Internet of Things Empowerment: Enhancing Healthcare Access for Deaf Patients

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***Abstract*—This paper designs an Internet of Things(IoT) based support system to empower deaf patients by enhancing communication with healthcare providers and family members through wireless communication. Hearing-impaired individuals, especially deaf patients, face communication barriers that prevent them from seeking efficient healthcare services, such as timely medication adherence and seeking assistance from healthcare providers and family members. To address these challenges for deaf patients, the proposed system provides alerts, enables patients to confirm medication adherence, monitors vital signs, shares real-time data updates on a hospital portal, and sends direct text notifications in case of emergencies. The device is trained using specific command phrases and has achieved an average accuracy of 98% during various data trials.**

***Index Terms*—Internet of Things (IoT), MERN, sign language, vital signs.**

I. Introduction

Internet of Things (IoTs) offers significant benefits for accessibility, navigation, monitoring, and communication of physically challenged community [1]. Among this community, hearing-impaired individuals face various daily challenges [2]. The communication barrier between deaf patients and healthcare workers stands out as one of the most significant hurdles to access quality healthcare services. Deaf patients are unable to express their emotions in the same way as hearing individuals without translation. When they feel unwell or need to visit the hospital, they must bring someone to interpret sign language for them. Besides these communication barriers, healthcare providers face challenges when they need to record the indicators of illness of a patient such as a heart rate, body temperature, respiration and blood pressure. These parameters must be consistently and accurately measured and recorded [3]. When the hospital is overwhelmed with patients, it becomes difficult for nurses to measure each patient at the specified time. Consequently, patients' lives may be at risk when they do not receive the necessary attention from nurses. [4] [5]. The main contributions of this article are as follows.

- Design an IoT-Empowered multi-purpose system to facilitate easy access to healthcare services for deaf patients. This system enables healthcare providers to monitor medication adherence and includes an alerting system for timed patient prompts directed by healthcare providers.
- Implement a patient status portal that enables healthcare providers to monitor the patient's real time status. It features a vital sign monitoring system and sign language translator, allowing nurses to access to the updates from their stations without the need to visit the patient's room.
- Include patient engagement features and emergency communication capabilities in the system. This allows patients to request assistance from nurses, family, and the device can send text messages with out-of-range values in case of urgent needs.

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The rest of this paper is organized as follows. We review related work in section II and present the system model in section III. We present the system implementation in section IV. We analyze the performance of our system and provide experimental results in section V. Conclusion and future enhancements are drawn in section VI.

II. Related Work

Various research works have addressed the communication barrier faced by hearing-impaired individuals. The authors in [6] proposed a gesture-based game using the Microsoft Kinect SDK to enable deaf and mute individuals to communicate through body movements. In [7], a gesture-based communication to text/speech model that can facilitate two-way communication without an interpreter was introduced. Additionally, in [8], hand gloves have been developed to detect American Sign Language by recognizing English alphabets.

While notable advancements have been made in previous works to address the communication barrier challenge, deaf patient's medication management and communication needs have not been adequately considered in recent works, which requires attention from the research community. In practice, there is often insufficient emphasis on notifying and monitoring deaf patients for timely medication intake. These individuals often rely on remote assistance from family members or healthcare providers to manage their medication regimens effectively. Additionally, monitoring patient status spikes, especially among those with chronic illnesses, is a

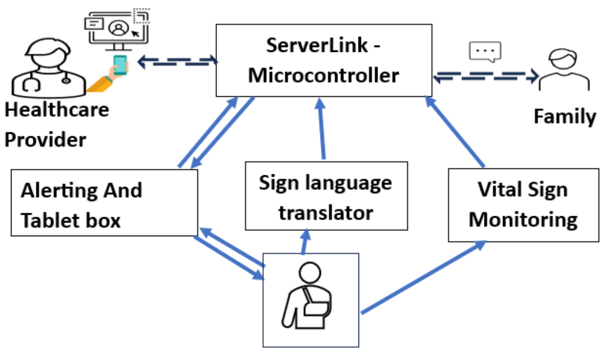

Fig. 1. System Model.

critical yet often overlooked aspect, as it requires frequent doctor visits and lifestyle adjustments.

