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Development of an IoT-based Augmentative and Alternative Communication (AAC) for stroke patients using QFD

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ABSTRACT

Stroke is one of the leading causes of death globally, after heart disease and cancer. It often results in brain damage that impairs the function of certain body parts, including the ability to communicate. Communication disorders in stroke patients can severely impact mental health and quality of life, with studies showing that 53% of affected individuals experience depression. This study aims to design and develop an assistive communication tool tailored to the needs of stroke patients. The Quality Function Deployment (QFD) method was employed to ensure that user requirements are thoroughly addressed in the design process. Data were collected through observations and interviews with nurses and families of stroke patients. The House of Quality (HoQ) analysis revealed three main priorities for development: an integrated information system, blink-based control, and a feature to detect patient needs. The resulting solution is IISAAC (IoT-based Integrated System with Augmentative and Alternative Communication), a communication system that uses eye blink signals detected via an EOG sensor. These signals are converted into specific messages and sent directly to the nurse's WhatsApp application. IISAAC enables more effective communication between patients, caregivers, and medical staff, helping to address the communication barriers commonly experienced by stroke survivors.

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1. INTRODUCTION

Stroke is the leading cause of death and long-term disability worldwide, ranking first in 2019 for both mortality and disability-adjusted life years [1]–[3]. In Indonesia, the 2018 National Basic Health Research

(RISKESDAS) survey estimated a prevalence of 10.9 stroke cases per 1,000 population—approximately 2,120,362 people [4]. Although most Indonesian stroke survivors are 45–75 years old, a substantial share (5.7 %) are in the productive 18–44-year age group [5].

Stroke arises from brain injury that disrupts the functions controlled by the affected cerebral regions [6]. According to Tadi and Lui [7], such injury may be precipitated by chronic hypertension, atherosclerosis, cardiac embolism, arterial dissection, or various vasculitides. One of the most debilitating sequelae is a disorder of verbal communication [8]–[13].

Verbal communication disorders manifest as difficulty expressing ideas, understanding spoken language, and forming words [14]. Because humans are inherently social, communication deficits profoundly affect mental health and overall quality of life: roughly 53 % of individuals with such disorders develop depression [15]. Post-stroke depression not only burdens caregivers but also impedes rehabilitation and daily functioning [14].

Interviews with three caregivers responsible for 17 stroke patients underscore this burden. Fifteen patients were completely bedridden, able to communicate only by blinking or slight nods. Caregivers struggled to interpret their needs, and misunderstandings often led to patient frustration. Continuous supervision was necessary because patients could not call for help in emergencies. These communication barriers thus reduce the quality of life of both survivors and caregivers, despite the well-established importance of family involvement in stroke care [16].

Accordingly, this study aims to design and develop an Augmentative and Alternative Communication (AAC) system based on Internet of Things (IoT) technology to overcome communication barriers experienced by stroke survivors.

2. METHODS

The development of an information system device utilizing Augmentative and Alternative Communication (AAC) based on the Internet of Things (IoT) was carried out using the Quality Function Deployment (QFD) method. QFD is a structured approach used in product planning and development to identify customer needs and translate them into technical specifications for product design and evaluation [17], [18]. This method helps transform the voice of the customer (VoC) into product features that effectively address their needs and expectations [19]. QFD has been widely applied in various product design studies [20]– [28] , including those related to healthcare products [29]–[32].

The development process of the device in this study consists of the following stages:

1. Data Collection
   The data required in this study includes the voice of the customer (VoC), which was obtained through interviews with hospital nurses who care for stroke patients and with family members of stroke survivors. In addition, anthropometric data, specifically head length and head width, were sourced from the Indonesian anthropometry database.
2. House of Quality (HoQ) Design
   The House of Quality (HoQ) is a matrix diagram shaped like a house that illustrates the relationship between customer requirements and the technical means by which a product is developed to meet those needs [33]. The House of Quality (HOQ) is the fundamental element in the first phase of QFD because it accurately translates customer needs into a set of technical requirements for the final product [29]–[32]. The construction of the HoQ in this study was based on the gathered VoC data.
3. Device Design
   The design of the device was guided by the results of the HoQ and anthropometric data to ensure that the product meets user needs and adheres to ergonomic principles. The design process began with the creation of conceptual models using the black box and transparent box approaches. These conceptual designs were then broken down into sub-functions. Subsequently, the detailed design was developed, including the device layout, Bill of Materials (BoM), and an overview of the system architecture.

