Research Article

Development of Nystagmus Test and Measurement for Benign Paroxysmal Positional Vertigo

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Abstract

Vertigo is the illusion of rotation occuring due to a problem or a set of problems in the balance system of the body, and it is the situation that objects or places around the patients are in a revolving position around themselves. In vertigo, which is examined under two main headings as central and peripheral, central vertigo can be caused by aneurysms, tumors, and brain vascular distruption caused by brain lesions, while peripheral vertigo can occur due to thyroid types and metabolic disorders. Benign paroxysmal positional vertigo, colloquially called 'crystal floating', is the most common type of peripheral vertigo and many diagnostic, exercise and treatment methods are used in case of BPPV. However, today, as a result of the increase in computer use, treatment interactions have increased significantly. In line with the software created in this study, a computer-based diagnosis system and measurement system of nystagmus movements due to BPPV were developed. The system consists of three parts: mechanical, software and hardware. Visual Studio c# software interface and connection control software were formed in accordance with the diagnostic methods obtained from the literature. Software panels prepared on the interface for bithermal caloric and other tests are opened and the electronystagmography data prepared accordingly are graphed on Digilent Waveforms Analog Discovery. The performance of the BPPV test and measurement system were applied to the control group consisting of 10 healthy individuals. Dix-Hallpike, gaze, head rotation, optokinetic, pursuit tracking, bithermal caloric, Head Shaking and Saccadic tests were applied. As a result, the time for the preparation of the bithermal caloric test to 30-degree temperature value of the 3900 ml and 2600 ml was calculated *as 4.00 ∓1.8 s and 3.67 ∓2.8 s. For 44-degree temperature value, they were -1,70 ∓2,75 s and -0,70 ∓3,09 s. Thus, it is seen that the developed system will enable the diagnosis of patients with BPPV to be determined in accordance with integrated visual stimuli in an accurate and ergonomic environment.*

Keywords: Bithermal Caloric Test, BPPV, ENG, Nystagmus, Vertigo

1. Introduction

Vertigo is the illusion of rotation occuring due to a problem or a set of problems in the balance system of the body, and it is the situation that objects or places around the patients are in a revolving position around themselves. In other words, it is the deterioration of balance because of the balance center in the inner ear or middle ear. Vertigo can be analyzed under two main headings, central and peripheral. Central vertigo is caused by hereditary brain disorders. Central vertigos can be caused by brain tumors, bleeding, aneurysms in the vessels or different disorders of the brain vessels [1]. Peripheral vertigo can be caused by a problem in the musculoskeletal system such as neck pain, metabolic diseases such as hypothyroidism, hyperthyroidism or hypoglycemia. "Benign Paroxysmal Positional Vertigo" (BPPV) is the most common type of vertigo, which is colloquially known as crystal floating. It occurs as a result of crystals located in the balance center of the inner ear falling into the posterior semicircular canals [2].

In anomalies occurring in the inner ear crystals, the patient encounters dizziness when changing shape in the supine position. Apart from this, neuritis nerve inflammations and Meniere's disease caused by upper respiratory tract infections are types of peripheral vertigo and originate from the ear. Dix-Hallpike test, VNG (Video Nystagmo Graph) or ENG (Electro Nystagmo Graph), liquid or air caloric tests, vHIT (Video Head Impulse Test), Posturography, VEMP tests are used to investigate vertigo and balance functions. It has been revealed in the literature that the tests performed give positive results in the diagnosis of vertigo and balance disorders. Today, the diagnosis of vertigo is made by using VNG, ENG, liquid and air caloric devices depending on the Ear Nose and Throat (ENT) departments of clinics and hospitals [3]. These systems are financially expensive and cannot be used in BPPV treatment planning since diagnostic materials are not combined in a single system for diagnostic purposes. On the other hand, the positive effects of ENG systems used in detection and treatment stages for diagnosis and treatment have been revealed in literature studies. This study aims to collect data in the diagnosis of balance disorders and vertigo diseases and to determine the disease according to these data. Another goal is to carry out the treatment of the detected disease easily and successfully. In conclusion, is is aimed to establish the diagnosis and treatment planning of balance disorders and vertigo diseases with a nystagmus test and measurement system due to benign paroxysmal positional vertigo.

