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Nasogastric nutrition pump design for intensive care patients

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ABSTRACT

In this study, the aim is to develop a fully equipped nasogastric (NG) feeding pump used for nasogastric feeding therapy in specific working environments such as hospitals, Intensive Care Units (ICU), and Clinical Units (CU). The project aims to address the issues encountered in the use of existing systems and to enhance accessibility for healthcare workers, while improving the portability, usability, and readability of the device. The developed device controls the feeding solution from the feeding bag through the nasogastric tube using an electrical motor and speed sensor within the device, directing it to the stomach in a controlled manner. This method works similarly to an infusion pump, but instead of a standard serum set and solution, it uses a special feeding bag and nasogastric tube. Throughout the study, various improvements were made in collaboration with nurses to ensure the device is user-friendly. The power connection was converted from AC to DC to increase portability, and the device was made remotely controllable. Additionally, a sensor-based system was developed to facilitate the detection of tube blockages. This study aims to examine and understand the existing device and enhance it to provide better experience for healthcare workers. The developed device aims to improve efficiency in healthcare services with its user-friendly interface and portable design.

Keywords: Nasogastric feeding pump, infusion, nutrient requirements, nasogastric tube.

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Introduction

Enteral feeding is a vital method of nutrition for patients with swallowing difficulties or those undergoing certain medical procedures. This method ensures the delivery of nutrients directly to the stomach or intestines, allowing patients to maintain their bodily functions and support their recovery processes. However, the use of enteral feeding pumps presents significant challenges for healthcare professionals in both hospital and home settings. These challenges stem from various factors, such as device portability, blockage detection, ease of use, and cost- effectiveness. Enteral feeding pumps are critical medical devices, and technological advancements in this field have the potential to alleviate the workload of nurses and enhance the quality of patient care. However, existing literature addresses a wide range of challenges associated with the use of enteral feeding pumps. Prominent among these challenges are issues related to device portability, ease of use, and reliability. Specifically, difficulties arising from the power cord connection, the non-ergonomic design of the device, and the challenges in detecting tube blockages are some of the most common problems faced by nurses. The study by Crocker et al. [1] makes a significant contribution by examining microbial growth in enteral feeding systems. The study compares microbial contamination of pre-filled and standard refilled enteral feeding bags, highlighting that pre-filled bags can delay contamination and emphasizing the importance of design changes in the equipment. These findings suggest new approaches to reduce microbial growth during enteral feeding. The research by Kwon et al. [2] discusses technological advancements related to the types, usage techniques, and placement of enteral feeding devices, contributing to the improvement of clinical practices. This study provides valuable insights aimed at enhancing the effective use of enteral feeding devices. Peter and Gill's [3] study, titled "Development of a Clinical Practice Guideline for Testing Nasogastric Tube Placement," compares various methods used during nasogastric tube placement test procedures, aiming to develop the most effective clinical practice guideline. This study offers practical guidelines to enhance the accuracy of nasogastric tube placement. Anderson's [4] research focuses on nursing care related to enteral feeding tubes, aiming to present best practices in this field. The study provides up-to- date information on the placement, maintenance, and management of complications associated with enteral feeding tubes, serving as a comprehensive guide for nurses. The study by Williams and Leslie [5] thoroughly examines nursing care related to the use of enteral tubes in critically ill patients. This research presents a significant literature review on the management of enteral feeding in critically ill patients. Heineck et al. [6] investigate the common issues encountered with drug administration via enteral feeding tubes in their study. The research evaluates how to safely and effectively administer medications through these tubes, the interactions of drugs with feeding formulas, and potential problems that may arise during this process. Additionally, the study aims to develop new approaches and guidelines to optimize the use of enteral feeding tubes in clinical practice. Stumpf et al. [7], in their study investigate the effectiveness of a protocol using Creon delayed-release pancreatic enzymes in clearing blocked enteral feeding tubes. This study offers practical solutions for managing complications such as blockages in enteral feeding tubes. The research by Scott and Bowling [8] addresses current approaches and innovations in enteral tube feeding in adults, providing clinical guidance and strategies. The study comprehensively examines indications for enteral tube feeding, tube placement techniques, and the selection of feeding formulas. Scott and Bowling aim to establish standardization in clinical practice by identifying best practices in the management of enteral tube feeding. Blumenstein, Shastri, and Stein [9] discuss the clinical applications of enteral tube feeding and the complications encountered during this process. The research details the mechanical, gastrointestinal, infectious, and metabolic complications of enteral tube feeding and emphasizes the importance of various factors in reducing these complications. The authors highlight the need for careful management of food composition, application rate, portion size, and food temperature, and propose innovative approaches in patient monitoring and application techniques to enhance the effectiveness of enteral feeding therapy.

Nasogastritis nutrition device use microcontrollers and sensors to identify the amount of remaining nutrition in the food bag and stops the intake flow when the required nutrition amount is reached. Next intake time is calculated based on the last intake schedule and the required elapsed time entry in the device. Identifying the patient's body reactions when the patient is hungry or not, has a crucial importance here and our work to develop such a system is ongoing.

professionals and the impact of these challenges on patient care in detail. Additionally, we evaluate existing solution proposals mentioned in the literature and the limitations of these proposals. In this context, the aim of our study is to enhance the portability of enteral feeding pumps, facilitate blockage detection, ensure ease of use, and increase cost-effectiveness, thereby reducing the workload of nurses and improving the quality of patient care (Figure 1).

Figure 1. Nasogastric tube.