3. RESULTS

3.1. Data Collection

Voice of customer (VoC) data were collected through interviews with two hospital nurses who cared for 16 stroke patients and 16 family caregivers of a stroke patient. Interviews were conducted both in person and via Zoom Meetings. The VoC was translated into customer needs, and corresponding functional requirements were identified. Table 1 presents the VoC, customer needs, and functional requirements.

Table 1. Voice of Customer, Customer Needs, and Functional Requirements

Voice of Customer	Customer Needs	Functional Requirements
Difficulty understanding the patient's needs	Translate the patient's needs	Device equipped with the need detection system
Must monitor patient 24/7	Real-time patient monitoring	Integrated with information system
The patient should know when the caregiver is on the way	Two-way communication	Equipped with a small speaker
Hard to detect emergencies	Fast response	Eye-blink control system
The patient's limited movement should not be a burden	Easy operation	Made of soft materials
Should not disturb the patient's comfort	Comfortable to wear	-

The design of this device was adjusted to the body dimensions of Indonesian adults. The width and length of the head were used to determine the appropriate length of the headband. Anthropometric data were obtained from the 2018 Indonesian Anthropometric Data Report. The relevant dimensions were head length (D26) and head width (D27) for individuals aged 45 and above, shown in Table 2.

Table 2. Anthropometric data [38]

Dimension	Description	Percentile Used	Size (cm)
D26	Head Length	95th	18.6
D27	Head Width	95th	20.5

3.2. House of Quality (HoQ) Design

The House of Quality was designed based on the customer needs and functional requirements. A questionnaire was distributed to the respondents to assess the Importance to Customer (IC) values. The questionnaire was designed using a Likert scale ranging from 1 to 5. The results from respondents are shown in Table 3.

Table 3. Importance to Customer (IC) results from respondents

Aspect	Score Total	Average
Translate patient's needs	13	4.33
Real-time patient monitoring	14	4.67
Two-way communication	13	4.33
Quick response to stimulus	12	4.00
Easy to operate	13	4.33
Comfortable to use	13	4.33

The IC values were then integrated into the HOQ matrix, including the relationship between customer requirements and functional requirements, and among the functional requirements themselves. This matrix was used to calculate the Technical Importance Rating, Relative Weight, and to determine the priority of features. The resulting HOQ matrix is shown in Figure 1.