2. Materials and Methods

Benign paroxysmal positional vertigo is caused by ear crystals in the semicircular canal, either attached to the cupula or floating freely in the endolymph. For positional detection of floating ear crystals and diagnosis of benign paroxysmal positional vertigo, Dix-Hallpike, gaze test, sinusoidal movement (pursuit tracking), optokinetic, head thrust, head shaking, bithermal caloric tests are used as diagnostic methods. The diagnosis is made by evaluating the videonystagmography (VNG) or electronystagmography (ENG) recordings of the applied tests. VNG is the name given to the method used to evaluate patients with suspected dizziness called vestibular dysfunction. The method is basically a technique for recording the movements of the eye in the spatial plane in order to detect the source of dizziness. Infrared video camera or digital video cameras are used to fulfill the purpose of detecting and recording eye oscillating movements. VNG is glasses with a camera on it to continuously examine the rotational movements of the patient's eye with image processing methods for directly detecting the nystagmus movements in the horizontal and vertical planes of the patients. VNG glasses are placed tightly on the patient's head and are used to minimize the patient's eye artifacts. Figure 1 shows the CCD camera setup that records the movement of the patient's eye [4].

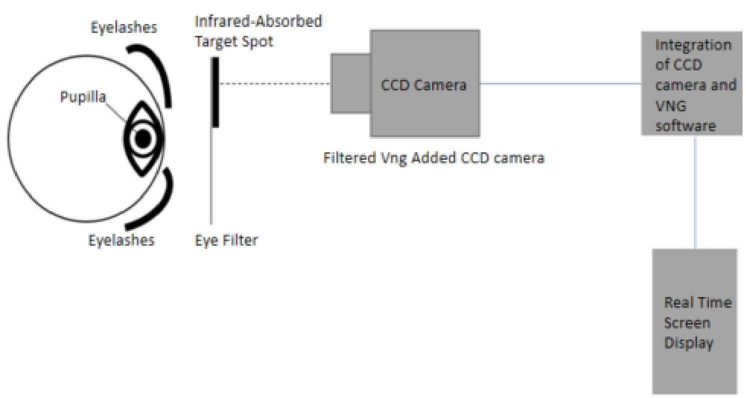


Figure 1: Videonystagmografy System Operation Principle

The ENG method is a graphical transfer of data obtained using the electrical potential difference between the retina and the cornea. ENG is the recording of eye movements by measuring pupil movement speed, sensitivity, corneo-retinal potential difference. The electrodes, whose positions are shown in Figure 2, are obtained by positioning the patient's right and left eye edges, at the closest points to the upper and lower muscle groups of the right eye, and in the area where the reference electrode is removed from the patient's eye. Obtained electrical potential differences are amplified with the help of electronic amplifier and transferred to electronic recording device or recording devices. The transferred data provides information about the amplitude, individual nystagmus morphology, intensity, function, pathology status, central lesion status, speed which are suitable for the treatment method as a diagnostic method [5].

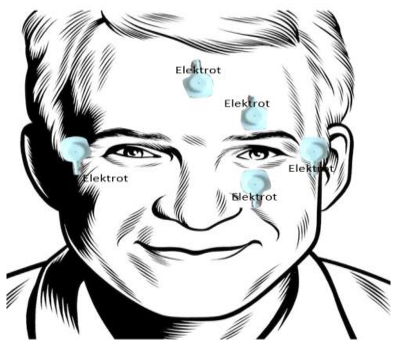


Figure 2: Placing ENG Electrodes on Patient [6]

2.1. General Structure of Nystagmus Test and Measurement System for Benign Paroxysmal Positional Vertigo

In the software developed for the examination of nystagmus movements in the Visual C# program shown in the block diagram (Figure 3), there is a database system where patient data are stored, an interface converter and a software panel where test methods are transferred. The software visuals prepared in accordance with the test method to be used during the test are projected onto the television or monitors, and the individual is asked to follow them, and they are recorded and classified by the ENG software prepared. In addition, by using the bithermal caloric test method, which is another test method, nystagmus movements that occur as a result of endolymph flow differences by creating a temperature change in the individual's ear are recorded and classified with the ENG software and recorded in the database [6].

