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A Smart Enteral Feeding System Using Artificial Intelligence of Things for Efficient Nutrition Delivery

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ABSTRACT

This research introduced a smart enteral feeding system, employing Artificial Intelligence of Things (AIoT) principles for autonomous nutrition delivery. The system was developed and simulated utilizing an Arduino Uno, motor shield, system camera module, and a precisely calibrated pump motor, targets the enhancement of patient care by responding to cues of hunger detected through mouth opening. Upon mouth detection, the system triggers the precise administration of necessary food substances via a submersible water pump, deactivating seamlessly upon mouth closure. Rigorous testing determined the system's accuracy and automated feeding functionality, showcasing its potential for aiding healthcare workers and patient relatives in providing essential nutrition even in their absence. The developed system underwent thorough testing, demonstrating precise functionality. The system autonomously administered the necessary food substances to the patient. This Research's innovative AIoT-driven enteral feeding system presented a promising leap in healthcare technology, showcasing precise, autonomous nutrition delivery based on mouth detection cues, building upon and expanding the advancements seen in IoT-enabled healthcare systems. The research recommends further exploration into real-world implementation, advanced sensor technologies, remote monitoring capabilities, improved user interfaces, and rigorous reliability testing to augment the system's efficiency and widespread application in healthcare settings.

Keywords: Enteral Feeding, Artificial Intelligence, Nutrition, Feeding tube, Mouth Detection.

INTRODUCTION

The healthcare landscape has experienced remarkable technological strides in recent years, notably within the domains of Artificial Intelligence (AI) and the Internet of Things (IoT). These advancements have brought about a paradigm shift in healthcare, transforming diagnostics, treatment modalities, and patient care. Among the focal points of innovation lies the realm of efficient enteral feeding systems powered by Artificial Intelligence of Things (AIoT) (Kumar and Silambarasan, 2019).

Enteral feeding, the direct delivery of nutrition into the gastrointestinal tract via a feeding tube, serves as a pivotal method for patients unable to orally consume food due to various medical conditions or surgical interventions. However, this process demands intricate oversight to meet patients' nutritional needs while mitigating complications (Dunn, 2015).

The evolution of enteral feeding systems from rudimentary gravity-based setups to sophisticated pump-controlled mechanisms, typically comprising a feeding tube, pump, and feeding container, underscores the quest for precision in nutrition delivery (Cresci and Mellinger, 2006; White and King, 2014).

AI's emergence as a potent healthcare tool, capable of analyzing extensive patient data to discern patterns and offer recommendations, has found application in optimizing enteral feeding system. Leveraging AI to analyze vital signs, medical histories, and nutritional requisites, promises enhanced precision in nutrition delivery (Jeyaraj and Nadar, 2019).

Studies have delved into AI's role in enteral feeding systems, from predictive algorithms for optimal feeding rates to the development of real-time decision support systems (Dunn, 2015). Traditional systems reliant on manual oversight, present challenges such as time inefficiencies, error susceptibility, and inadequate real-time feedback. Addressing these limitations necessitates the creation of intelligent enteral feeding systems that harness AI and IoT to automate processes and optimize outcomes (Bond, Mccay, and Lal, 2023).

The specific objectives that guided the development of this smart enteral feeding system, and the simulations include:

i. Designing a system capable of accurately detecting and responding to cues of mouth opening for timely and precise administration of necessary nutrition.
ii. Creating a system that operates autonomously, minimizing the need for constant oversight by healthcare providers or caregivers.
iii. Leveraging AI algortihms and IOT devices to enable real-time monitoring, responsive feeding, and data-driven decision-making for optimized patient care.
iv. Conducting a thorough simulation to validate the system’s functionality, accuracy in mouth detection, pump control precision, and overall reliability, serving as a representative model for real-world implementation.

This research crafted an efficient enteral feeding system leveraging AIoT. Employing AI algorithms and IoT devices, the system aims to monitor and regulate enteral feeding in real-time, ensuring precise nutrition delivery while mitigating complications on patients. The project involved designing and prototyping an AIoT-based enteral feeding system, followed by comprehensive evaluations via simulations and experiments.

RELATED WORKS

The healthcare system poses one of the foremost challenges globally, drawing immense attention from researchers. The fusion of Internet of Things (IoT) technology with healthcare introduces a multitude of advantages through the integration of sensors, actuators, and intelligent devices (Tyagi, Agarwal and Maheshwari, 2016). Technologies like Wireless Sensor Area Network (WSN) enable the sensing, monitoring, and tracking of data through sophisticated sensors, contributing significantly to the IoT's evolution (Xu, He and Li, 2014).