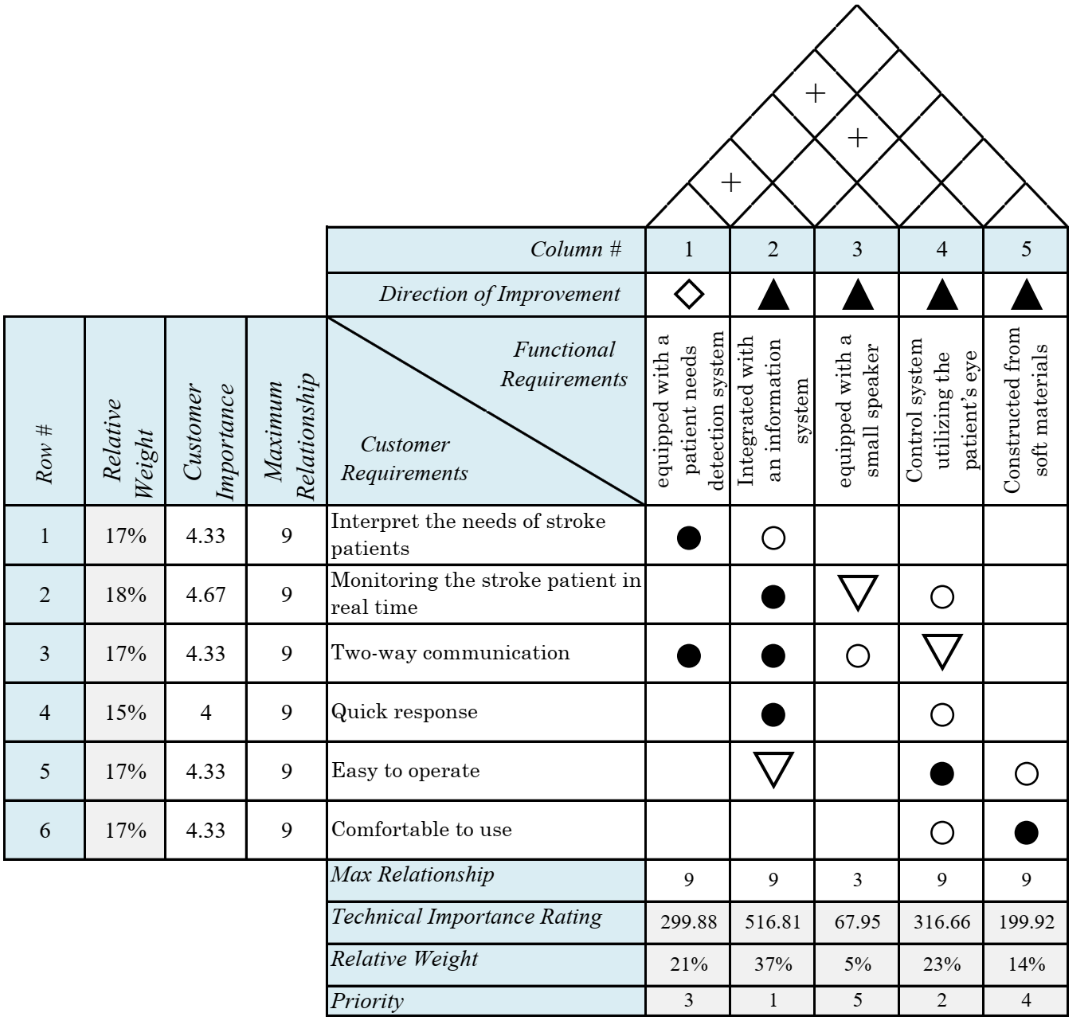
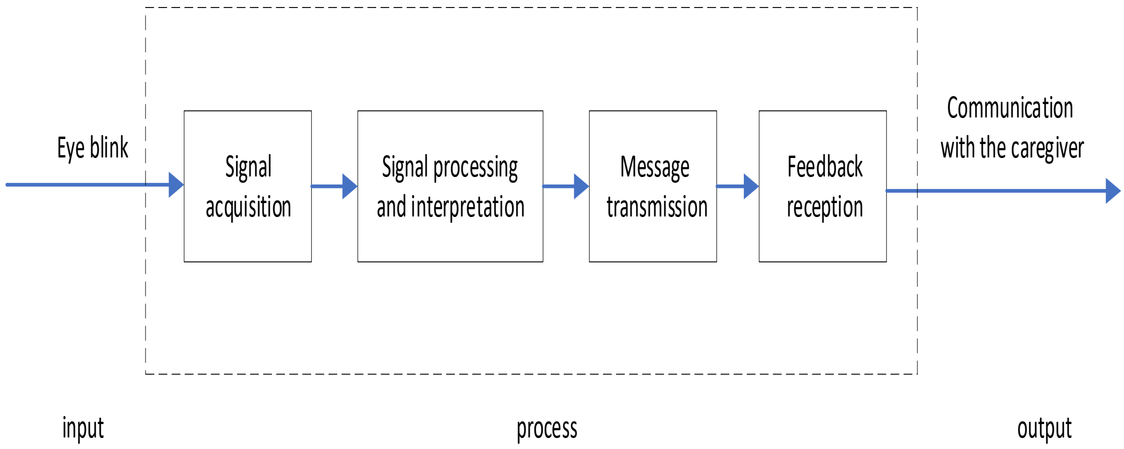


Figure 1. House of Quality (HOQ)

3.3. Device Design

Device development will prioritise an integrated information system, eye-blink-based control, and a need-detection mechanism for stroke patients before addressing other functional requirements, such as the use of soft materials and integration of a small speaker. The design process begins by developing a basic concept using black box and transparent box models. These models are then translated into the device's subfunctions. The general conceptual design of the device is presented in Figure 2, while the sub-functions are outlined in Table 4.