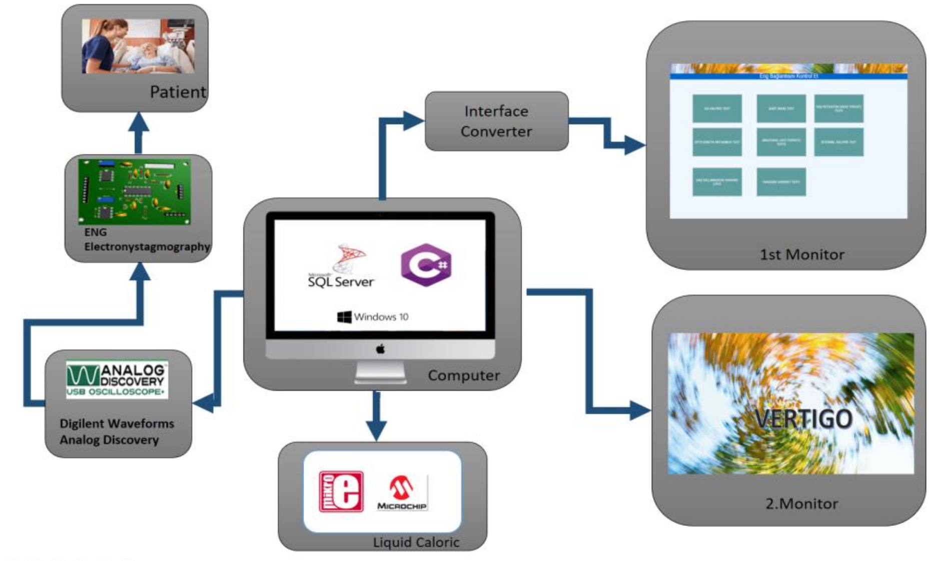


Figure 3: Developed Computer Aided ENG System and Liquid Caloric System Block Diagram

In the bithermal caloric test setup, the microcontrollers produced by Microchip as microcontroller were coded in Micro C Pro for PIC software. Thermostats are used in the system, which bring the liquid temperature to the desired temperature in specially designed insulated containers containing 44 degrees and 30 degrees liquid [7]. In addition, electronic liquid detection tools are positioned in order to determine the minimum and maximum levels of liquid levels. Thanks to the positioned liquid detection tools, the liquid level and temperature values are automatically adjusted with the help of the microcontroller. The adjusted system is used to obtain the liquid levels and temperature values required for the test. The liquids obtained are transmitted to the required motors by taking the command with the microcontroller, thanks to the specially positioned liquid keys on the 30 degree or 44 degrees liquid transmission equipment, in accordance with the test order, and remains active for the desired time.

2.2. Software Structure of Nystagmus Test and Measurement System for Benign Paroxysmal Positional Vertigo

The software structure of the test and measurement system in Figure 4, the test module selection area is shown in case the ENG system connection and the connections of the auxiliary monitors or screens required for the system are approved. One of the Dix-Hallpike, optokinetic nystagmus, head shaking tests is selected on the created test modules selection screen. The 'Start test!' and 'Open test software!' buttons are positioned on the new screens opened after the selection. After the buttons are activated, the modules and materials prepared in accordance with the test are directed to the patient on the television or screen until the end of the test. The test is concluded with the 'Test is done!' command and the results are saved and stored in storage units. Unlike other test methods, the system requests the user to confirm the preparation of the bitermal caloric test setup after starting the bithermal caloric test with the 'Start test! and 'Open test software!' button. After the request is approved, 30 degrees caloric fluid transmission phase is initiated. Transmission continues for 30 s by the system and ENG images are recorded for 5 s after it ends. After waiting for a certain time, the 44-degree caloric fluid transmission process is started, and all other stages are completed in the same way. After the completed test, vertigo is classified and recorded.

