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Analysis of Control System and Signal Gain on Internet of Things-Based Electroencephalograph Circuit

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Abstract

Epilepsy, characterized by recurrent seizures, exhibits changes in brain signals with amplitudes far exceeding normal conditions (up to 800µV versus 5-200µV). The varying phases of seizures (from a few seconds to minutes and accompanied by tonic-clonic seizures) pose a risk, especially in public spaces. In this case, we designed a wearable, portable EEG that provides real-time seizure detection. Our design uses four voltage amplifiers with good accuracy and one filter circuit (differential: 97.83%, non-inverting: 96.92%, 96.5%, and 97.99%). The signal is amplified for detection, then filtered for optimal compatibility with the microcontroller. In addition to amplified brain signals, balance, light, and GPS sensors are used as binary indicators of epileptic conditions. This data is transmitted via the IoT system, showing Quality of Service in the Good and Very Good categories in the parameters Packet Loss, Throughput, Delay and Jitter. It can be concluded that the transmission data system shows data in the good category and jitter value in the very good category.

***Keywords**: EEG, Brain Signal, Amplifier, Quality of Service*

Abstrak

Epilepsi, ditandai dengan kejang berulang, menunjukkan perubahan sinyal otak dengan amplitudo yang jauh melebihi kondisi normal (hingga 800µV dibandingkan 5-200µV). Fase kejang yang bervariasi (dari beberapa detik hingga menit dan disertai kejang tonik-klonik) menimbulkan resiko, khususnya di ruang publik. Dalam kerangka ini, kami merancang EEG portabel yang dapat dipakai dan memberikan deteksi kejang secara *real-time*. Rancangan kami menggunakan empat penguat tegangan dengan akurasi yang baik dan satu rangkaian filter (diferensial: 97.83%, non-inverting: 96.92%, 96.5%, dan 97,99%). Sinyal yang diperkuat untuk deteksi, kemudian difiltrasi untuk kompatibilitas optimal dengan mikrokontroler. Di samping sinyal otak yang diperkuat, sensor keseimbangan, cahaya, dan GPS digunakan untuk indikator biner kondisi epilepsi. Data ini ditransmisikan melalui sistem IoT, menunjukkan *Quality of Service* berkategori Baik dan Sangat Baik pada parameter *Packet Loss*, *Throughput*, *Delay*, dan *Jitter*. Dapat disimpulkan bahwa sistem data transmisi menunjukkan data pada kategori baik dan *jitter value* pada kategori sangat baik.

Kata kunci: *EEG, Sinyal Otak, Amplifier, Quality of Service*

Introduction

Epilepsy is a medical word that encompasses a variety of consistent symptoms, or "syndromes," all of which are characterized by recurrent, unprovoked seizures to [1]. Current medical research provides light on the epileptogenesis of epilepsy, which is primarily caused by aberrant electrical waves in the brain that cause impulses in the affected individual. The causes and treatments of epileptic seizures have changed significantly as a result of the quick advancement of neuroscience. Numerous studies were conducted to establish that the origins of this illness were Carlo Matteucci (1811–1868) and Emil Du Bois-Reymond (1818–1896), who after conducting a battery of experiments with a galvanometer, noted that electrical signals were successfully emitted from muscle nerves. From these discoveries, a new field of study known as neurophysiology was born [2]. Research on EEG signals is a fundamental component in the development of neurophysiology. The first individual to examine and quantify human EEG signals was Hans Bergers (1873–1941). A human EEG recording that lasted one to three minutes on photographic paper in 1929 was the first report pertaining to EEG signals. The primary component of the artificial EEG signal was the alpha rhythm component, which Hans Berger included using a one-channel bipolar technique with leads at the fronto-occipital location.

Given the historical trajectory of neurophysiology and the actual situations faced by Indonesian epileptics, further research is necessary to safeguard the community. As a result, the goal of this research is to build an instrument known as an electroencephalograph that can be linked to both an Internet of Things system and a control system. The tool called Epy-Tech is a set of systems that contains an Electroencephalograph block, a control block and an Internet of Things block. These three blocks are combined in such a way as to produce a signal output and end up becoming data on the smartphone screen interface. A non-invasive brain imaging tool called an electroencephalograph, or EEG, uses electrodes on the scalp to record the electrical activity of the brain (scalp electrode). In addition to its application in healthcare, EEG is employed as a sensor for robotic arms, wheelchair controllers, drones, and gaming consoles [3]. Generally speaking, EEG functions by recording brain waves and transforming them into observable waveforms for analysis. The purpose of EEG is to capture the inherent characteristics of human brain impulses. One of the human organs that functions on the basis of electrical signal principles is the brain; an impulse signal's magnitude is measured in microvolts, which is a very small amount. Thus, the fundamental idea of EEG is to multiply the intercepted signal by thousands of times [4].

Numerous researches on the design of EEGs reveal a significant rate of error in the output voltage values. Imaging the signal after amplification frequently reveals irregularities in the signal's structure and unstable output outcomes. To create decreased error values, consistent signal forms, and steady output findings, more study was conducted. The EEG designed is a tool intended for epilepsy sufferers. Using this tool will enable users to get appropriate first aid when they experience a relapse, especially in tonic-clonic seizures. After the signal data is evaluated, the Internet of Things is used to notify the user's family about the circumstances in real-time and during recurrent episodes of epilepsy. Internet of Things (IoT) is essential tools by switching the wifi network [13]. Sending data from the smartphone to the family's Android is slowed down by the delay problem. Therefore, it is necessary to measure and confirm that the IoT system latency is within a suitable range and in excellent working order.

Literature Review

The goal of the project is to provide a basic electroencephalography for people with epilepsy so that relapses can be detected in public settings. Electroencephalograph (EEG) is a product of the design and testing process of an EEG instrument which is strengthened in three stages with errors of 0.082%, 0.85% and 0.6% respectively [5]. Arduino Board, and NodeMCU were the main Internet of Things components. The data transmission process makes use of this parameter [6]. Control Protocol results in less data loss than User Datagram Protocol, and Transmission Control Protocol results in less delay than User Datagram Protocol. According to the ESP32 control system, the system is extremely viable because the tool's comparison data with standard measurement instruments demonstrates that the error difference is quite tiny [7].