Mishra, Kumari, Sajit, and Pandey (2018) proposed an IoT-based smart healthcare system for real-time patient data transmission. Utilizing sensors connected to patients and an Arduino Uno controller, the system transmitted body parameters to the cloud. Authors incorporated an AD8232 ECG sensor by Texas Instruments for web-based ECG monitoring, transmitting data to the MQTT cloud accessible via a web application. Focus was placed on real-time detection by collecting patients' physiological and environmental data through IoT in various healthcare realms, from pediatric to elderly care.

Srinivasan, Charan and Babu (2020) designed an IoT-based Health Monitoring System to record and alert critical patient readings.

Using Arduino Uno, LM35 Temperature Sensor, ESP8266 Wi-Fi Module, and Pulse Rate Sensor, the system collected patient data and promptly notified both guardians and doctors via emails and SMS. This remote monitoring approach swiftly diagnosed patient conditions, integrating data recording via ThingSpeak to enable internet-based health monitoring.

Santhosh, Ramanjaneya, Chakri and Ghai (2022) developed an IoT-based Auto-Feeding Machine for Animals, employing NTP server-synchronized microprocessors to activate feeding mechanisms for pets at scheduled times. Notifications were dispatched to monitor food container statuses, ensuring timely feeding and easing pet owners' concerns.

Kumar, Kaushal and Panda (2021) introduced the "Smart Portable Intensive Care Unit," an IoT-based model for real-time patient monitoring and remote drug delivery. Employing a five-parameter vital sign machine and a cloud-based server, the system transmitted patient data securely. An android-based mobile application allowed real-time access to patient data and facilitated remote drug infusion under professional supervision.

Abu-Khadrah, Shahzad, Issa, Ateeq, Aslam, and Hussain (2022) designed an IoT-based Smart Fish-Feeder and Monitoring System utilizing Raspberry-Pi-B+, Pi-Camera, and sensors to feed and monitor fish remotely. Despite some limitations, the system offered considerable benefits to fish owners.

Moreover, Mishra, Sheikh, Chore, and Kshirsagar (2019) created an IoT-enabled system for poultry bird care, integrating sensors and microcontrollers for feeding, water supply, and environmental observations. This IoT infusion facilitated ease of operation and real-time data observation through the internet, addressing crucial factors in preventing bird diseases.

The integration of IoT technology in healthcare has revolutionized patient monitoring and management. Various innovations have emerged, including smart medicine boxes, real-time patient data transmission, and remote monitoring systems, highlighting the immense potential and diverse applications of IoT in the healthcare domain.

As witnessed through these diverse studies, IoT's integration into healthcare not only streamlines processes but also empowers both healthcare providers and patients. The continual evolution and innovation in this field open doors for further exploration and refinement, propelling the healthcare industry towards a future marked by comprehensive, data-driven, and patient-centric care paradigms, hence this research.

MATERIALS AND METHODS

The method adopted for the development of a smart enteral feeding system is Artificial Intelligence of Things (AIoT), with the integration of Arduino Uno, Motor Drive Shield, submersible pump, and other necessary components for the simulation. The simulation process began by gathering and analyzing the requirements, such as the specific needs of patients, healthcare professionals, and the healthcare facility. Identify key features and functionalities, such as real-time monitoring, accurate feeding parameter recommendations, and integration with Arduino Uno and Motor Drive Shield. The system was built upon the Arduino Control Module and focused on the logic for dispensing nutrition accurately. This logic involved considering factors like the face's position or additional sensors for precise control. The motor control code was written and debugged on the Arduino IDE and then imported to the Arduino UNO microcontroller. The algorithm for the proposed system model is described as follows:

Data collection

i. Prepare a dataset of image frames capturing the patient's mouth open using a mediapipe python package.
ii. Label the dataset to indicate when the mouth is open and ready for feeding.
iii. Capture a variety of mouth-open scenarios to get the different conditions and patient characteristics.

Model training

i. Preprocess the collected image frames.
ii. Split the dataset into training and testing sets.
iii. Design and train a machine learning model using convolutional neural network to train data for detecting an open mouth.