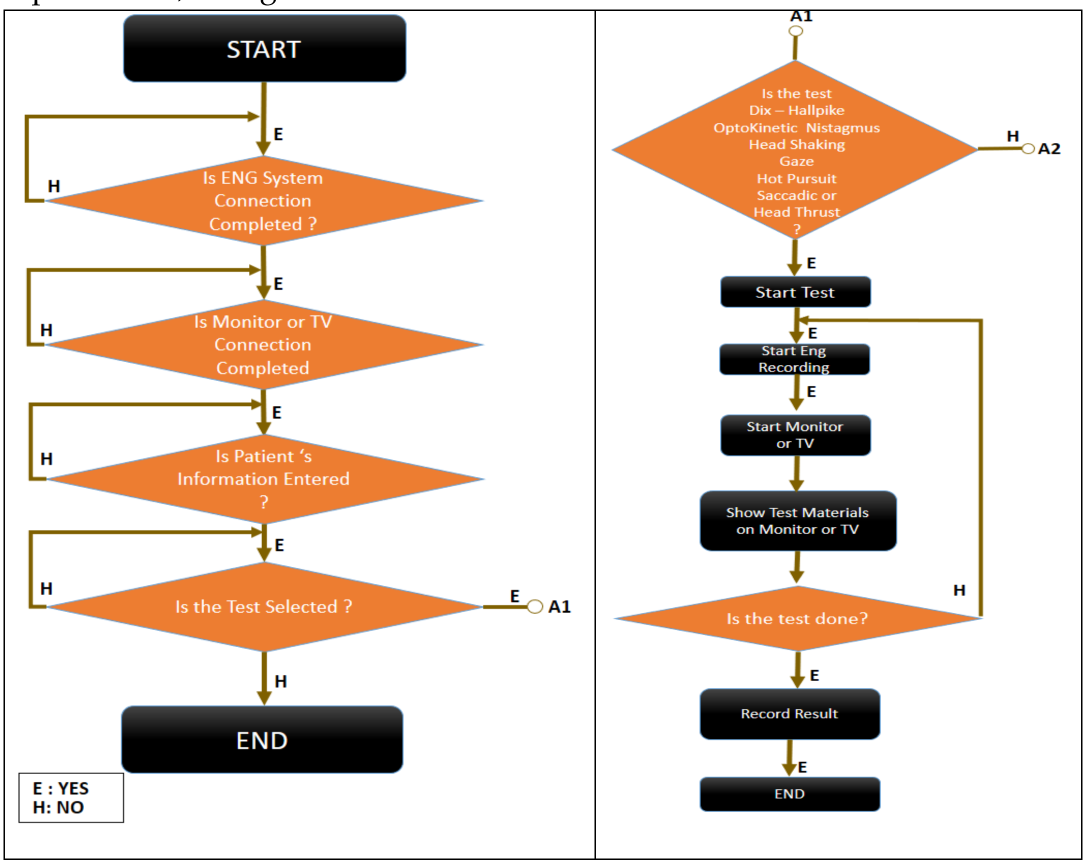


Figure 4: Flow diagram of the software structure of nystagmus test and measurement system due to benign paroxysmal positional vertigo