Method

The first step in building an electroencephalograph circuit for an individual with epilepsy is identifying societal issues. A review of the literature will come after the problem analysis's findings. Subsequently, the developed circuit is tested and the model is designed till a final conclusion is reached.

a. EEG System’s Work

Electrodes, which are conductive materials positioned at specific locations and amplified multiple times to produce numbers that are easily distinguishable as distinct signals between normal and seizure/epileptic conditions, are used by electroencephalographs to tap relatively small brain signals [8]. Three skin electrodes are used to capture brain signals: one electrode serves as a ground point that is connected to one ear, and the other two electrodes are input signals from which a comparison of signals from the two locations will be made. After passing via an instrumentation amplifier, the signal is boosted once more via three non-inverting amplifier circuits before finishing with a filter circuit to remove undesired high frequencies.

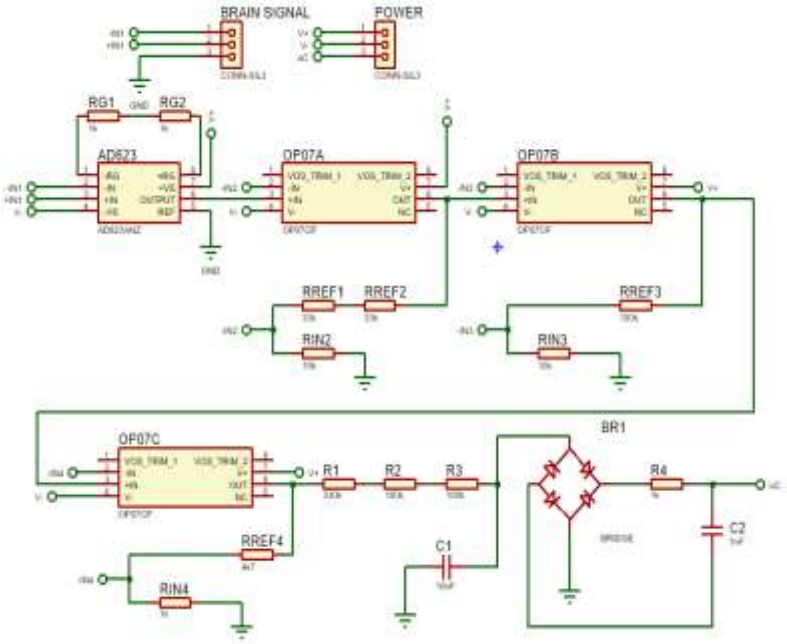


Figure 1. Schematic of the EEG circuit

A filter circuit, a rectifier circuit, three non-inverting amplifier units, and a differential amplifier make up the Epy-Tech EEG circuit. The signal received by tapping brain signals is strengthened by the differential to non-inverting amplifier. The low frequency signal is then sent through a series of filters that eliminate the high frequency portion of the signal. As a closing circuit, the rectifier circuit converts the alternating signal waveform into a unidirectional signal.

Skin electrodes, a sensor that catches brain signals and has conductive qualities so it can transfer sensitive microvoltage signals and flow them to the circuit, are used to put the EEG system in direct touch with the scalp. There are spots that indicate the expected appearance of signals with stronger intensity relative to positions outside the designated points, based on the international 10/20 system electrode placement approach [9]. Using the alpha and tetha signals, which have the highest amplitudes, the design is then carried out [10]. Thus, the electrode is positioned at the ground, or FPz-FP2-tragus, point.

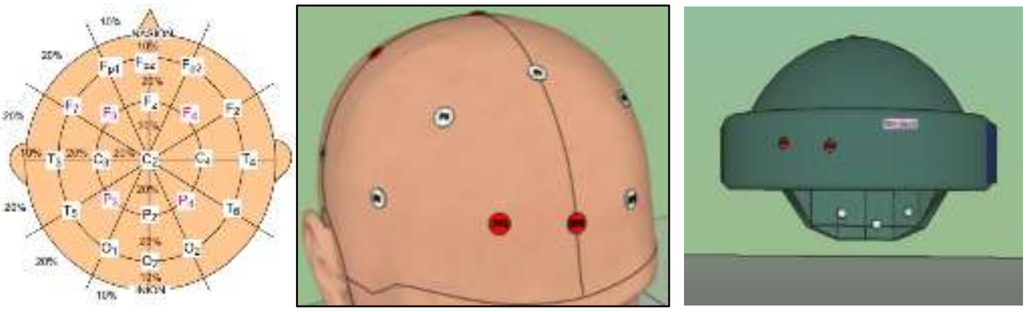


Figure 2. [left] International 10/20 electrode placement system, [middle] Prefrontal front view electrode positions, [right] Epy-Tech Cap Design

A flared section around the forehead of the beanie-style hat rotates to face the back of the head. Electronic components will be positioned in an enlarged location with consideration for user safety and comfort. The first amplifier to directly interact with a brain signal is the differential amplifier. Because it has lower noise than other Op-Amp circuits, it is positioned at the start of the EEG circuit. This initial amplifier's signal gain is set to Gain (G) 50 times to prevent excessive noise. The gain resistance value (RG) for IC AD623, assuming a gain of +/- 50 times, is 2,040k ohm.

$$R_G = 100\,k\Omega/(G-1) \quad \ldots\ldots\ldots\ldots \quad (1)$$

An RG of 2kΩ was taken once resistor components were available for purchase. 51 times is the strengthening value as a result.