In this study, we examine the current design of enteral feeding pumps which increases practical challenges faced by healthcare

Materials and Methods

This research aims to improve the enteral feeding pumps used in both hospital and home settings. Based on literature and field observations, the main issues nurse's face when using enteral feeding pumps can be summarized as follows (Figure 2):

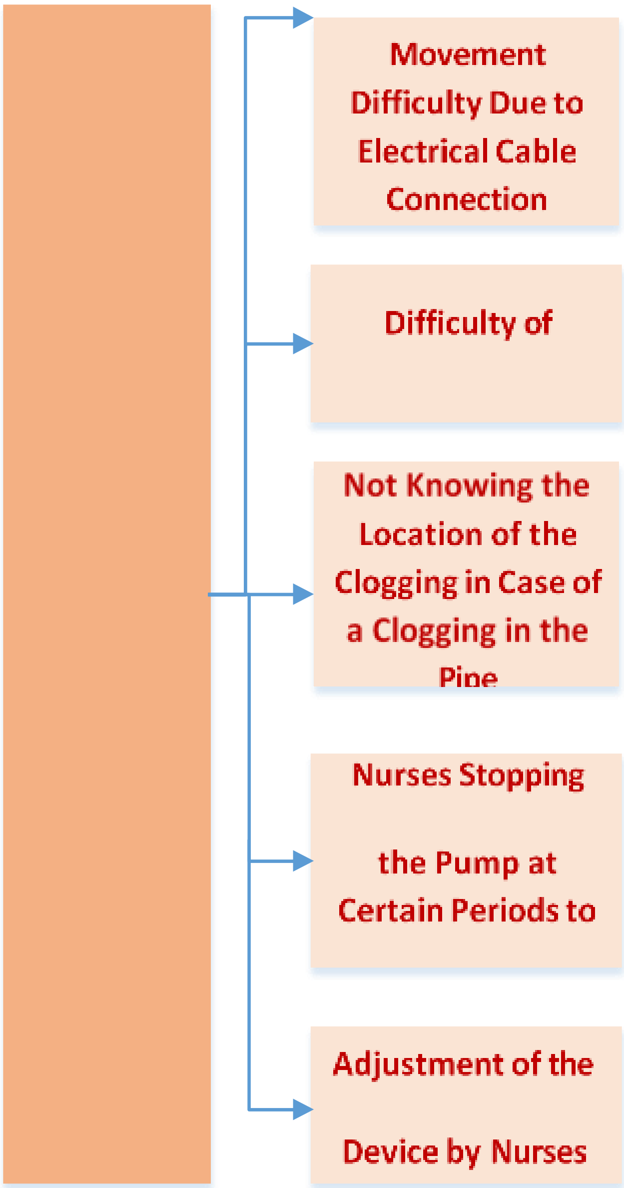


Figure 2. Major problems nurses face when using enteral feeding pumps.

These issues hinder the efficient and effective use of enteral feeding pumps and increase the workload of nurses. Therefore, the aim of our research is to enhance the portability, ease of use, and blockage detection of enteral feeding pumps, thereby alleviating the workload of nurses and improving the quality of patient care. In line with this objective, the following key aspects have been considered:

- ***Portability:*** Current enteral feeding pumps require a continuous AC power connection, which poses challenges during relocation and transportation. To address this issue, we aim to convert the power connection to a DC power source, making the device more portable and easier to use.
- ***Blockage Detection:*** In enteral feeding systems, it can be difficult to determine the exact location of a blockage in the tube. To address this issue, we plan to develop a system that uses research-derived data to provide nurses with probable blockage locations and scenarios. This will help to reduce the time spent identifying and resolving blockages.
- ***Ease of Use:*** Nasogastric (NG) feeding pumps require constant attention and monitoring by nurses. Patients need to be periodically rested, and the flow rate of the feeding solution and fluid flow must be controlled, necessitating the continuous presence of nurses. This situation can lead to work pressure on nurses who must care for multiple patients simultaneously. To alleviate this issue, we plan to make the device remotely accessible, allowing multiple devices to be controlled simultaneously with a single button.
- ***User-Friendliness:*** NG tube feeding should begin slowly and gradually. After filling the syringe with food, the feeding process should be carried out slowly over approximately 10-15 minutes. This allows nurses to use their time more efficiently and prevents issues such as nausea and vomiting that

can occur if the feeding is too rapid. The device will facilitate faster and more careful feeding, making nurses' tasks easier. Additionally, reducing syringe use will contribute to the reduction of plastic waste.

- ***Cost-Effectiveness:*** Currently, NG tube pumps are not manufactured in Türkiye and must be obtained at high costs from domestic and international sources. Each intensive care unit typically requires only one of these devices. Within the scope of this study, we aim to develop and market a cost-effective device to ensure that everyone in need can easily access it.
- ***Innovative Design:*** We plan to develop an NG feeding pump with a special design, inspired by infusion and enteral feeding pumps. The NG feeding pump will have a smaller and lighter body, making it easy to transport and move.

In line with these objectives, our study aims to reduce the workload of healthcare professionals and improve the quality of patient care.