III. System Model

Our system model comprises of four components, including a deaf alerting and tablet box, a vital sign monitoring, a sign language translator, and a ServerLink-Microcontroller. The deaf alerting system alerts the patient to take the appropriate medication from the tablet box. The vital sign monitoring system records the patient data and receives the instructions from the healthcare provider using a wireless communication system, either as text or database updates. The sign language translator is a wearable device placed on the hand of the disabled person enabling the interpretation and translation of sign language gestures. The ServerLink-Microcontroller is connected with the user interface and facilitates wireless transmission and reception of data commands among the deaf patient, healthcare provider, and family member, as shown in Fig. 1. Detailed implementation is present in the next section.

IV. System Implementation

In this section we discuss our system design and data flow in each component. For the alerting system, when the doctor or caregiver needs to recommend the patient to do specific task, such as taking tablet, or when they have a message to convey, they send an instruction using either direct message or a user interface. The message command is formatted as "T-hour-minute-day-month, message", indicating the specified time for the task. To send this message, we use ServerLink-Microcontroller, which includes a Raspberry Pi micro-controller connected with a server. A real time clock module is connected to the micro-controller. When the user needs a reminder, the micro-controller checks the set time for the message, and the micro vibration motor awakes the patient and displays the message on the LCD screen. After a few minutes, when the patient takes the tablet, the load cell inside the compartment registers a decrease in weight, and activates the non-contact magnetic switch. If the switch is not activated, it stays in an inactive state and sends back message to the caregiver indicating task has not done, as shown in Fig. 2.

The vital sign monitoring system consists of a non-contact temperature sensor, a pulse sensor, a Raspberry Pi and a

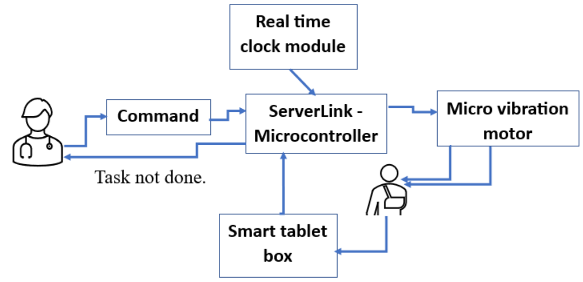

Fig. 2. Deaf Alerting and smart tablet box .

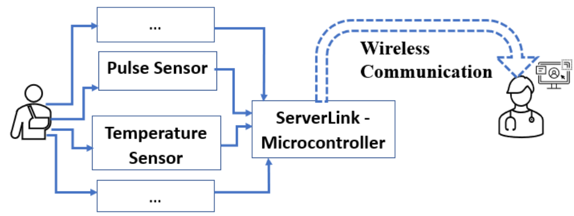

Fig. 3. The IoT Based Vital Sign Monitoring System.

wireless communication system. It measured both the body temperature and pulse rate. The Raspberry Pi retrieves the recorded patient information and sends patient data via internet or direct message. Healthcare providers can view the updates in the client side of the patient portal, as shown in Fig. 3.

The gesture recognition system consists of accelerometers and flex sensors, all integrated and placed on the hand of the disabled person. Flex sensors are employed to detect the hand movements, such as finger bending, and convert them into electrical signals. The microcontroller receives data from flex sensors, processes it, and sends instructions based on the specific gestures. To detect the tilt movements of the patient, we use the MPU-6050. Moreover, the system contains switches for power control and mode switching from healthcare provider to family member and vise versa. We separate the switching and controlling electronic components to ensure a flexible and light weight device.

The User Interface is a portal interface that enables the healthcare provider to send data and visualize the patient status remotely. When there is a spike in the patient health status or when patient requires assistance, the device sends a message to the healthcare provider, allowing them to access detailed patient status information in the portal. The Raspberry Pi micro-controller is used to send and receive the messages as needed. We use MERN stack [9] to implement user interface, server data reading and data storage.