$$G = (100\,k\Omega/R_G) + 1 \quad \ldots\ldots\ldots\ldots \quad (2)$$

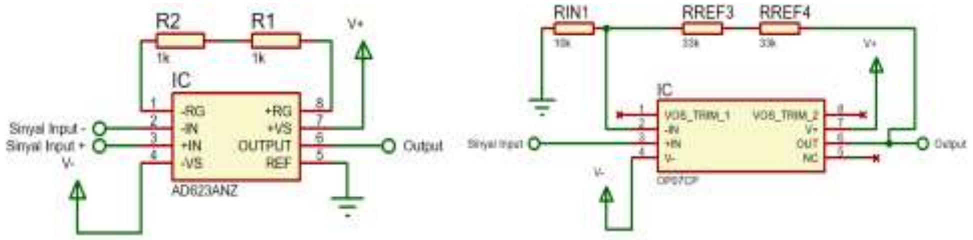
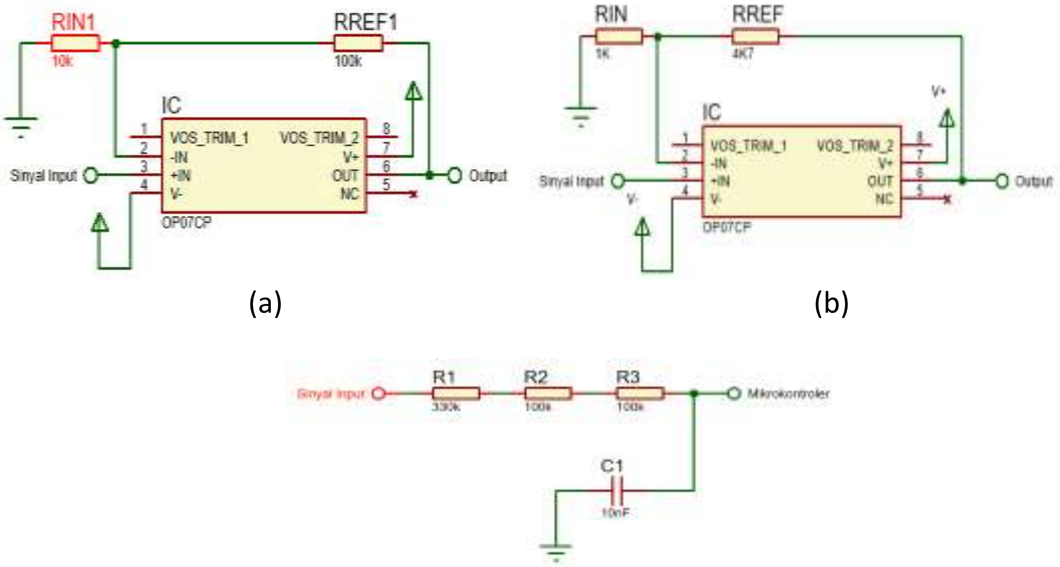


Figure 3. Schematic: (a) AD623AN Differential Amplifier Circuit, (b) Non-Inverting Amplifier Circuit (1).

The non-inverting amplifier IC OP07CP is used in the following step. The signal will be amplified eight times by the non-inverting amplifier (1). The quantity of feedback resistance (RF) and the amount of gain (AV) are determined by the current formula's specifications. RF is therefore worth 70k, and R1 is worth 10k. The RF is filled with two 33kΩ resistors to give it a 66kΩ value, depending on the state of the market. 7.6 times the gain was attained.

$$A_v = 1 + R_f/R_1 \quad \ldots\ldots\ldots\ldots \quad (3)$$



(a) (b)

Figure 4. Schematics: (a) Non-inverting Amplifier Circuit (2), (b) Non-Inverting Amplifier Circuit (3), (c) Low Pass Filter Circuit

The non-inverting amplifier (3) is designed to amplify the signal 5 times with Rf = 4kΩ and R1 = 1kΩ. The 4kΩ resistor size was not found on the market and was replaced with 4k7Ω with a gain of 5.7 times. To prevent large signal frequencies from passing through the output path, a passive low pass filter circuit is needed to block large frequencies. Based on figure 5(c), the desired cut off frequency is 30Hz, following equation (4) then R = 530kΩ, C = 10nF.

b. Epy-Tech Control System Working

Sensors are included in the operations of Epy-Tech's control system. The SW-520D sensor (tilt detection), the LDR sensor (light), and the EEG sensor are the sensors that Epy-Tech owns. The resultant brain signal will be amplified in the EEG circuit and sent into the microcontroller as direct current (DC) at a maximum voltage of 5 volts, depending on the microcontroller's operating voltage. The microprocessor receives the configuration and wiring of the various sensors, processes the data, and outputs the loud speaker and the activation of cellular communications through the SIM800L module to the actuator.

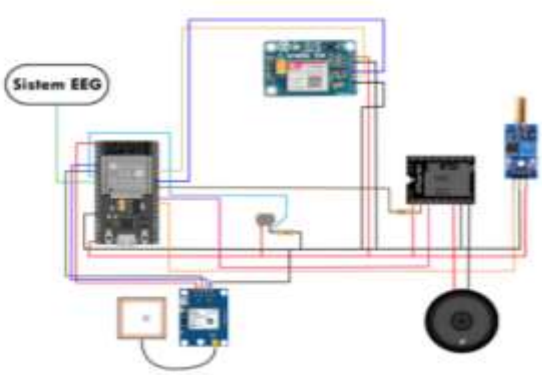


Figure 5. Epy-Tech Control System Wiring Diagram

Based on the diagram in Figure 5, the control system related to Epy-Tech's sensors shows the ESP32 pin configuration as a microcontroller device connected to the pins on each sensor.

Table 1. Pin Configuration of EEG, LDR, and SW-520D Sensors with Microcontroller

Sensor & Actuator	Pin Internal	ESP32
Sensor EEG	Analog Pin	33
	GND	GND
Sensor SW-520D	VCC	5V
	GND	GND
	DO	16
Sensor LDR	Analog Pin	32
	GND	GND
	VCC	5V

An ESP32 microcontroller powers the Epy-Tech control system, ESP32 is used because in its design it can achieve good power and RF performance, resulting in durability and reliability in control system applications and power scenarios [11]. The SW-520D, LDR, and EEG sensors are the ones that are employed. The DFPlayer Mini and GSM SIM800L modules receive the microcontroller's output signal. With a predefined phone number, the GSM module serves as a communication link for the Epy-Tech system. The DFPlayer Mini module is designed to be amplified over loud speakers and is utilized as a sound processor and memory device.