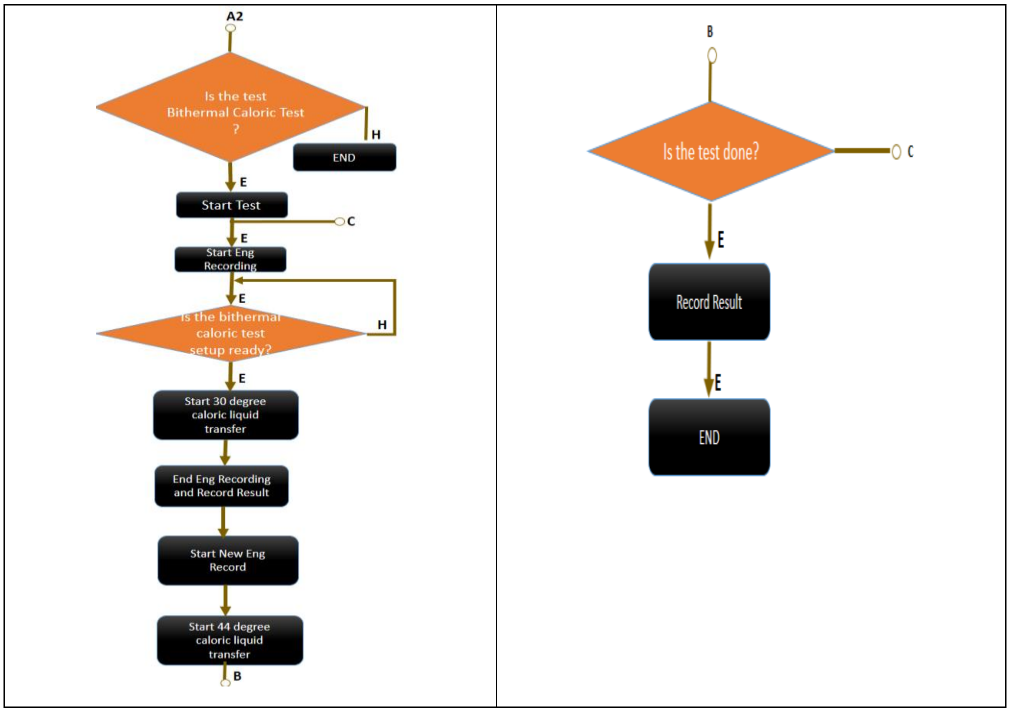


Figure 4 (Continued): Flow diagram of the software structure of nystagmus test and measurement system due to benign paroxysmal positional vertigo

2.3. Mechanical Design of Nystagmus Test and Measurement System for Benign Paroxysmal Positional Vertigo

The mechanical design of the test and measurement system was made with the computer aided design program Solidworks, and the test setup shown in Figure 5 was transformed into a 3D view with Adobe Illustrator rendering program. The rendered ENG system consists of image transmission and a bithermal caloric test setup. The bithermal caloric system shown in Figure 5 is positioned on wheels that make it movable within the clinic. There are computer and liquid transmission tools required for the software on the setup.

Figure 5: The Setup of Bithermal Caloric Test

In addition, the electronic equipment of the system, circuit diagrams and PCB designs were made with the Proteus program. Design schemes and 3D images of the PCB are given in Figure 6 of the article.