System Initialization

i. Set up the Arduino Uno and motor shield.
ii. Connect the motor shield to the feeding pump motor using the JST plug connector.
iii. Set up and configure the system camera module.
iv. Establish communication between the Arduino Uno, Python codes, system camera module, and some other components.
v. Calibrate the motor shield to control the pump motor accurately.

Mouth opening detection

i. Process each image frame through the machine learning model.
ii. Analyze the model's output to determine if the mouth is open or closed.
iii. Set a confidence level for detecting a reliable mouth opening.

Pump motor controller

If the mouth is detected as open:

i. Send a control signal to the Arduino Uno to activate the pump motor.
ii. Calculate and set the desired feeding parameters i.e. the feeding flow rate and its volume based on the detected mouth opening.

Monitoring feeding process

i.Continuously monitor the feeding process through the camera module.
ii.Check for any issues, such as blockages, pump malfunctions, or changes in mouth opening status.
iii.If an issue is detected, pause the feeding process, alert the user, and provide appropriate instructions for troubleshooting.

Repeating the feeding cycle

i.If there are more feeding schedule sessions, then go back to step 4 above.
ii.If all feeding sessions are complete, then proceed to the next step.

Process termination

i.Provide a summary of the feeding sessions, which includes the total delivered volume and any recorded issues if it occurs.
ii.Allow the user to review and export the feeding session data if desired.

System shut down

i.Disconnect the feeding tube from the patient mouth.
ii.Clean and disinfect the equipment following the appropriate medical protocols.

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RESULTS AND DISCUSSION

Image Processing and Recognition Module

Figure 1 visually illustrates the sequence of operations conducted within this module: the capture of input frames from the webcam or camera, subsequent processing to detect the patient's facial features, and the output depicting the bounding box coordinates of the specifically identified mouth region.

Figure 1: Coordinates of Detected Face with Mouth Part

Within the image processing and recognition module, the utilization of OpenCV and MediaPipe libraries facilitated the processing and analysis of images captured by a camera. These libraries were instrumental in detecting the patient's facial features, particularly focusing on the precise identification of the face and mouth regions. The acquired data from MediaPipe's face detection mechanism provided essential information, notably the bounding box coordinates outlining the detected facial features.

The principal objective of this module centered on the accurate identification and continuous tracking of the patient's facial features through webcam or camera input. The identification of the patient's face served as a critical determinant in the enteral feeding process. It played a pivotal role in decision-making regarding the initiation or cessation of the enteral feeding procedure based on the detected facial features.

Arduino Control Module

The Arduino Control Module used an Arduino Uno with a motor shield that controlled the submersible water pump which was used as simulator of the proposed system. The Arduino listened for commands from the Python script through PySerial and adjusted the pump accordingly.

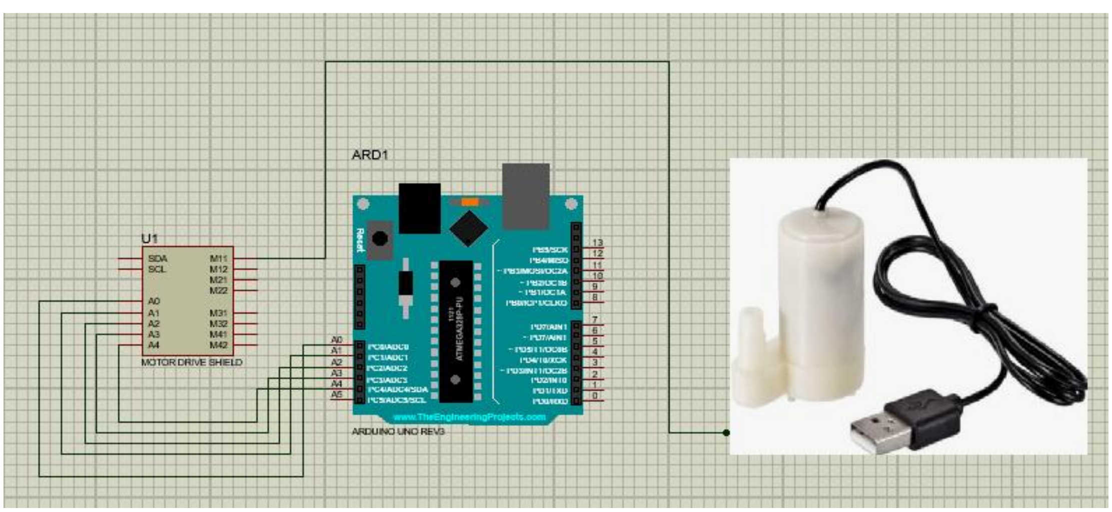

Figure 2: The Arduino Control Module

The PySerial was a Python module that provided a way to interact with serial ports on a computer. This module involved controlling the submersible water pump connected to an Arduino Uno and activating or deactivating the pump accordingly. The input commands were received via PySerial from the Python script, was processed by interpreting the received commands and controlled the motor shield to either start or stop the pump. Which represent either the system should feed the patient or not, this is depicted in Figure 2.