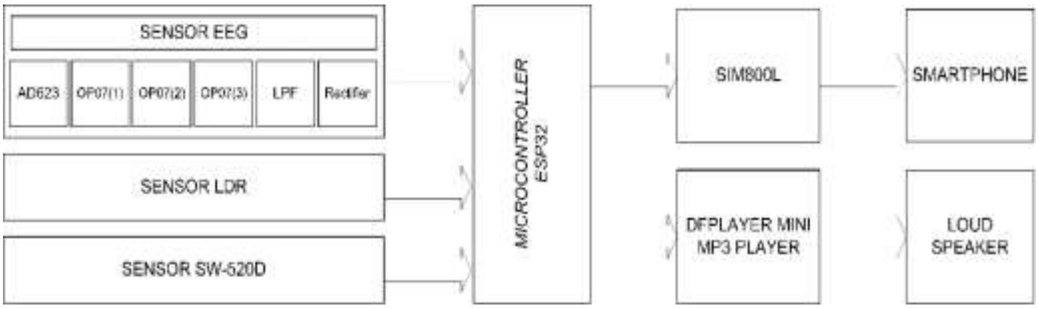


Figure 6. Epy-Tech Control System Block Diagram

c. Internet of Things System Works

The link between an Epy-Tech application software system and a hardware system made up of several EEG and other sensors is demonstrated by the Internet of Things in App-Tech applications. In IoT systems, Quality of Service analysis is to test the reliability of the network used in IoT, in other word, QoS is providing service differentiation and performance assurance for Internet applications [12]. There are 4 parameters that will be tested, namely: Throughput, Delay, Packet Loss, and Jitter.

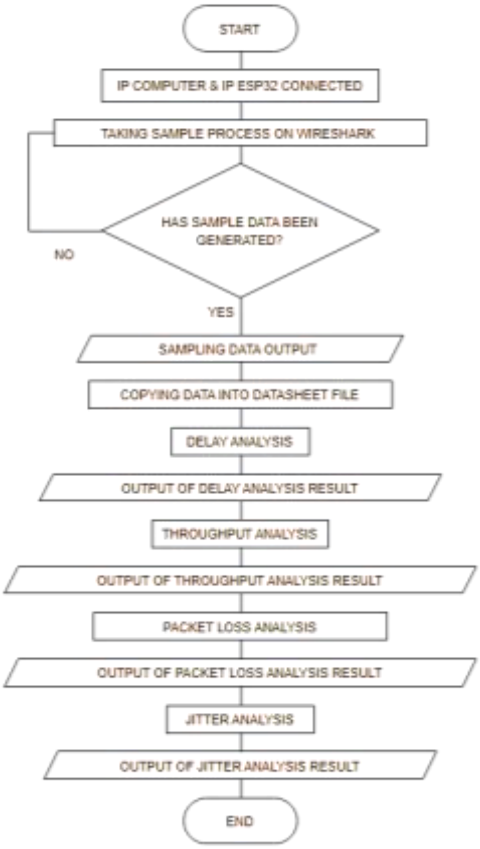


Figure 7. QoS Analysis Flow Diagram

Result and Discussion

All of Epy-Tech's system components are positioned to surround the user's forehead. Figure 8(a) illustrates how Beanies were used in the design of Epy-Tech, serving as the framework for the system. The EEG circuit and wires, ESP32, GPS module, LDR circuit, SW520D sensor circuit, SIM800L cellular module, DFPlayer + speaker, voltage regulator circuit, and 9V battery are among the parts, circuits, and modules arranged around the forehead.

Figure 8. Views: (a) Epy-Tech Outside and Bottom, (b) EEG Circuit Consisting of Amplifier and Filter.

a. Signal Amplification

The circuit components are evaluated independently in Figure 8(b). Three circuits from a non-inverting amplifier, a low pass filter circuit, and a differential amplifier circuit were tested. The first test of the differential amplifier was carried out on the AD623AN instrumentation amplifier IC series. Tools used to support the testing process include, DC Power Supply, Function Generator, Oscilloscope and Voltmeter.

Table 2. AD623AN Differential Amplifier Circuit Test Results (Voltage Supply = 5 V)

V_{IN+} (mV)	V_{IN-} (mV)	V_{OUT} (mV)		Amplifier (A)	% Error
		Test	Count		
1	0	50.34	51	50.34	1.294117647
5	0	263.9	255	52.78	3.490196078
8	0	420.6	408	52.575	3.088235294
10	0	531	510	53.1	4.117647059
15	0	756.1	765	50.40666667	1.163398693
18	0	901.7	918	50.09444444	1.775599129
20	0	1019	1020	50.95	0.098039216
25	0	1199.8	1275	47.992	5.898039216
30	0	1550.2	1530	51.67333333	1.320261438
50	0	2540.2	2550	50.804	0.384313725
75	0	3731.2	3825	49.74933333	2.452287582
90	0	4521.9	4590	50.24333333	1.483660131
100	0	5090	5100	50.9	0.196078431
120	0	5732	6120	47.76666667	6.339869281
150	0	7655	7650	51.03333333	0.065359477
180	0	9107.4	9180	50.59666667	0.790849673
200	0	9889.2	10200	49.446	3.047058824
		Error Mean			2.176765347

The voltage was given 5 Volts DC with a gain value of 51 times and 16 experiments were carried out with an input range from 1 to 200 milli Volts. The results obtained are in the form of varying reinforcement and error values. The gain value closest to the calculated value occurs at an input of 20 mV, namely 50.95 times with an error value of 0.098%. The gain value farthest from the calculated value occurs at an input of 120 mV, namely 47.76 times with an error value of 6.33%. The average error value in testing the AD623AN instrumentation amplifier was 2.17%.

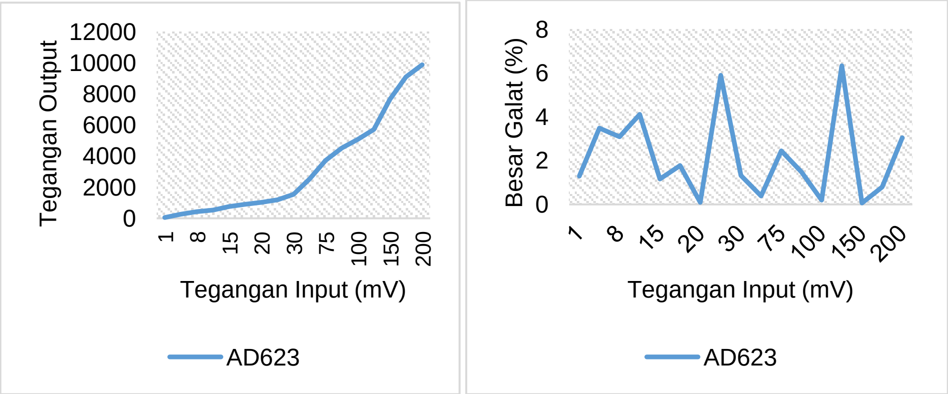


Figure 9. Graph: (a) Function of Vout Against Vin of the Differential Amplifier, (b) Magnitude of the Differential Amplifier Error.