Our priority is to facilitate people's daily lives and offer practical solutions to the challenges they face. This device is of vital importance, especially for patients who cannot be orally fed due to conditions like dysphagia or partial intestinal surgery. Nutrient support is provided directly to the stomach or intestines through a tube. In this process, ensuring the correct intake of nutrients is crucial for maintaining patients' bodily functions. Our aim is to enable healthcare professionals to administer injections safely and effectively. Several studies have been conducted on control and command: Morten Gjerding et al. [10] introduces a framework for automating computational workflows in atomic simulations. Locatelli et al. [11] explore innovations in device discovery and tracking using Bluetooth Low Energy (BLE) technology, aiming to enhance energy efficiency and reliability in this field. Shih et al. [12] investigate liquid pouring-based sequential flow control on a centrifugal platform for precise liquid manipulation in laboratory environments. Berkovitz [13] discusses the use of variational methods in control and programming problems, focusing on the application of mathematical optimization techniques. Ariza et al. [14] introduce a fully open-source, real-time remote laboratory for automatic control systems education, providing practical application opportunities for students and researchers. Binder et al. [15] introduce Qudi, a modular Python software for experiment control and data processing, highlighting its capability to integrate various devices and data acquisition systems used in laboratory experiments. Qudi's flexible and modular structure provides a customizable and extendable platform for different experiments, enabling researchers to conduct experiments more efficiently and effectively. Its foundation on the Python programming language and provision as an open-source solution makes Qudi an important tool for enhancing the efficiency and effectiveness of experiment processes in scientific research.

This study will focus on three main components for product development: mechanical design, electronic system design, and control software design. The device controls the intake amount for the patients and prevents the extra amounts of intake. Establishing a controlled nutrition system using the data collected from the patients, would contribute to the device control and avoid the extra amounts of intakes.

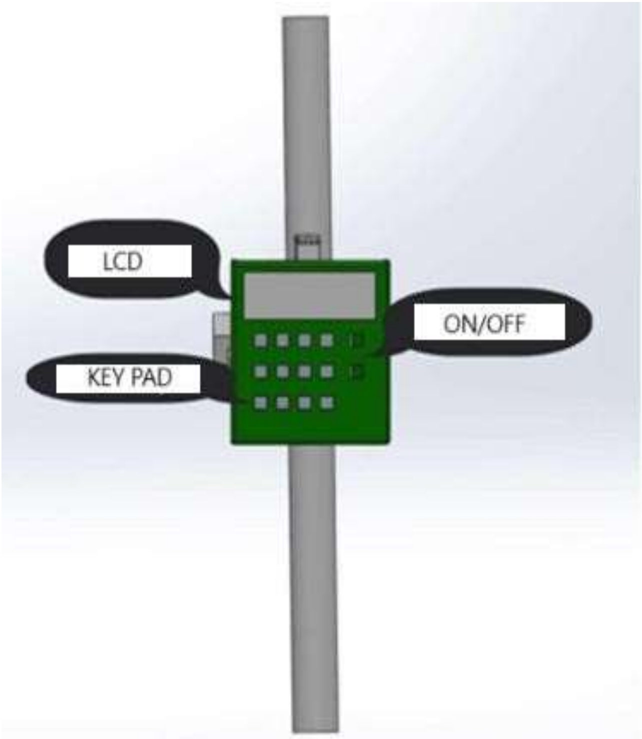


Figure 3. The chassis.

Mechanical Design

The Chassis Design: The mechanical design generally consists of components such as the chassis, a keypad, a feeding bag, an NG tube, tubing, device ports, and a motor. Dimensions have been set at 35x35x40 for improved portability. A durable clamp connection compatible with the device's type has been designed to hold the tube securely. The keypad on the chassis allows for speed adjustments, and nurses can reset or clear all settings by pressing the 'C' button. An additional button is dedicated to stop alarms. A door is provided to access and clean the NG tube section inside the device (Figure 3).

Machine Design: The device will employ a linear motor for precise and controlled delivery of formulas at a set speed, which is crucial for its operation. Unlike commonly used drive

