (HX710)
- TP3: LCD interface circuit (Nextion)

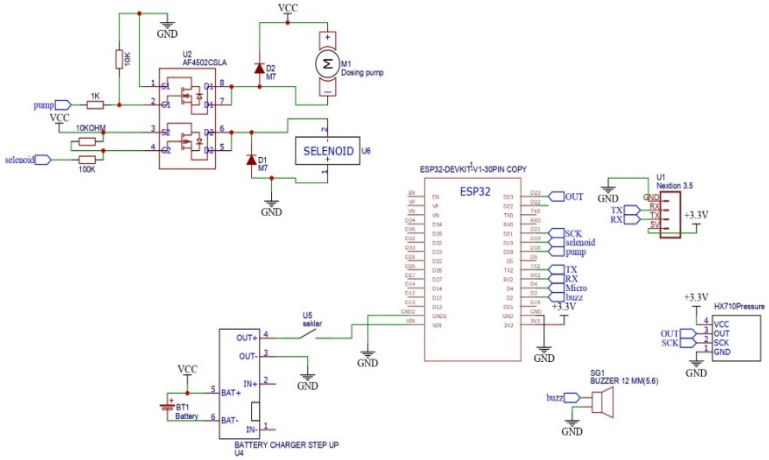

Figure 4. Complete Wiring Diagram

Software Design

The software is developed using Arduino IDE (C/C++) for the ESP32 microcontroller and Nextion Editor for LCD UI design. It supports three therapy modes:

- Continuous Mode: constant vacuum pressure.
- Intermittent Mode: cycles of vacuum and pause.
- Dynamic Mode: variable vacuum with upper/lower pressure bounds.

The system monitors real-time pressure data, regulates motor/valve control via PID algorithm, and displays therapy parameters on the LCD. Safety protocols are embedded to detect anomalies such as leakage or blockage.

RESULT AND DISCUSSION

Measurement Analysis – TP1 (Battery Output)

The first measurement point (TP1) involved checking the voltage supplied to the ESP32 microcontroller from a 7.4V 2S battery through a voltage regulator. Measurements

were taken five times using a digital multimeter, resulting in an average output voltage of 5.03 V compared to the theoretical reference of 5.00.

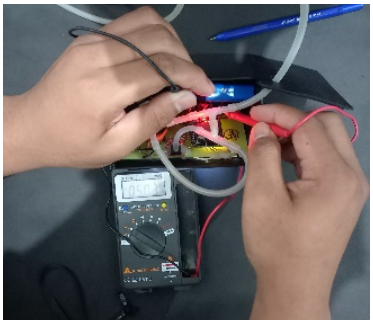

Figure 5. TP1 – Battery Voltage Measurement Point

Table 1. Voltage Measurement Results for TP1

Measurement Results 1			
No	Measurement Instrument	Voltage	Reference
1	Measurement 1	5,03 V	5 V
2	Measurement 2	5,04 V	
3	Measurement 3	5,04 V	
4	Measurement 4	5,03 V	
5	Measurement 5	5,03 V	
	Average	5,03 V	

The calculated percentage error is:

$$\left|\frac{5{,}03\ \text{V} - 5\ \text{V}}{5\ \text{V}}\right| \text{x } 100\%$$

$$= 0{,}006 \text{ x } 100\%$$

$$= 0{,}006\ \%$$

This minor deviation indicates excellent accuracy and falls well within the acceptable tolerance range.

Measurement Analysis – TP2 (Pressure Sensor Input)

TP2 measured the voltage supplied to the HX710 pressure sensor, which operates within 1.8–5.5V. The sensor received an average voltage of 2.57 V, as output from the ESP32 board.

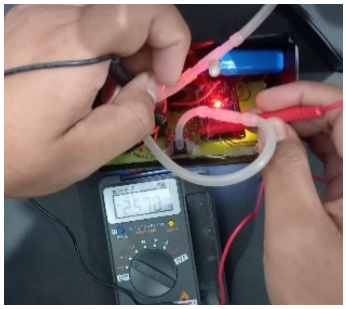

Figure 6. TP2 – HX710 Sensor Voltage Point

Table 2. Voltage Measurement Results for TP2

Measurement Results 1			
No	Measurement Instrument	Voltage	Reference
1	Measurement 1	2,57 V	1,8 – 5,5 V
2	Measurement 2	2,56 V	
3	Measurement 3	2,57 V	
4	Measurement 4	2,57 V	
5	Measurement 5	2,52 V	
	Average	2,57 V	

Percentage error with reference to the upper limit (5.5V):

$$\left|\frac{2{,}57\ \text{V} - 5{,}5\ \text{V}}{5{,}5\ \text{V}}\right| \text{x } 100\%$$

$$= 0{,}01 \text{ x } 100\%$$

$$= 0{,}01\ \%$$

Despite the lower operating voltage, the value is still within the recommended sensor range, validating compatibility with the controller.

Measurement Analysis – TP3 (LCD Input)

TP3 involved measuring the voltage supplied to the 3.5” Nextion LCD interface, which typically requires 5V. The measured average voltage was 3.27 V.