In Figure 9(a), a semi-exponential graph is shown, an exponential increase occurs at an input voltage of 30 mV. Figure 9(b) shows the error curve graph with the highest error at inputs of 25 mV and 120 mV. An amplifier circuit that was not inverting was used for the second test. This kind of amplifier was created with a positive voltage in mind. The output signal from the differential amplifier circuit was intended to be amplified by a factor of 7.6 by the first non-inverting amplifier.

Table 3. Test Results for Non-inverting Amplifier Circuit 1 (Voltage Supply = 5 V)

V_{IN+} (mV)	**V_{OUT} (mV)**		**Amplifier (A)**	**% Error**
	Test	**Count**		
1	7.1	7.6	7.1	6.578947368
3	21.9	22.8	7.3	3.947368421
5	36.9	38	7.38	2.894736842
7	50.1	53.2	7.157142857	5.827067669
9	69.4	68.4	7.711111111	1.461988304
10	81.23	76	8.123	6.881578947
12	85.2	91.2	7.1	6.578947368
15	103.2	114	6.88	9.473684211
18	134.2	136.8	7.455555556	1.900584795
20	155	152	7.75	1.973684211
24	182.1	182.4	7.5875	0.164473684
27	206.5	205.2	7.648148148	0.633528265
30	224.4	228	7.48	1.578947368
40	302.9	304	7.5725	0.361842105
50	371.5	380	7.43	2.236842105
60	437.2	456	7.286666667	4.122807018
70	521.1	532	7.444285714	2.04887218
80	621.4	608	7.7675	2.203947368
90	649.3	684	7.214444444	5.073099415
100	751.7	760	7.517	1.092105263
		Error Mean		3.351752646

Table 3 explains that the signal gain does not always comply with the design of 7.6 times the gain. At 20 signal input variations, the highest error level occurred at 15 mV input, namely 9.5% or the gap was 7.2 times the expected gain. The lowest error rate occurred at 24 mV input, namely 0.16% with a gain of 7.58 times, a difference of approximately 0.02 times from the proper gain.

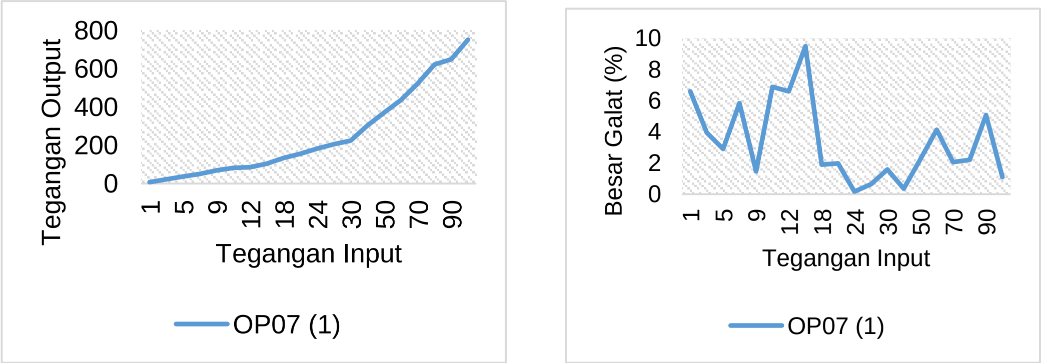


Figure 10. Graph: (a) Vout Function Against Non-Inverting Vin (1), (b) Non-Inverting Error (1).

With an input voltage of 30 mV serving as the exponential starting point, the function graph of output voltage vs input voltage in the first OP07CP non-inverting amplifier circuit in Figure 10(a) exhibits characteristics of an exponential form. The error size at each input in Figure 10(b) is not indicative of the internal state of the amplifier component; instead, it may be the result of external influences such a fluctuating voltage source. This is because the curve that forms in this error size lacks pattern. The next test was carried out on the 2nd non-inverting amplifier using IC OP07CP with a gain of 11 times. Table 4 shows the test results and is compared with the calculated results for the output voltage with 20 input voltage variations from 1 mV to 100 mV. The largest error level in the second stage amplifier is at the input point of 10 mV with an error percentage of 8.9%, namely a gain of 10.02 times. The smallest error level occurs at an input of 90 mV with an error percentage of 0.30%, namely a gain of 10.96 times. The average error generated in this amplifier is 3.42%.

Table 4. Test Results for Non-inverting Amplifier Circuit 2 (Voltage Supply = 5 V)

V_{IN+} (mV)	**V_{OUT} (mV)**		**Amplifier (A)**	**% Error**
	Test	**Count**		
1	10.42	11	10.42	5.272727273
3	32	33	10.66666667	3.03030303
5	53.6	55	10.72	2.545454545
7	73.6	77	10.51428571	4.415584416
9	98.1	99	10.9	0.909090909
10	100.2	110	10.02	8.909090909
12	135.7	132	11.30833333	2.803030303
15	155.5	165	10.36666667	5.757575758
18	202	198	11.22222222	2.02020202
20	207	220	10.35	5.909090909
24	259.5	264	10.8125	1.704545455
27	287.7	297	10.65555556	3.131313131
30	345.6	330	11.52	4.727272727
40	449	440	11.225	2.045454545

50	587	550	11.74	6.727272727
60	668.4	660	11.14	1.272727273
70	774.5	770	11.06428571	0.584415584
80	867.4	880	10.8425	1.431818182
90	987	990	10.96666667	0.303030303
100	1156	1100	11.56	5.090909091
	Rata-Rata Galat			3.429545455

Figure 11(a) shows the graphic form of IC OP07CP with 11 times gain. It can be seen that the shape of the graph tends to be exponential and a significant increase begins to appear at the input point of 30 mV. Figure 11(b) shows a pattern less curve for the error produced by this amplifier, an error spike occurs at an input of 10 mV and is followed by an input of 50 mV.