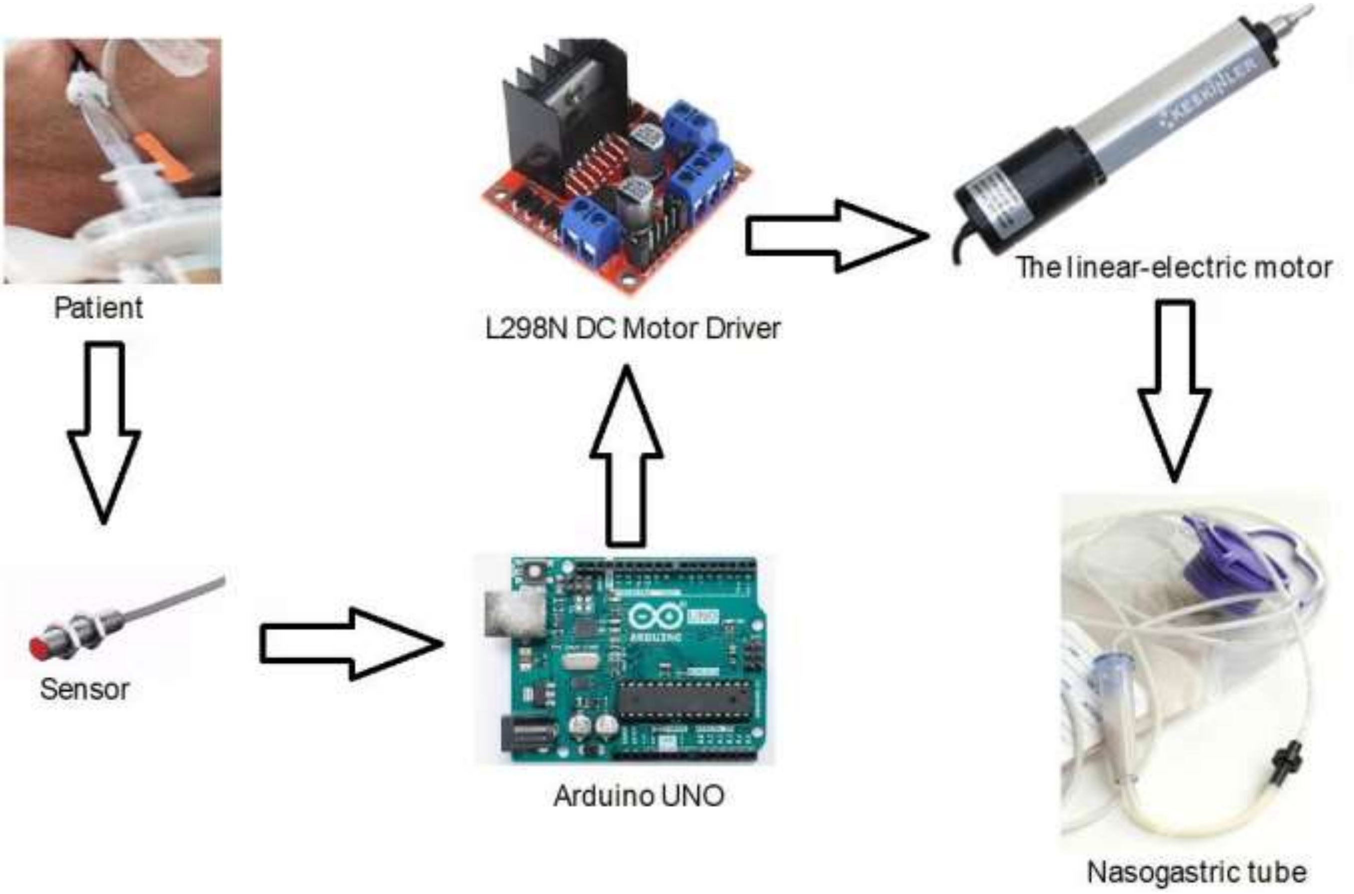


Figure 4. The order of operation of the nasogastritis system elements.

elements such as timing belts, racks and pinions, the threaded spindle offers advantages such as precision, speed, high force capability, and extended travel distance simultaneously. Linear motors are widely utilized in high-efficiency automation equipment due to their versatile applications.

Working Method: When the nurse adjusts the speed, the motor will move the speed clamp, allowing the formula to drip down from the bag in droplets. Subsequently, the speed sensor inside the NG tube device will measure the speed, which will be displayed on the LCD screen (Figure 4).

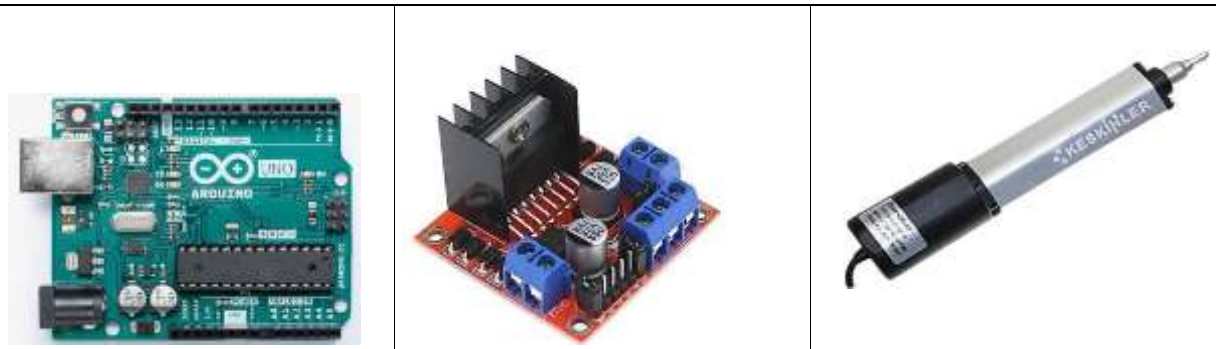
System components: The technical specifications of the Arduino UNO used are as follows: ATmega328P processor Operating Voltage: 5 Volt, Input voltage: 7 to 20 Volt, Digital I / O pins: 14 (pins 3, 5, 6, 9, 10 and 11 can provide PWM output), UART: I^2C :1, SPI: 1, Analog Input Pins: 6, DC for each pin Current/O Pin: 20 mA, DC current for 3.3 V pin: 50 mA, SRAM: 2 KB, EEPROM: 1 KB, Clock speed 16Mhz (Figure 5.a)

Arduino uno, a control signal is sent to the electric motor driver circuit. By using the signals coming from the electric motor drive circuit, the linear electric motor parts are moved in the vertical direction and oriented accordingly. Drive circuits control the linear motor with comprehensive information (output signal) from Arduino UNO. It is a double Hybridge DC motor driven module with growth circuit with L298N Integration (Figure 5.b). It is designed to provide 12V, 2A current to each channel. Figure 5 shows the image of starting the engine using the proposed system. This type can be used directly or connected to the Arduino uno output and used as a controlled drive element. In Figure 5.c, a linear electric motor is an electrical machine that directly moves electrical energy without using an additional system. These machines are connected to two groups, personalized AC and DC. According to Lorentz's law, force occurs when current passes through a conductor placed in a magnetic field. The magnitude of the force is calculated by equation (1) as follows:

$$F = L.I.B = B.L.I.Sin\theta \qquad (1)$$

Here, F is the force formed in the conductor, L is the length of the conductor, I is the current through the conductor, B represents the magnetic flux density, and sin θ is the angle between the current and the magnetic flux. The linear motor driver circuit designed in line with the information received from Raspberry PI 2 and designed with L298N integrated.