Nutrition Dispensing and Pump Control Module

The Nutrition Dispense Module operated within the Arduino Control Module, utilizing facial detection outcomes to control the pump's activation. Upon detecting the patient's open mouth, the system automatically administered the prescribed nutrition or food substances. Conversely, when the patient's mouth closure was detected, the feeding process ceased. This command was executed through the Python script, which integrated the logic governing the dispensing of nutrition within the Dispense Nutrition function. Ultimately, the system regulated the dispensing of nutrition through a simulated representation of the enteral feeding system, achieved via a submersible water pump.

Figures 3 and 4, presented below, illustrate the system's functionality in detecting mouth openness and closure, respectively. The system's design anticipates the patient's response to hunger, triggering mouth opening, whereby immediate feeding with prescribed food substances occurs upon detection. Conversely, mouth closure deactivates the feeding process, aligning with the system's responsive design.

DISCUSSION

This research presents an innovative approach towards enteral feeding by incorporating AIoT principles. It focused on leveraging AI algorithms and IoT devices to create an autonomous feeding system that responded to patients' cues for nutrition intake. The system's main components are: Arduino Uno, motor shield, system camera module, and a precisely calibrated pump motor to enable precise and automated nutrition delivery upon mouth detection and closure. Rigorous testing showcased the system's accuracy and its ability to autonomously administer food substances upon detecting mouth opening.

Similarly, it seamlessly deactivates upon mouth closure. This core functionality demonstrates responsiveness to patients' cues for nutrition intake, which is particularly beneficial in the absence of caregivers. The research utilized a simulated setup with a submersible water pump to emulate the feeding process allowed for thorough testing. However, transitioning this simulation to real-world settings through clinical trials would offer deeper insights into its practicality, efficiency, and user-friendliness.

The system discussed in this research stands out by integrating AIoT principles, surpassing conventional enteral feeding systems. While Mishra *et al*. (2018) and Srinivasan *et al*. (2020) focused on IoT-based patient monitoring, this system goes further by using AI for real-time decision-making regarding nutrition delivery based on detected cues, enhancing precision. Unlike the systems developed by Santhosh *et al*. (2022) for animal feeding or Kumar *et al*. (2021) for patient monitoring, this system uniquely incorporates facial recognition.

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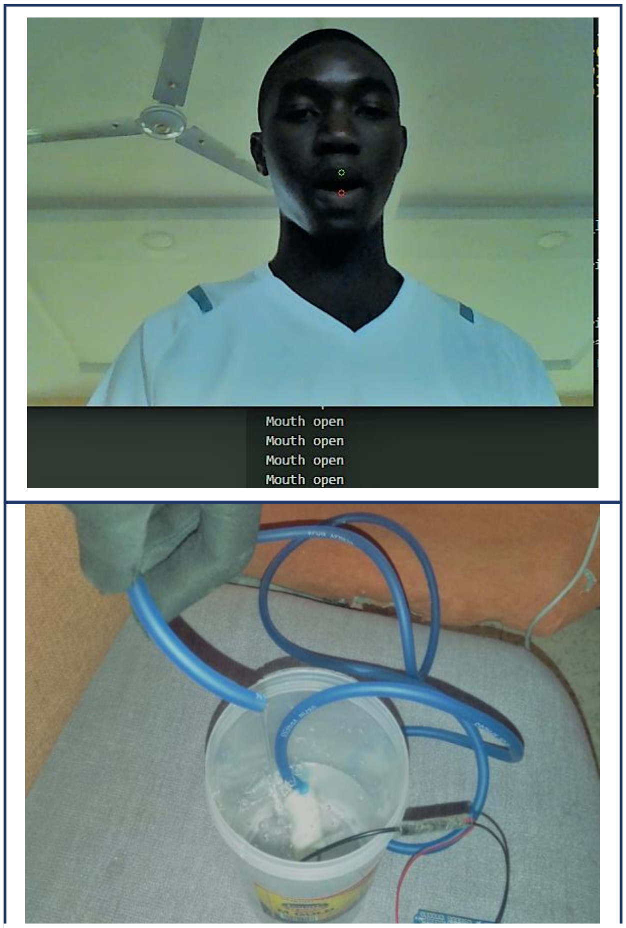