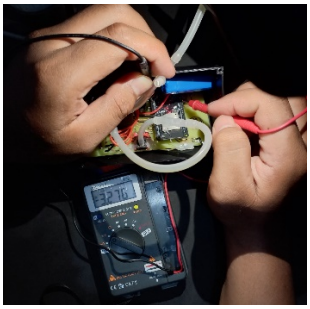

Figure 7. TP3 – LCD Voltage Measurement Point

Table 4. Voltage Measurement Results for TP3

Measurement Results 1			
No	Measurement Instrument	Voltage	Reference
1	Measurement 1	3,27	5V
2	Measurement 2	3,27	
3	Measurement 3	3,27	
4	Measurement 4	3,27	
5	Measurement 5	3,27	
	Average	3,27	

Percentage error:

$$\left|\frac{3{,}27\ \text{V} - 5\ \text{V}}{5\ \text{V}}\right| \text{x } 100\%$$

$$= 0{,}34 \text{ x } 100\%$$

$$= 0{,}34\ \%$$

Although the voltage is slightly lower than the recommended 5V, the LCD functioned correctly throughout the test, indicating operational reliability.

Functional and Performance Testing

A performance comparison was conducted using a Digital Pressure Meter (DPM) alongside the NPWT device under three therapy modes:

Table 5. Functional Test Results

No	DPM Pressure	NPWT Pressure	Mode	Time
1	50,9mmHg	50mmHg	*Continous*	1 Menit
2	75,8mmHg	75mmHg	*Intermitten*	3 Menit
3	*error*	132mmHg	*Dynamic*	3 menit

The Continuous and Intermittent modes showed close correlation between DPM and NPWT readings, with minor variations. The Dynamic mode exceeded the DPM's measurable limit, resulting in an error reading. However, the NPWT device maintained the expected -132 mmHg output, confirming proper function.

Mode-Specific Operational Results

In Continuous mode, the NPWT device was configured to operate at a negative pressure of -50 mmHg for a duration of 2 minutes. The system successfully maintained a steady vacuum throughout the session, indicating that the pressure control algorithm functioned effectively under constant conditions.

In Intermittent mode, the device was set to operate at -50 mmHg for a total of 3 minutes, with a rise time of 1 minute and a fall time of 1 minute. This mode required the system to alternate between suction and release phases. The device responded well to the timing instructions, indicating that it could reliably perform cyclic pressure adjustments.

In Dynamic mode, the system was tested under more complex operating conditions. The pressure was programmed to fluctuate between a maximum of -150 mmHg and a minimum of -100 mmHg over a 3-minute session, with 1-minute intervals for both rising and falling phases. The device demonstrated strong responsiveness and precision in adjusting the vacuum pressure across this dynamic range.

All three therapy modes functioned according to their respective programming logic. The device effectively executed time-based transitions, consistently maintained the targeted negative pressure levels, and exhibited responsive control dynamics. This indicates the potential reliability of the NPWT system for varied clinical wound care applications.

Discussion

The experimental results confirm that the NPWT device functions effectively and accurately under real-world operating conditions. Voltage outputs from TP1 to TP3 are within acceptable tolerances, confirming reliable power supply and component integration. Functional tests demonstrated accurate pressure regulation across all modes, validating the effectiveness of the control algorithm and hardware configuration.

The minor discrepancies in pressure readings were within expected margins and can be attributed to component tolerances and environmental variations. Furthermore, the Dynamic mode test highlights the device’s capability to reach higher vacuum thresholds beyond standard measurement tools, suggesting robust vacuum performance.

The successful implementation of all core functionalities supports the potential use of this device in small-scale clinical or home-care settings. With further refinements, such as improving LCD voltage input and enhancing pressure feedback, the system could be optimized for broader clinical deployment.

CONCLUSION

Following a series of stages involving literature review, system planning, data acquisition, functional testing, and analysis, several conclusions can be drawn from the development of the Negative Pressure Wound Therapy (NPWT) device:

1. The NPWT device was successfully designed and built to support the treatment of open wounds in diabetic patients, particularly those with diabetic foot ulcers. The system integrates key components including the NodeMCU ESP32 microcontroller, vacuum motor pump, negative pressure sensor, solenoid valve, and a 3.5-inch Nextion LCD. It is capable of operating in three therapy modes—Continuous, Intermittent, and Dynamic—within a controlled negative pressure range of 50 to 150 mmHg, meeting the clinical requirements for chronic wound care.
2. Testing results demonstrated stable performance and high measurement accuracy, with voltage error percentages of 0.006% at TP1, 0.01% at TP2, and 0.34% at TP3—all within acceptable tolerance limits. Functional testing confirmed that the device accurately maintained the target pressure in Continuous mode (50 mmHg) and Intermittent mode (75 mmHg), with values closely aligned with those measured by the Digital Pressure Meter (DPM). Although the DPM registered an error in Dynamic mode due to exceeding its threshold, the NPWT device itself maintained a consistent output of 132 mmHg, indicating proper function.

In summary, the NPWT device not only meets the technical requirements for wound therapy but also offers an accessible and efficient solution for healthcare providers. Its ability to enhance blood perfusion, reduce infection risks, and manage exudate effectively suggests strong potential to accelerate wound healing and improve the quality of diabetic wound care.

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