The L298 is an integrated monolithic circuit



a) b) c)

Figure 5. System components.

in a 15-lead multi watt and PowerSO-20 packages. It is a high- voltage, high-current dual full-bridge driver designed to accept standard TTL logic levels and drive inductive loads such as relays, solenoids, DC and stepping motors. The electrical circuit diagram and switching signals of the L298 N driver are given in Figure 5 a, b and Figure 6.

Production and Assembly: The body, switch, and connection part to the tube will be 3D printed. Enteral bags and other materials will be ordered externally. However, as a contingency plan, if a suitable enteral bag is not available for the project, a compatible feeding bag with the NG tube, empty serum, and syringe head will be included.

Electronic Circuit Design: We can summarize the connections in the electronic circuit as follows (Figure 7):

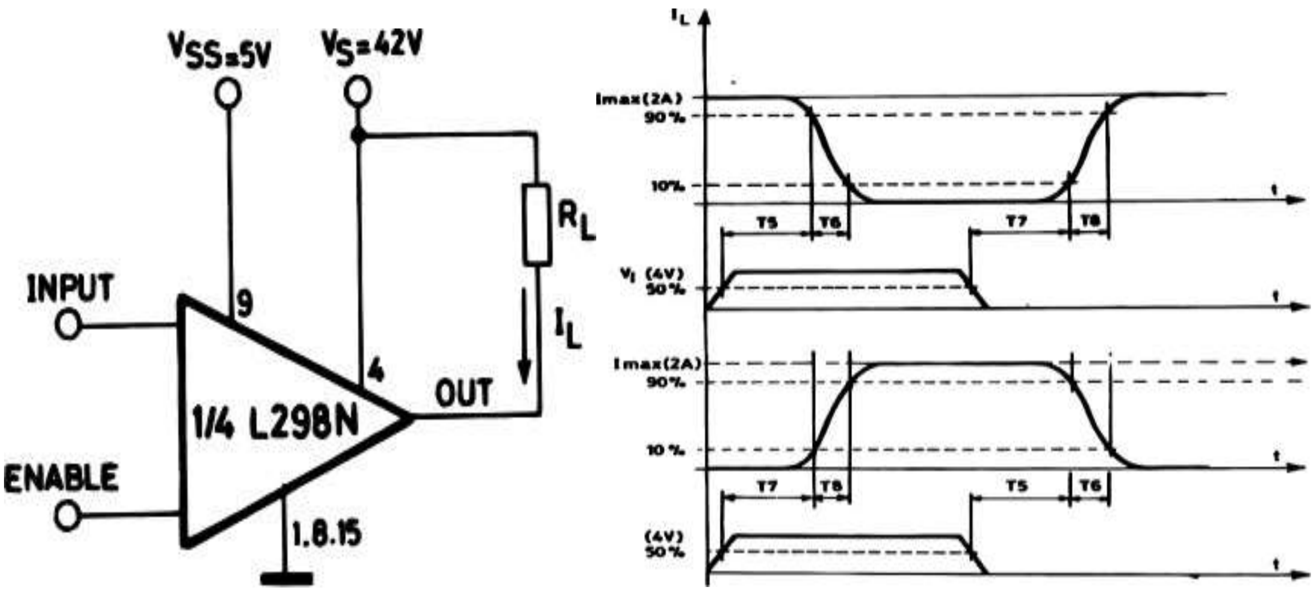


Figure 6. Electrical diagram and operating curves of 298 integrated circuit.

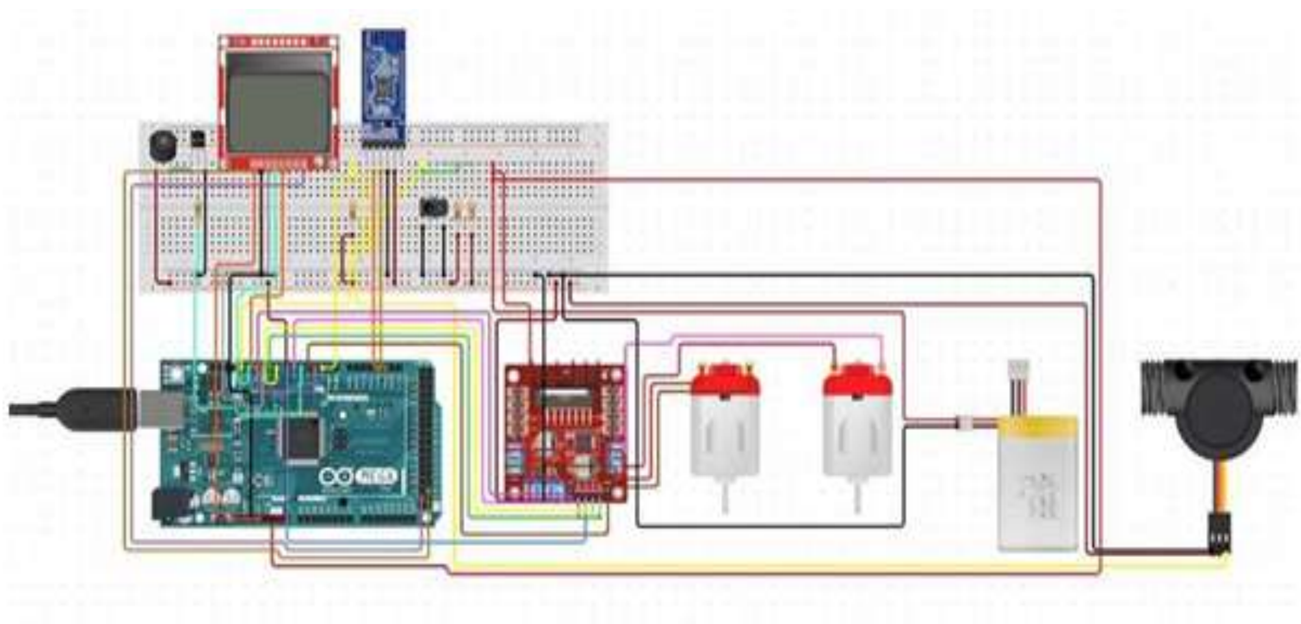


Figure 7. Electronic circuit diagram.