(a) Black box model



(b) transparent box model

Figure 2. General conceptual model of the device: (a) black box model; (b) transparent box model

Table 4. Sub-function of the device

No	Sub-function
1	Signal reception
2	Signal processing and translation
3	Message transmission
4	Feedback reception

The device was designed by aligning each sub-function with the prioritized functional requirements identified in the HOQ analysis. Because the highest-ranked requirement is seamless information exchange, the core architecture adopts an Internet-of-Things (IoT)–enabled information system combined with Augmentative and Alternative Communication (AAC) features. The resulting prototype, termed IISAAC (Integrated Information System with Augmentative and Alternative Communication), consists of two main components: (i) a hardware module worn by the patient and (ii) a cloud-based software platform. To maximise accessibility, the software layer is interfaced with WhatsApp, a widely used messaging application.The next design priority is an intuitive control mechanism that captures eye blinks from stroke patients. All subjects in the preliminary study retained the ability to blink, whereas other voluntary movements were far less consistent. Consequently, the head-mounted device incorporates Electrooculography (EOG) sensors that detect eye-blink signals. These signals are processed by an onboard algorithm and translated into predefined statements that convey the patient's needs. Need-detection logic resides within the hardware. Sensor data are filtered, feature-extracted, and classified to generate a text command, which forms the basic communication unit transmitted to the caregiver via WhatsApp.Comfort was also a critical requirement; therefore, the device is embodied as a soft, adjustable headband. A headband offers secure placement without impeding the patient's limited mobility. Soft materials reduce pressure points and skin irritation, while dimensional parameters follow the 95th-percentile values for head width Eq.1 (D26 = 18.6 cm) and head length Eq.2 (D27 = 20.5 cm) from the 2018 Indonesian anthropometric database. The resulting headband length is calculated to ensure a comfortable fit for the vast majority of adult stroke patients.

$$headbend\ width = \quad D26 = 18{,}6\ cm \tag{1}$$

$$headbend\ length = \sqrt{(D26)^2 + (D27)^2} = \sqrt{(18{,}6)^2 + (20{,}5)^2} = 27{,}6805 \ \approx 28 \text{ cm} \tag{2}$$

The device is also equipped with a small speaker, which serves to deliver audio messages or cues to the stroke patient, even from a distance. This feature enhances two-way communication by allowing caregivers to provide verbal feedback or instructions, thereby improving interaction between both parties. An illustration of the IISAAC system is presented in Figure 3.

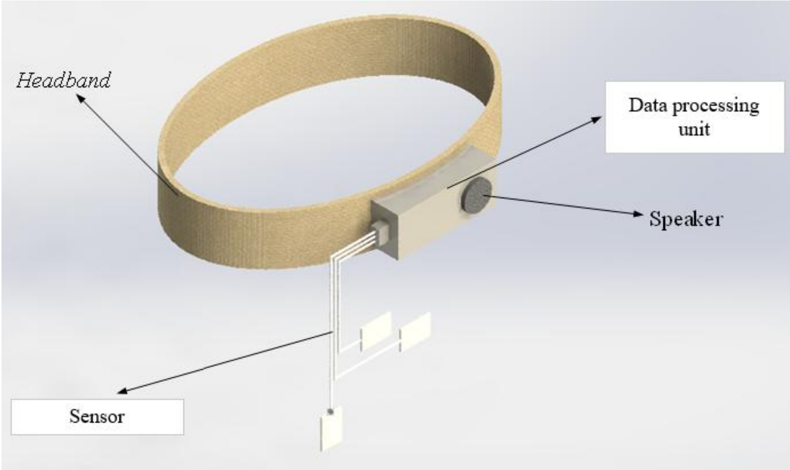


Figure 3. IISAAC design illustration

4. DISCUSSION

In accordance with consumer needs, the device was developed based on IoT technology. The aim is to enable communication between patients and their caregivers even when they are far apart. The functions of the developed technology can be seen in Figure 4.