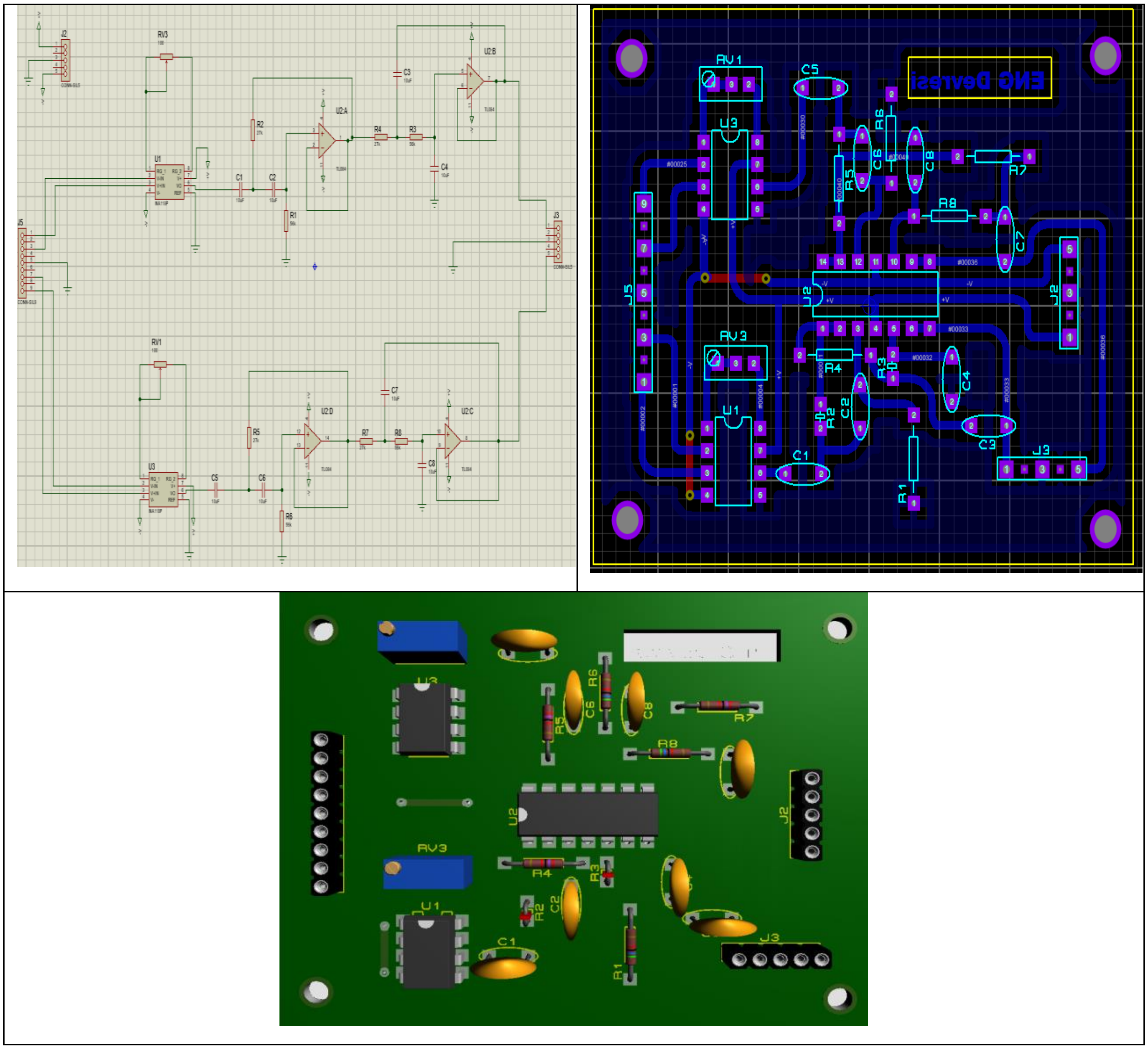


Figure 6: Developed Computer Aided ENG System Circuit Diagram and Ares Drawings

2.4. System Test Setup

Microprocessor-controlled bithermal fluid caloric system is a vestibular evaluation method performed by changing the endolymph flow by creating temperature differences in the patient’s ear. For the system design, a microcontroller is needed for the initiation of the liquid transfer and controls by transferring the signals received from the liquid transfer buttons. For this, pic microcontrollers produced by Mikrochip company were used. The block diagram of the created system is given in Figure 7. The circuit diagram and 3D printed circuit image of the system are given in Figure 8.