Notification Systems: The TCRTSOOO Infrared Sensor will be continuously communicating with a microcontroller (Arduino Uno R3). The device will control the dripping of the nutrient solution, thereby sending signals to the microcontroller in case of clogging or depletion of the solution, triggering alert notifications through a pre-connected buzzer and Bluetooth. A water flow sensor (flow meter) will connect to the microcontroller to exchange signals and monitor the flow rate of the nutrient solution through the feeding tube. The flow rate will be communicated to nurses via an LCD screen and Bluetooth, allowing them to adjust using a linear motor connected to the microcontroller, depending on whether the speed needs to increase or decrease.

Access System: The access system consists of three main components. The HC06 Arduino Bluetooth Module connects to the microcontroller (Arduino Uno R3) to facilitate remote signal, alert, and information delivery for nurses' use. Similarly, the LCD screen and keypad connect to the microcontroller to play a crucial role in providing close-range data input and interaction.

Power Connection: The circuit's power connection will be achieved using a rechargeable LiPo battery. The battery will form the primary power source for the circuit and will also be connected to the microcontroller (Arduino Uno R3) to measure the charge level. When a specific percentage level is reached, signals will be sent both to the LCD screen and via Bluetooth.

Design of Control Software: Firstly, the relevant libraries (RPi.GPIO, LCDLibrary, and Bluetooth) are imported into the Python program to utilize the functions of the LCD screen, keypad, and Bluetooth module. Pin connections for the used components are specified. GPIO settings are configured, and input/output pins are defined. Functions are defined for initializing and using the LCD screen. Subsequently, a function is defined to read input from the keypad. Another function is defined to facilitate data exchange using the Bluetooth module. A loop is created to read sensors and perform associated operations. Once all components are set up, the final test setup depicted in Fire 8 is obtained and the device is designed.

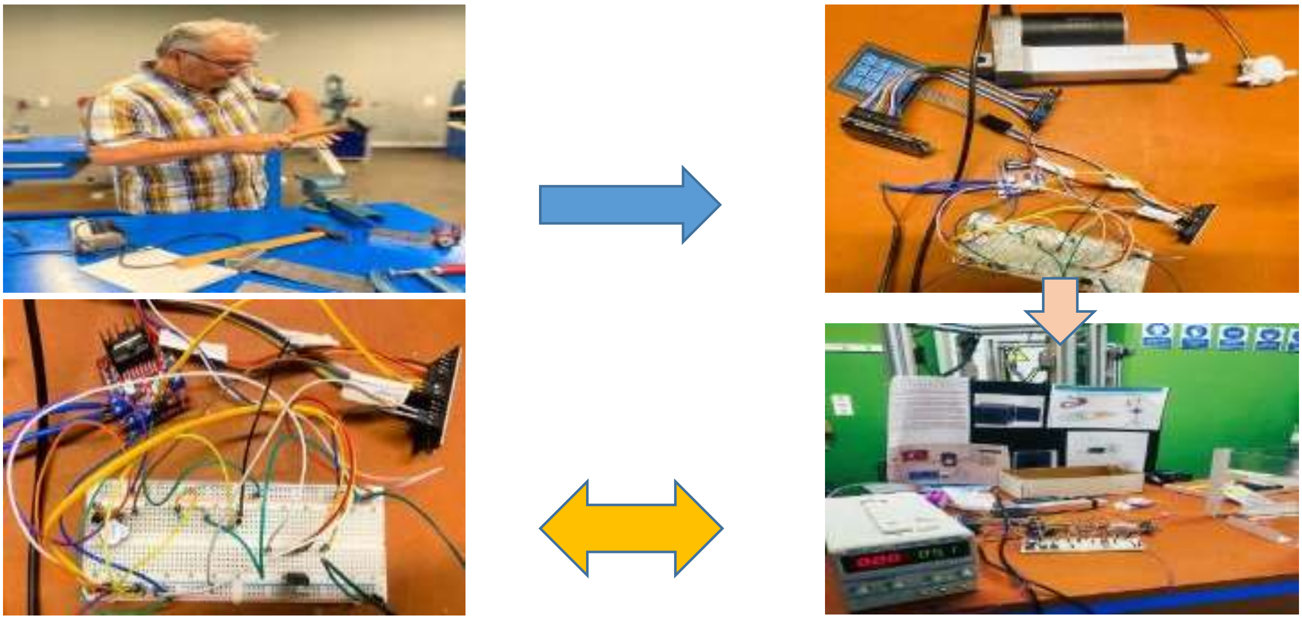


Figure 8. Experimental setup.

Results

In this study, a microcontroller-controlled nasogastric feeding pump was designed and evaluated through experimental tests. The key findings are as follows: Flow Rate Stability: The feeding pump successfully maintained a consistent flow rate of 50 mL/min throughout testing, with a ±2.5% error margin. The flow rate was measured over 10 independent trials, each lasting 5 minutes, demonstrating the system's ability to maintain stable performance under varying conditions (Figure 9). This precise regulation ensures accurate enteral nutrition delivery in critically ill patients.