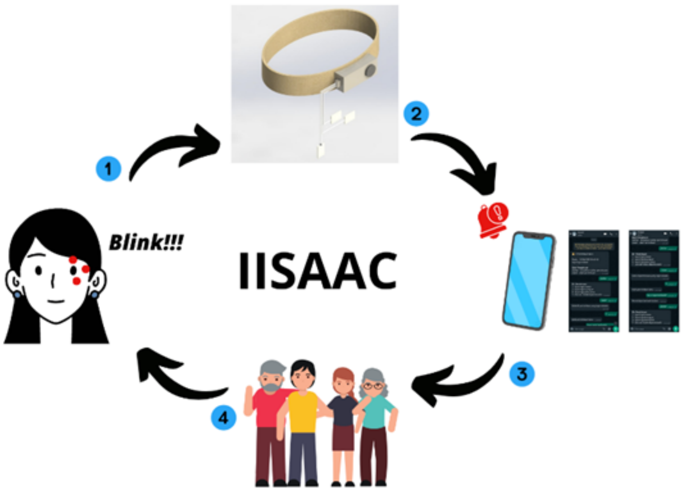


Figure 4. Flow diagram illustrating the usage process of the device

The following is the description of the IISAAC operation.

1. Eye-Blink Acquisition
   Stroke survivors wear IISAAC—a soft headband fitted with three eye-blink sensors positioned on the face (Figure 5). When the user requires assistance, they deliberately blink in pre-defined patterns; corresponding verbal statements are summarised in Table 5.

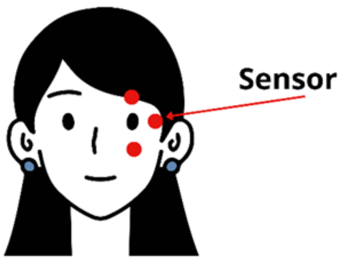


Figure 5. Position of the sensors

Table 5. Example of blink commands

Blink Count	Meaning
1	I want to eat
2	I need to go to the bathroom
3	I want to walk
…	…
7	Emergency!!!

2. Signal Processing
   The resulting eye blinks are captured by Electrooculography (EOG) sensors and converted into raw EOG signals. These signals undergo a multi-stage processing pipeline (Figure 6):

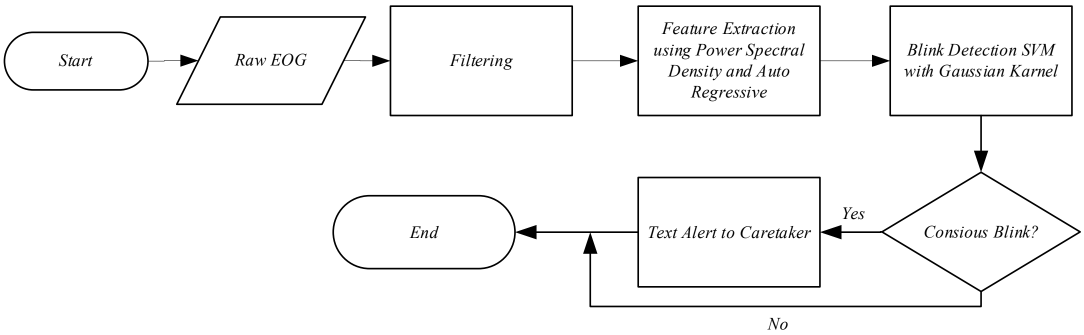


Figure 6. The algorithm of signal processing

Eye blinks of stroke patients are captured using Electrooculography (EOG) sensors that generate EOG signals. These signals are then filtered to remove and clean noise by separating frequencies that are too high and too low, which are considered noise. This method is called band pass filtering. The next step is to smooth the signal lines for easier processing using Moving Average Filtering. The subsequent step is feature extraction to select the most influential features on the calculation results. This algorithm uses the power spectral density and auto-regressive methods because they map the strength of the blink and the previous blink, enabling the required features to be extracted accurately. Next, classification is performed using SVM with a Gaussian RBF kernel because it is suitable for the density level of EOG signals. After that, blinks can be categorised as conscious blinks and unconscious blinks. Each blink is then counted and matched with the configured commands so that the message sent to the caregiver via WhatsApp is more accurate. These signals go through the following step-by-step processing.