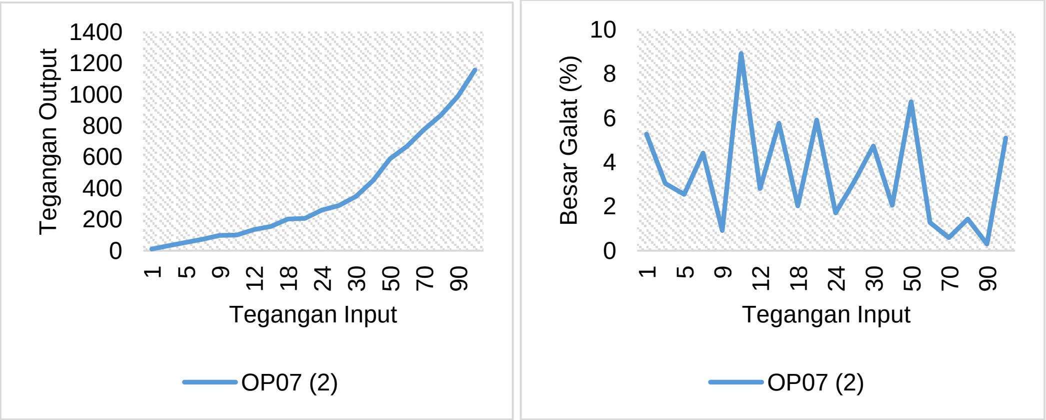


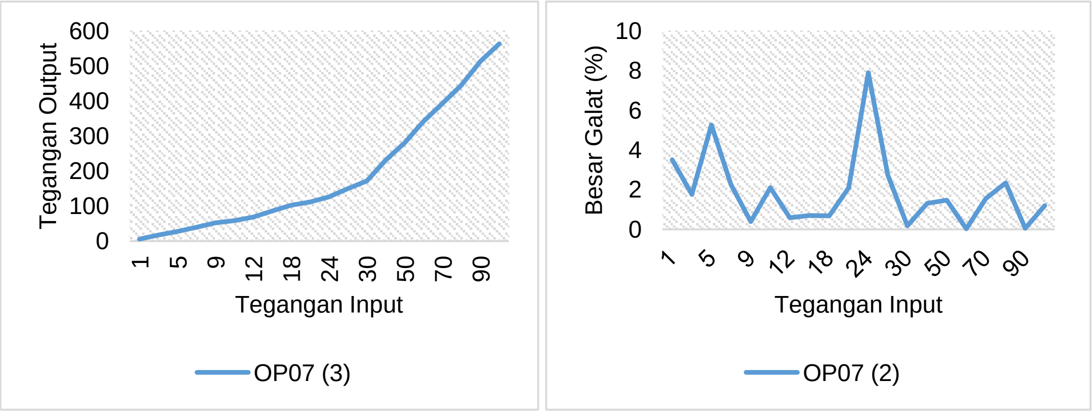
Figure 11. Graph: (a) Vout function against non-inverting Vin (2), (b) non-inverting error (2)

Table 5 shows the test results on the third non-inverting amplifier circuit in the form of a comparison between the output voltage of the test results and the calculation results. The designed gain is 5.7 times in 20 experimental variations based on differences in input voltage. The largest error occurred at 24 mV input, amounting to 7.89% error with a gain of 5.25 times. The smallest error occurred at 60 mV input of 0.02% with a gain of 5.69 times. The average error that occurs in this amplifier is 1.9%.

Table 5. Test Results for Non-inverting Amplifier Circuit 3 (Voltage Supply = 5 V)

V_{IN+} (mV)	V_{OUT} (mV)		Amplifier(A)	% Error
	Test	**Count**		
1	5.5	5.7	5.5	3.50877193
3	17.4	17.1	5.8	1.754385965
5	27	28.5	5.4	5.263157895
7	39	39.9	5.571428571	2.255639098
9	51.5	51.3	5.722222222	0.389863548
10	58.2	57	5.82	2.105263158
12	68	68.4	5.666666667	0.584795322
15	86.1	85.5	5.74	0.701754386
18	101.9	102.6	5.661111111	0.682261209
20	111.6	114	5.58	2.105263158
24	126	136.8	5.25	7.894736842
27	149.7	153.9	5.544444444	2.729044834
30	171.3	171	5.71	0.175438596

40	231	228	5.775	1.315789474
50	280.8	285	5.616	1.473684211
60	341.9	342	5.698333333	0.029239766
70	392.8	399	5.611428571	1.553884712
80	445.3	456	5.56625	2.346491228
90	513.3	513	5.703333333	0.058479532
100	563.2	570	5.632	1.192982456
	Rata-Rata Galat			1.906046366



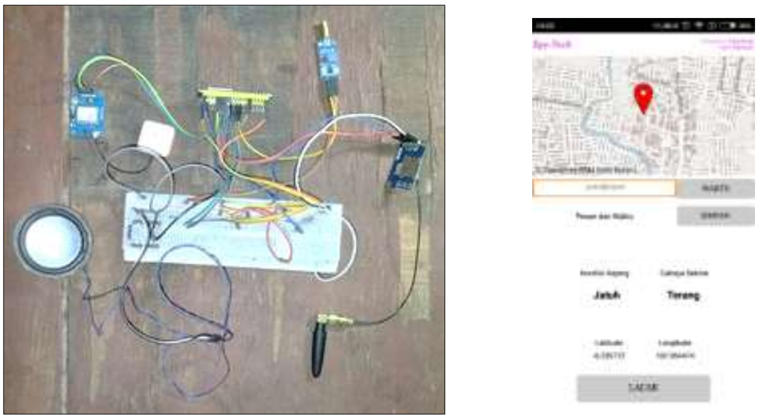
(a) (b)

Figure 12. Graph: (a) Vout function against non-inverting Vin (3), (b) non-inverting error (3)

Figure 12(a) shows the graphic form of the input voltage function against the output voltage. The shape of the graph tends to be exponential with the significant point being at the input of 30 mV. Figure 12(b) shows the pattern less curve shape of the percent error of this amplifier, the most significant error increases at an input of 24 mV.

b. Epy-Tech Control System

Five characteristics of the Epy-Tech control system, are Maps Display, Alarm, Seizure Condition, Light Sensor, and Latitude and Longitude Location Information—are displayed in the Epy-Tech application. The EEG, light, and balance sensors are the three primary sensors that regulate the Epy-Tech system. These sensors are essentially what control Epy-Tech.