When powered on, the system begins recording patient data. After recording the patient's data, the system verifies whether the data falls within predefined boundaries to identify a potential spike in patient's status. If such an anomaly is detected, the system promptly notifies the healthcare provider through a secure portal or a text message, ensuring that healthcare professionals are alerted to any concerning patient data. Once the system has ensured that the patient's data is

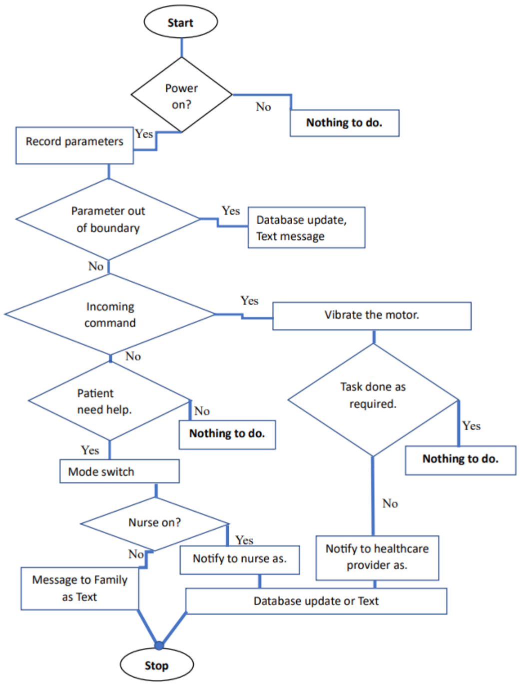

Fig. 4. Data Flow Diagram.

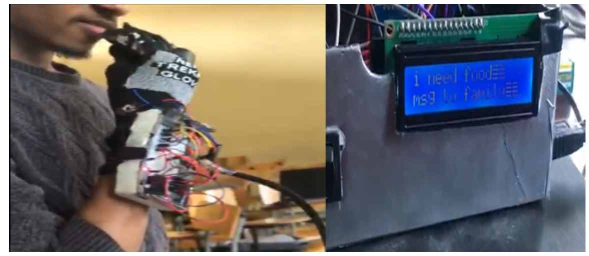

Fig. 5. Hardware prototype

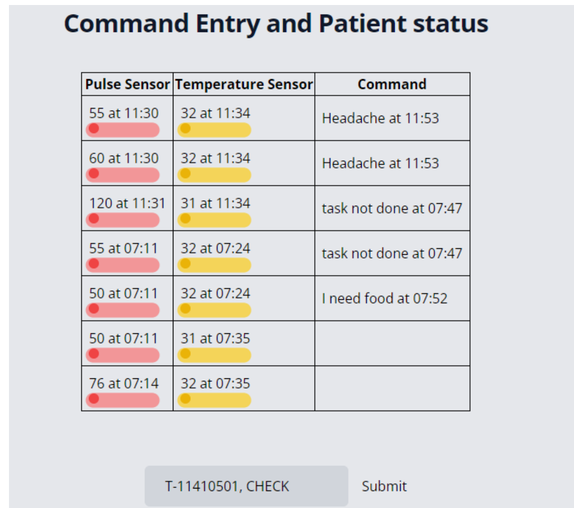

Fig. 6. Patient portal.

within expected ranges, it awaits incoming commands from the healthcare provider. If a command is received, the system takes action by activating a motor to vibrate, awakening a deaf patient. Subsequently, it checks whether the patient has successfully completed the task specified in the command or not. If the patient has complied, no further action is taken. However, if the task is not completed as required, the system updates the database on the portal or sends a text notification to the healthcare provider, keeping them informed of the situation. In the absence of incoming commands from the healthcare provider, the system assesses whether the patient requires assistance. If the patient needs an assistance, the system switches to the appropriate mode, which can be designates as a 'family member' or 'nurse' mode. In nurse mode, the system notifies the nurse through the database portal or via text message, indicating that the patient requires assistance from a healthcare professional. In family member mode, the system sends a message to a designated family member, requesting assistance, such as bringing food or providing support. The data flow diagram is shown in Fig. 4.

V. Performance Evaluation

A. Hardware Prototype

The overall hardware prototype of the project is shown in Fig. 5. The proposed prototype includes a sign language translator, the tablet box, and the component casing and shows "I need food " as an example of command sent to the family, in which the patient gesture records accordingly the microcontroller sends the message to the family saying that I need such assistance.

Fig. 6 shows the sample portal user interface update when an anomaly happens. The spike data is recorded from the deaf patient and displayed on the simple web portal. Along with that, it allows the healthcare provider to send any command to the patient to do some tasks. For example, task code "T-11410501, CHECK" means that the patient should take a tablet at 11:41, 05/01.