a. Band-pass filtering removes high- and low-frequency noise.
b. Moving-average smoothing eliminates residual artefacts, producing a cleaner waveform.
c. Feature extraction applies power-spectral-density and autoregressive analyses to identify the most discriminative blink characteristics.
d. Classification employs a Gaussian radial-basis-function support-vector machine (SVM), which is well suited to the signal density of EOG data. The classifier differentiates conscious blinks from involuntary ones, counts valid blinks, and maps them to the pre-configured command set.
e. The recognised command is forwarded as a text message—or, in emergencies, as a voice call—through the WhatsApp interface to the designated caregiver. The message can also be changed as desired, as shown in Figure 7.

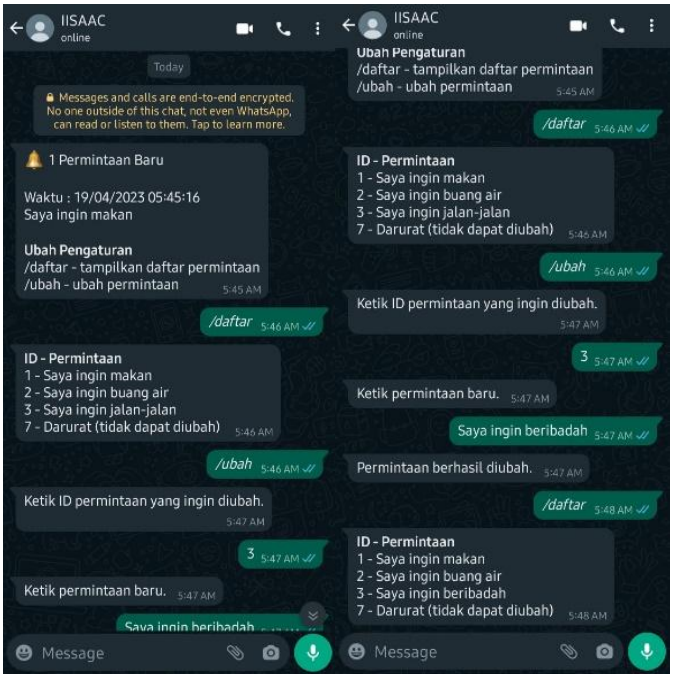


Figure 7. Example display on the WhatsApp application

3. Caregiver Notification and Response
   Caregivers receive the WhatsApp notification, interpret the encoded request, and proceed to assist the patient. In parallel, the system's miniature speaker announces that help is on the way, thereby reassuring the patient and closing the communication loop.

5. CONCLUSION

Based on observations and data collection from stroke patients, most of them are unable to move their limbs but can still blink. From the results of user needs identification and product design using the Quality Function Deployment (QFD) method, it can be concluded that the tool needed to address the problems faced by stroke patients is a communication device between stroke patients and their caregivers. This device prioritises functional needs such as an integrated information system, blink-based control, and a tool to detect the patient's needs. The device is named IISAAC, following the principles of IoT-based AAC and considering ergonomic aspects. IISAAC is shaped like a headband with an EOG sensor device on one side. EOG signals from eye blinks are processed into information and transmitted to a WhatsApp application, enabling caregivers to understand the patient's intentions and needs. As a result, communication becomes smoother. The availability of this device is expected to provide an effective solution for addressing communication challenges in stroke patients. The study resulted a conceptual design and a visual prototype of IISAAC. Nevertheless, further research is required to fabricate the device, perform functional testing, and conduct a comprehensive usability evaluation.

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