Blockage Detection Performance: The blockage detection system was tested under different occlusion conditions (50%, 75%, and 100% blockage levels). The system successfully identified complete occlusions within an average of 3.2 seconds, while partial blockages were detected within 5.5 seconds. The detection method utilized real-time sensor-based monitoring to measure sudden pressure variations within the feeding tube (Figure 10). Additionally, the false alarm rate was recorded at 1.8%, ensuring high detection accuracy. This feature is crucial for preventing feeding interruptions and reducing clinical risks

Table 1. Performance summary of the developed nasogastric feeding pump.

Parameter	Developed Device
Flow Rate (mL/min)	50 ± 2.5% (10 trials)
Blockage Detection Time (sec)	3.2s (100% occlusion) / 5.5s (partial occlusion)
False Alarm Rate (%)	1.8%
Power Consumption (W)	6.5W
Battery Life (hours)	8h

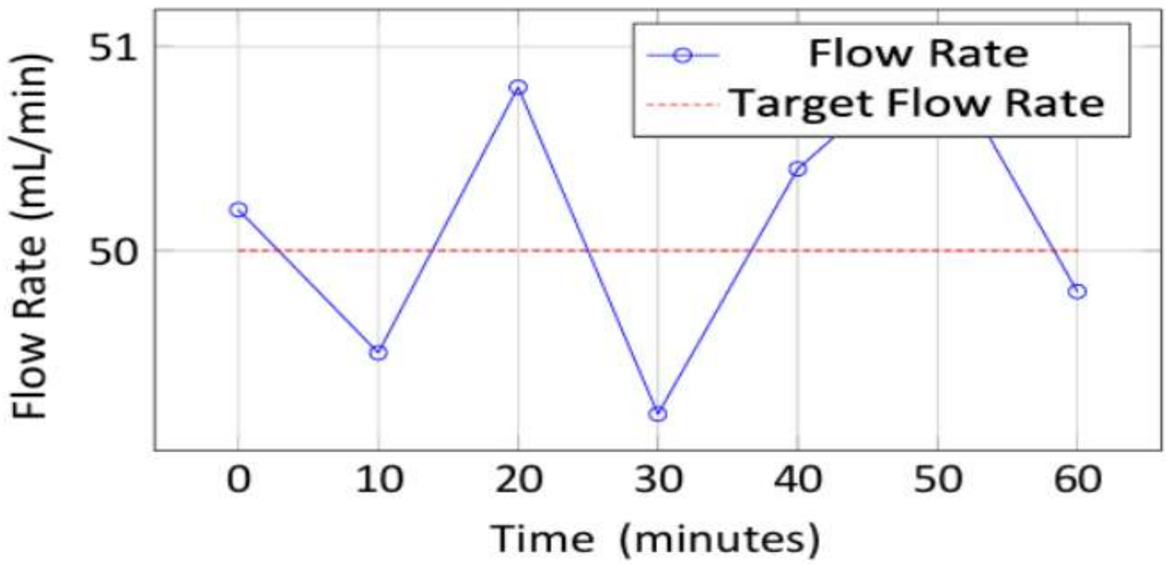


Figure 9. Flow rate stability over time.

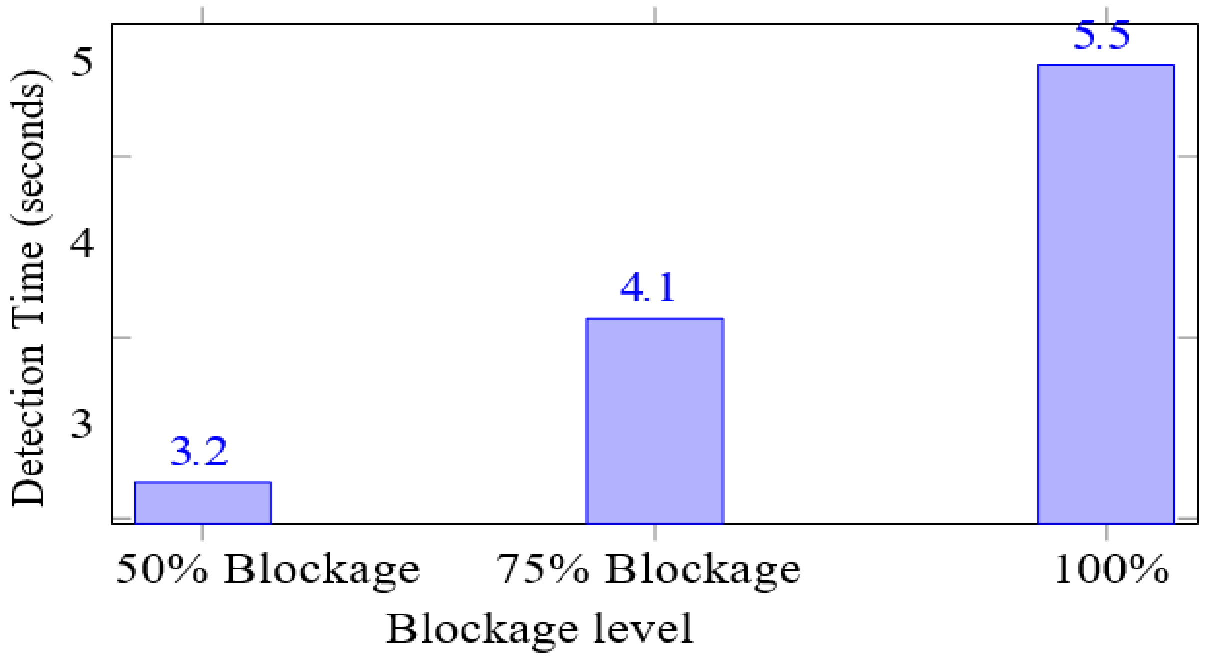


Figure 10. Blockage detection time at different occlusion levels.