Figure 3: Open mouth detected

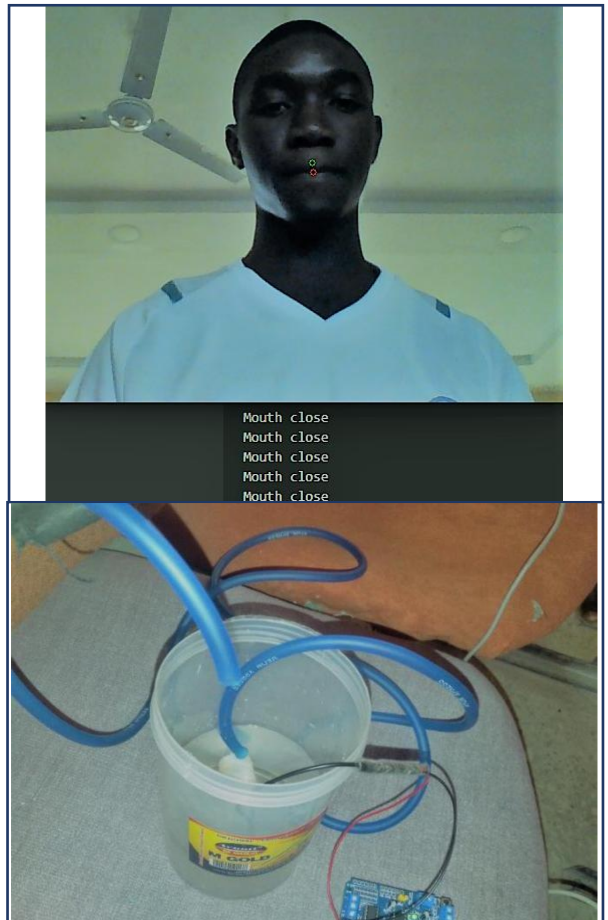

Figure 4: Closed mouth detected

The utilization of facial detection mechanisms aligns with the trend seen in Mishra *et al.* (2018) work on IoT-enabled patient data transmission. However, this research takes it further by training a machine learning model specifically for detecting mouth opening, which is crucial for precise enteral feeding. The progression from rudimentary gravity-based setups to sophisticated pump-controlled mechanisms, as discussed by Cresci and Mellinger (2006) and White and King (2014), serves as the foundation for the precision sought in enteral feeding. This research introduces a new layer of precision by incorporating AI algorithms to detect and respond to patient cues for feeding.

By drawing from and expanding upon these previous studies, the current research on an AIoT-based enteral feeding system contributes to the evolution of healthcare technology. It showcases advancements in automation, precision, and patient-centric care, addressing specific challenges associated with enteral feeding while building upon the groundwork laid by prior research in IoT-driven healthcare innovations.

CONCLUSION

The developed system, simulated using a submersible water pump, underwent thorough testing, demonstrating precise functionality. Upon detecting mouth opening, the system autonomously administers the necessary food substances to the patient. Conversely, upon mouth closure, the feeding process deactivates seamlessly. This functionality showcases the system's accuracy and responsiveness to the patient's cues for nutrition intake, even in the absence of caregivers.

Recommendations

Implementing these following recommendations could augment the system's efficiency, accuracy, and practicality, paving the way for its widespread adoption in healthcare settings.

1. Real-world Implementation: Consideration should be given to transitioning this simulated system into a real-world setting for clinical trials and further validation. Real-time patient trials could offer valuable insights into its practicality and efficiency.

2. Enhanced Sensor Technology: Exploring advanced sensor technologies to augment the system's accuracy in detecting and interpreting patient cues, thereby refining the feeding process and responsiveness.

3. Remote Monitoring Features: Incorporating remote monitoring capabilities could enhance the system's utility, enabling caregivers to oversee and adjust feeding protocols remotely, adding convenience and flexibility.

4. User Interface Improvement: Enhancing the user interface and communication features to facilitate seamless interaction between caregivers, patients, and the system, ensuring ease of operation and understanding.

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