(a) (b)

Figure 13. (a) Control System and Other Supporting Components on Epy-Tech, (b) Epy-Tech Application Interface

EEG, light, and balance sensors are employed as parameters while testing seizure situations. The user's condition will be displayed on the display and the system will be deemed successful if any one of the three values is 1. Three situations in a different light sensor test show whether the user is in the alert, bright, or normal phases. If the three conditions adapt to the lux level of light hitting the sensor, then it is declared that the conditions are met.

Table 6. Conditions of Control System

Control Features		**Information**
Seizure Conditions	Tonic-Clonic	Active, shows Tonic-Clonic writing when the EEG Sensor, Light Sensor and Balance Sensor show condition 1.
	Almost Seizure	Active, shows the message "Almost Seizure" when the EEG Sensor and Light Sensor show condition 1 and the Balance Sensor 0.
	Fall	Active, shows the message "Falling" when the EEG and Light Sensors show condition 0 and the Balance Sensor shows condition 1.
	Normal	Active, shows the “Normal” display when the EEG Sensor, Light Sensor, and Balance Sensor show condition 0
Ambient Light Conditions	Alert	Active, shows the “Alert” display when the lighting intensity reaches >750 lux
	Bright	Active, shows the “Bright” display when the lighting intensity reaches 500-750 lux
	Normal	Active, shows the “Normal” display when the lighting intensity reaches >500 lux

After testing the sensor features on the Epy-Tech control system, validation needs to be carried out to compare real conditions and planned conditions.

Table 7. Sensor Validation for Prospect and Real Conditions.

No	**Test Sensor**	**Test Condition**		**Description**
		Prospect	***Riil***	
1.	EEG	When the output voltage exceeds the normal signal limit (2000 ADC), the sensor will give instructions to the microcontroller to go on standby, waiting for the other 2 sensors to be in the ON condition to display the tonic-clonic or Almost Seizure parameter and activate the IoT system.	When the output voltage exceeds the normal signal limit, the sensor gives the ON instruction to wait for the status of the other 2 sensors to display the tonic-clonic parameters on the smartphone screen.	Succeed
		When the output voltage is below the normal signal limit, the sensor is in a state that gives an OFF instruction.	When the sensor is used on a non-ODE user, the sensor gives an OFF instruction.	
2.	LDR	When the light exceeds 750 lux, the sensor gives instructions displaying the Alert status! on the Epy-Tech screen, and gives instructions to the microcontroller to give the ON condition for Seizure Condition along with 2	When the light conditions exceed 750 lux, the microcontroller gives an ON instruction, waits for the other 2 parameters to turn ON to display the Tonic-Clonic condition.	Succeed

		other parameters.		
		When the light is below 750 lux, the sensor gives an OFF instruction in Seizure Condition	When the light is dim, the sensor prevents Tonic-Clonic Seizure Conditions from occurring, and displays Bright and Normal indicators.	
3	SW-520D	The sensor instructs the microcontroller to turn off while awake (vertical), putting the seizure status in the Normal or Nearly Seizure category.	The vertical sensor condition shows that the Seizure Condition is in the Normal and Almost Convulsive categories based on the second and fourth condition tests.	Succeed
		When the condition falls (horizontal), the sensor gives ON instructions to the microcontroller to enter the Fall and Tonic-Clonic categories.	The horizontal sensor condition shows the Fall and Tonic-Clonic categories based on tests one and three.	

c. Internet of Things

The analysis carried out is Quality of Service with test parameters, namely: delay, throughput, packet loss and jitter with the help of the Wireshark tool.

Table 8. Status of Quality of Service Testing

Test Name	Quality of Service
Testing Objects	ESP32
Testing Objectives	Obtain data and analytical conclusions
Testing Procedure	Testing is carried out by running the IoT system Run the WireShark application for collecting and monitoring data Analyzing Delay, Throughput, and Packet Loss Draw conclusions on testing

The amount of time needed for data to move from one place to another is known as the delay. The ESP32 data delivery delay test ran from the zeroth to the forty-eighth second. 249 packets were listed, according to 6969. The initial packet's and the subsequent packet's time deltas were used to calculate the delay, giving the amount of data delivered in milliseconds.

Table 9. ESP32 Delay Testing

No	*Time*	*Source*	*Destination*	*Time delta from previous displayed frame (s)*
1	0	192.168.0.107	192.168.0.1	0.001094
2	0.001094	192.168.0.107	192.168.0.1	0.023072
3	0.024166	192.168.0.1	192.168.0.107	0.00621
4	0.030376	192.168.0.1	192.168.0.107	0.004522
5	0.034898	192.168.0.107	142.250.4.147	0.001161
6	0.036059	192.168.0.107	142.250.4.147	0.027692
7	0.063751	142.250.4.147	192.168.0.107	0.005751
8	0.069502	192.168.0.107	142.250.4.147	0.012944
9	0.082446	142.250.4.147	192.168.0.107	0.002113

10	0.084559	192.168.0.107	142.250.4.147	0.000281
.	.	.	.	.
.	.	.	.	.
244	44.5907	192.168.0.107	192.168.1.255	1.244703
245	45.8354	LiteonTe_01:95:9a	Espressi_7c:9d:24	0.113242
246	45.94864	Espressi_7c:9d:24	LiteonTe_01:95:9a	0.652177
247	46.60082	192.168.0.107	192.168.1.255	1.854728
248	48.45555	192.168.0.107	20.185.212.106	0.241355
249	48.6969	20.185.212.106	192.168.0.107	0.014402
		Mean		0.197153441

The average delay in Table 9 is 0.197 seconds. The category range inputted is 150-300 mS, or 0.15-0.30 seconds, based on the delay index in Table 10, and it may be concluded that data transmission has a good delay category.

Table 10. Delay Index

Category	Large Delay	Index
Very Good	< 150 ms	4
Good	150-300 ms	3
Currently	300-450 ms	2
Bad	>450 ms	1

Throughput is the effective data transfer speed, measured in bits per second. The way to get the throughput value is by rationalizing the data packets received with the length of observation carried out. The experimental results in Wireshark software showed that the number of bytes was 83312 and a time span of 48.697 seconds. Using equation (5), the throughput value was 1710.82408 kbps.

$$Throughput = \frac{ByteTotal}{TimeSpan} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

Based on the throughput index in table 11, the throughput quality classification is good with index 3.