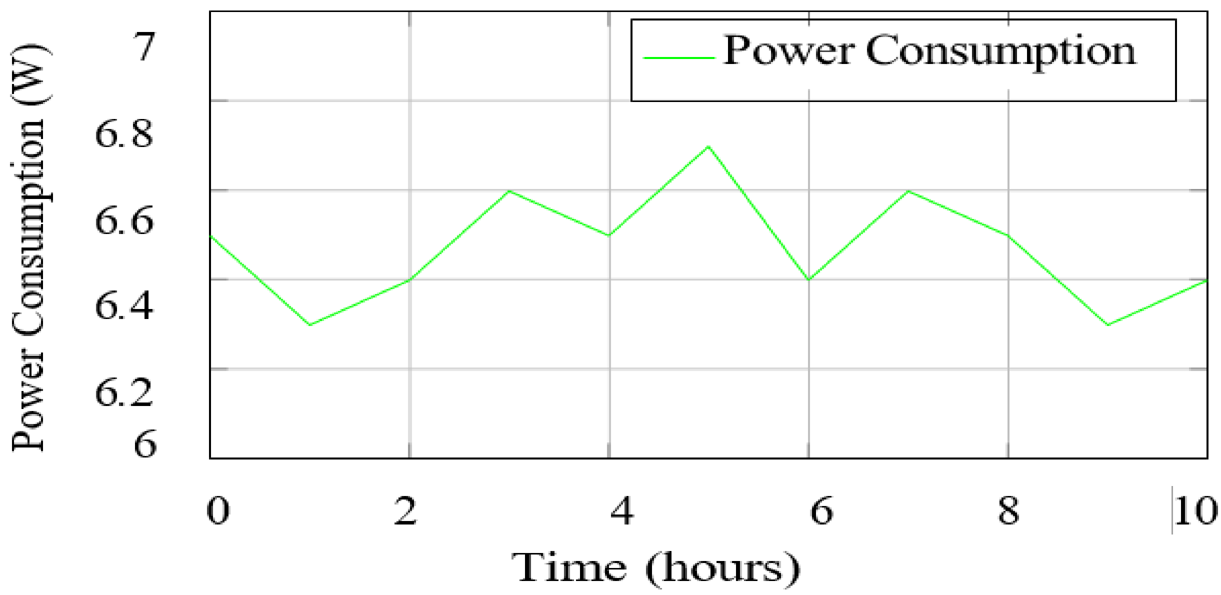


Figure 11. Power consumption over time.

associated with undetected tube occlusions. Power Consumption and Portability: The device exhibited a low average power consumption of 6.5W during operation. Battery efficiency tests showed that the system could operate continuously for 8 hours on a single charge (Figure 11). This extended battery life enhances the device's portability, making it suitable for both hospital and home-care applications where continuous feeding is required without reliance on direct AC power. Performance Summary: Table 1 provides a summary of the system's key performance metrics.

The performance of the developed microcontroller-based nasogastric feeding pump was analyzed in terms of flow rate stability, blockage detection time, and power consumption. The results demonstrate the effectiveness of the system in ensuring precise and reliable enteral feeding. As illustrated in Figure 9, the feeding pump maintained a stable flow rate of 50 mL/min over 60 minutes with minor fluctuations of approximately ±1.5 mL. This stability is essential for critically ill patients who require precise nutrient delivery. The ability to regulate flow rate with minimal deviation indicates that the device can be reliably used in intensive care settings.

The blockage detection system exhibited efficient response times for different levels of occlusion, as shown in Figure 10. The pump successfully identified 50%, 75%, and 100% occlusions within 3.2s, 4.1s, and 5.5s, respectively. While the detection time increased with higher occlusion levels, the device still demonstrated a rapid response, reducing the risk of prolonged tube blockages and associated complications. This feature is particularly advantageous in clinical applications where immediate intervention is required. The energy efficiency of the feeding pump was evaluated over a 10-hour operating period, as depicted in Figure 11. The device maintained an average power consumption of 6.5W, with minor fluctuations of ±0.3W. This low power consumption ensures extended battery life and enhances portability, making it suitable for continuous use in hospital or home-care environments. The findings from the performance evaluation indicate that the developed nasogastric feeding pump provides stable flow rate regulation, efficient blockage detection, and low power consumption. These characteristics make it a promising solution for improving enteral nutrition administration in critical care settings. The rapid response of the blockage detection system and the device's energy efficiency further emphasize its potential for enhanced patient safety and usability in clinical environments.

Discussion and Conclusion

In this study, a microcontroller-controlled pump and unit were designed to be used for nasogastric nutrition therapy. The deficiencies identified in currently available systems have been eliminated and a fully controlled nutrition system has been developed. The nutrition solution is transferred to the stomach with the help of a motor that uses sensor data. The undesirable situations, e.g., clog in the system, are monitored and the failures are reported (potential future failures are predicted). The developed system aims to increase efficiency in healthcare with its user-friendly interface and it being portable. The developed nasogastric feeding pump provides an innovative solution for precise, automated, and portable enteral feeding. The sensor-based blockage detection system enhances patient safety, while the low power consumption increases usability in both hospital and home-care settings. Future work will focus on integrating wireless monitoring systems and AI-based predictive maintenance to further optimize the device's performance.

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Conflict of Interest: *The authors declare that they have no conflict of interest.*

Ethical statement: *This study has been conducted in accordance with international ethical standards.*

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