The Flex value reading collects analog values from the sensor, which range from 0 to 1023, and the x, y, z gravitational forces, representing the tilt movement of the hand with values varying from -1.2 to 1.2. We conducted training with five different hand sizes, as illustrated in Table I, and observed a small difference in values as the hand size changed. From the collected data, we established boundaries for each command, as shown in Table II. For example, "x" indicates that the value is out of boundary and we failed to record the gesture.

B. Performance Evaluation Metrics and Results

In this subsection, we evaluated the performance of our proposed system. To that end, we defined the metrics used for the evaluation. Specifically, True Positives (TPs) are the data points, which the device classified as spike and the actual outputs are also spike. True Negatives (TNs) are the data points which the device classified as normal and the actual outputs are also normal. False Positives (FPs) are the data points which the device classified as spike and the actual outputs are normal.

TABLE I
DATA TRIAL FOR "I HAVE SEVERE HEADACHE CMD"

Sensors	*Trial1*	*Trial2*	*Trial3*	*Trial4*	*Trial5*	*Range diff*
Flex1	447	443	442	449	451	9
Flex2	514	512	508	508	518	10
Flex3	487	480	479	485	488	9
Flex4	494	483	483	485	486	11
Flex5	512	512	519	527	522	15
X	0.16	0.17	0.17	0.20	0.19	0.04
Y	-0.69	-0.69	-0.70	-0.70	-0.71	0.02
Z	0.82	0.80	0.79	0.80	0.79	0.01

TABLE II
PERCENTAGE RESULT OF THE SAMPLE TRIALS

CMD	*Trial1*	*Trial2*	*Trial3*	*Trial4*	*Trial5*
I need food	✓	✓	✓	✓	✓
I need money	x	✓	✓	✓	✓
Severe headache	✓	✓	✓	✓	✓
Help nurse	✓	✓	✓	✓	✓
Stomach ache	✓	✓	✓	✓	✓
Accuracy (%)	80	100	100	100	100

False Negatives (FNs) are the data points which the device classified as normal and the actual outputs are spike.

For the monitoring sensor evaluation purpose, we conducted 10 measurements for both the temperature sensor and the pulse sensor (five normal and five spike values by adding offset). To assess the accuracy, precision, sensitivity and specificity of the monitoring sensors, we employ a confusion matrix, which summarizes the prediction results in a classification table.

Table III shows the recorded data from the temperature and pulse sensors. From the table, we observe five true positives and zero false positives (indicating five out-of-boundary anomalies), along with five true negatives and zero false negatives (representing five patient records in normal status) recorded from the temperature sensor. However, our system device experienced a failure, resulting in four true positives, zero false positives, five true negatives, and one false negative. With the same expectations for the pulse sensor, we encountered a discrepancy as we recorded four true negatives and one false positive. Utilizing these data, we evaluate the accuracy, precision, sensitivity, specificity of the temperature and pulse sensor, which are determined by

$$\text{Accuracy} = \frac{TP + TN}{TP + TN + FN + FP},$$
$$\text{Precision} = \frac{TP}{TP + FP},$$
$$\text{Sensitivity} = \frac{TP}{TP + FN},$$
$$\text{Specificity} = \frac{TN}{TN + FP}.$$

The results are demonstrated in Table IV.

TABLE III
CONFUSION MATRIX

Sensor	*Normal*	*Spike*	*TP*	*TN*	*FP*	*FN*
Temperature sensor	5	5	4	5	0	1
Pulse sensor	5	5	5	4	1	0

TABLE IV
SENSOR EVALUATION

Sensor	*Accuracy(%)*	*Precision(%)*	*Sensitivity(%)*	*Specificity(%)*
T-sensor	90	100	80	100
P-sensor	90	83	100	80

VI. CONCLUSION AND FUTURE ENHANCEMENTS

In our study, we delved into the feasibility of recognizing sign language to empower deaf patients to request assistance remotely. We introduced an IoT-based multi-purpose system designed to enhance the overall patient experience during treatment. Notably, our proposed system has demonstrated remarkable success in accurately capturing the patient's hand gestures and executing corresponding commands, thus showcasing its potential to significantly improve the quality of care and accessibility for deaf patients. In future work, we would like to advance the development of the proposed system by expanding the data command storage capability.

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