Table 11. Throughput Index

Category	Bit per second	Index
Very Good	>2.1 Mbps	4
Good	1200 Kbps – 2.1Mbps	3
Sufficient	700 – 1200 Kbps	2
Bad	338 – 700 Kbps	1
Very Bad	0 – 338 Kbps	0

A parameter called "Packet Loss" can be used to indicate certain circumstances and display the total number of packets lost. Data describing the quantity of data transferred and the number of packet losses were gathered for this test; specifically, 248 packets were sent, 2 packet losses were recorded, and 246 packets were received, according to equation (6).

$$Packetreceived = packetsent - packetloss \ \ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

$$PacketLoss = \frac{Packetsent - packetsreceived}{packetsend} 100\% \ \ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

Based on equation (7), we get a packet loss value of 0.8%, which when compared with the THIPON index in table 12, we get a very good category with an index of 4.

Table 12. Packet Loss Index

Category	*Packet Loss*	Index
Very Good	0 – 2%	4
Good	3 – 14%	3
Current	15 – 24%	2
Bad	>25%	1

Jitter is a variation in packet arrival, caused by variations in queue length, in data processing time, and also in the reassembly time of packets at the end of the jitter journey. The total delay variation is the sum of the delay variations between the time before and after. Based on table 9, the value of Total Delay Variation = 0.0442015 seconds, with the number of packets received being 247 packets. Then the jitter value is:

$$Jitter = \frac{0.0442015}{247-1} = 0.00017968 second = 0.1796 ms \text{ ……………………………….. } (7)$$

Based on the jitter index in table 13, the ESP32 network jitter value is in the Very Good category and the index value is 4.

Table 13. Jitter Index

Category	Jitter Value (ms)	Index
Very Good	0 ms	4
Good	0-75 ms	3
Current	75-125 ms	2
Bad	125-225 ms	1

Concussion

On the signal strengthening side, the AD623AN Differential Amplifier IC was tested with a function generator and found an average error of 2.17%. The non-inverting amplifier (1) with a gain of 7.6 times has an average error of 3.07%. The non-inverting amplifier (2) with a gain of 11 times obtained an average error of 3.50%. The non-inverting amplifier (3) with a gain of 5.7 times produces an average error of 2.01%. The Epy-Tech control system was tested with 4 Seizure Conditions, namely, Condition 1 (Tonic Clonic) the EEG, LDR, & SW-520D sensors were all active. Condition 2 (Almost Seizure) EEG & LDR sensors are active, SW-520D is not active. Condition 3 (Fall) EEG & LDR sensors are not active, SW-520D is active. Condition 4 (Normal) EEG, Light, & SW-520D sensors are all non-active. The results of the IoT system's data transmission test indicate that the average delta time delay value is 0.197153441, placing it in the (Good) category. 1710.82408 KB/s throughput value; in the "Good" category. 0.8% packet loss value; (Very Good) classification. 0.1796 ms is the jitter value; (Very Good) category.

References

[1] B. S. Chang and D. H. Lowenstein, "Mechanisms of Disease: Epilepsy," *The New England Journal of Medicine*, vol. 349, no. 13, pp. 1257-1266, 2003.

[2] S. Sanei and J. A. Chambers, EEG Signal Processing and Machine Learning, 2nd Edition, Hoboken, NJ: Jhon Wiley and Sons, 2021.

[3] R. A. M. Sakinah and S. M. Hidayad, "Perancangan Electroencephalograph Sebagai Media Monitoring Sinyal Otak Terintegrasi Dengan Android," Institut

Teknologi Sepuluh Nopember , Surabaya, 2018.

[4] R. Carter, The Human Brain Book, New York: Dorling Kindersley Limited, 2014.

[5] J. W. Rusli, P. Siwindarto and Nurussa'adah, "Desain Alat Instrumentasi Medis," *Jurnal Mahasiswa Teknik Elektro Universitas Brawijaya,* vol. 1, no. 3, pp. 1-7.

[6] P. V. Romony, L. Sitanayah and J. B. Sanger, "Perbandingan Quality of Service Protokol Komunikasi Data Pada Sistem Deteksi Asap Rokok Berbasis Internet of Things," *Jurnal Realtech,* vol. 16, no. 1, pp. 19-24, 2020.

[7] A. P. W. Hendrawan and N. P. Agustini, "Simulasi Kendali Dan Monitoring Daya Listrik Peralatan Rumah Tangga Berbasis ESP32," *ALINIER: Journal of Artificial Intelligence & Applications,* vol. 3, no. 1, pp. 54-68, 2022.

[8] O. A. E. Putera and I. S. Faradisa, "Rancang Bangun Electroencephalograph (EEG) Sebagai Perekam dan Pendeteksi Sinyal Biolistrik Otak yang Terintegrasi dengan PC Berbasis Mikrokontroler Atmega8535," *Jurnal Elektro ELTEK* , vol. 2, no. 1, pp. 115-122, 2011.

[9] B. B. Murti and A. B. Pradana, "Rancang Bangun Sistem Pemonitor Gelombang Otak Nirkabel Berbasis Mikrokontroler," *Jurnal Listrik, Instrumentasi, dan Elektronika Terapan,* vol. 2, no. 2, pp. 7-13, 2021.

[10] S. M. Bryan, A. Rizal and S. Hadiyoso, "Pembuatan Aplikasi Penerima Data Eeg Tiga Kanal," *Jurnal Mahasiswa Teknik Elektro Universitas Telkom,* 2015.

[11] D. Atmajaya, N. Kurniati and Y. Salim, "Sistem Kontrol Timbangan Sampah Non Organik Berbasis Load Cell dan ESP32," in *Seminar Nasional Teknologi Informasi Dan Komunikasi (SEMNASTIK) X*, Palembang, 2018.

[12] W. Zhao, D. Olshefski and H. Schulzrinne, "Internet Quality of Service: an Overview," Department of Computer Science, Columbia University, New York, 2000.

[13] Kurniawan, K., Wahyuni, S., Mursyidin, M. (2023). The Design of IoT Based Lighting Installation Tools in Electrical Installation Engineering and Microcontroller Systems Courses. *Circuit: Jurnal Ilmiah Pendidikan Teknik Elektro,* vol.7, no.2, pp.154-163