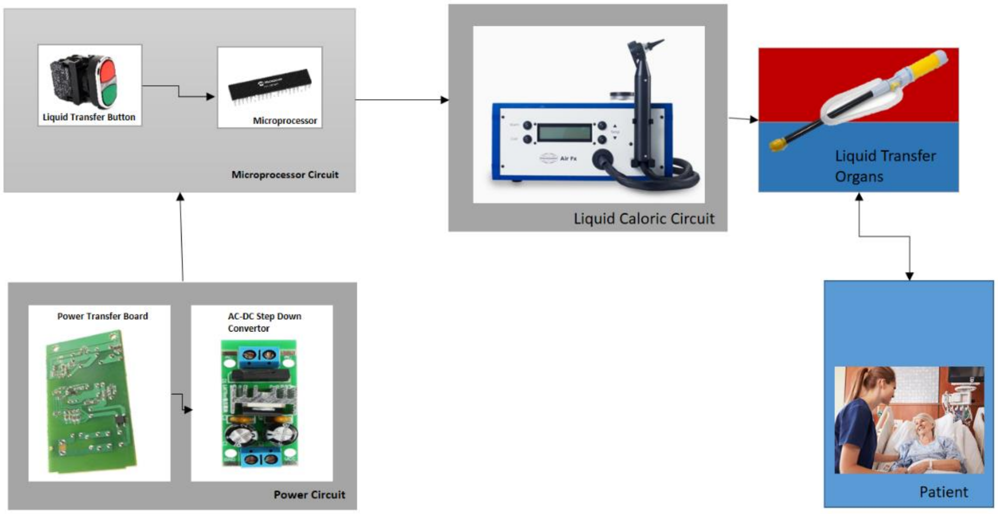
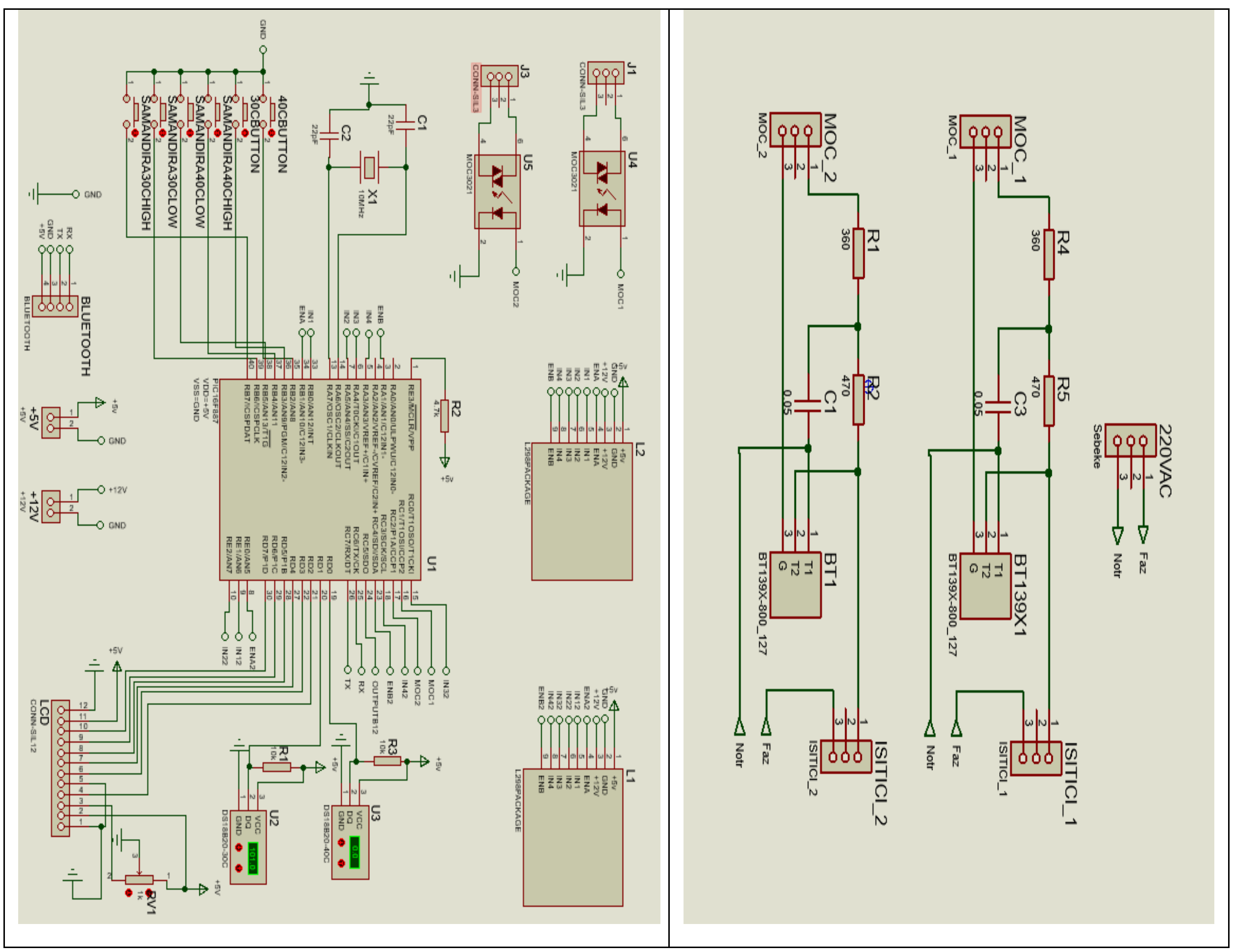


Figure 7: Block Diagram of Microprocessor Controlled Bitermal Liquid Caloric System



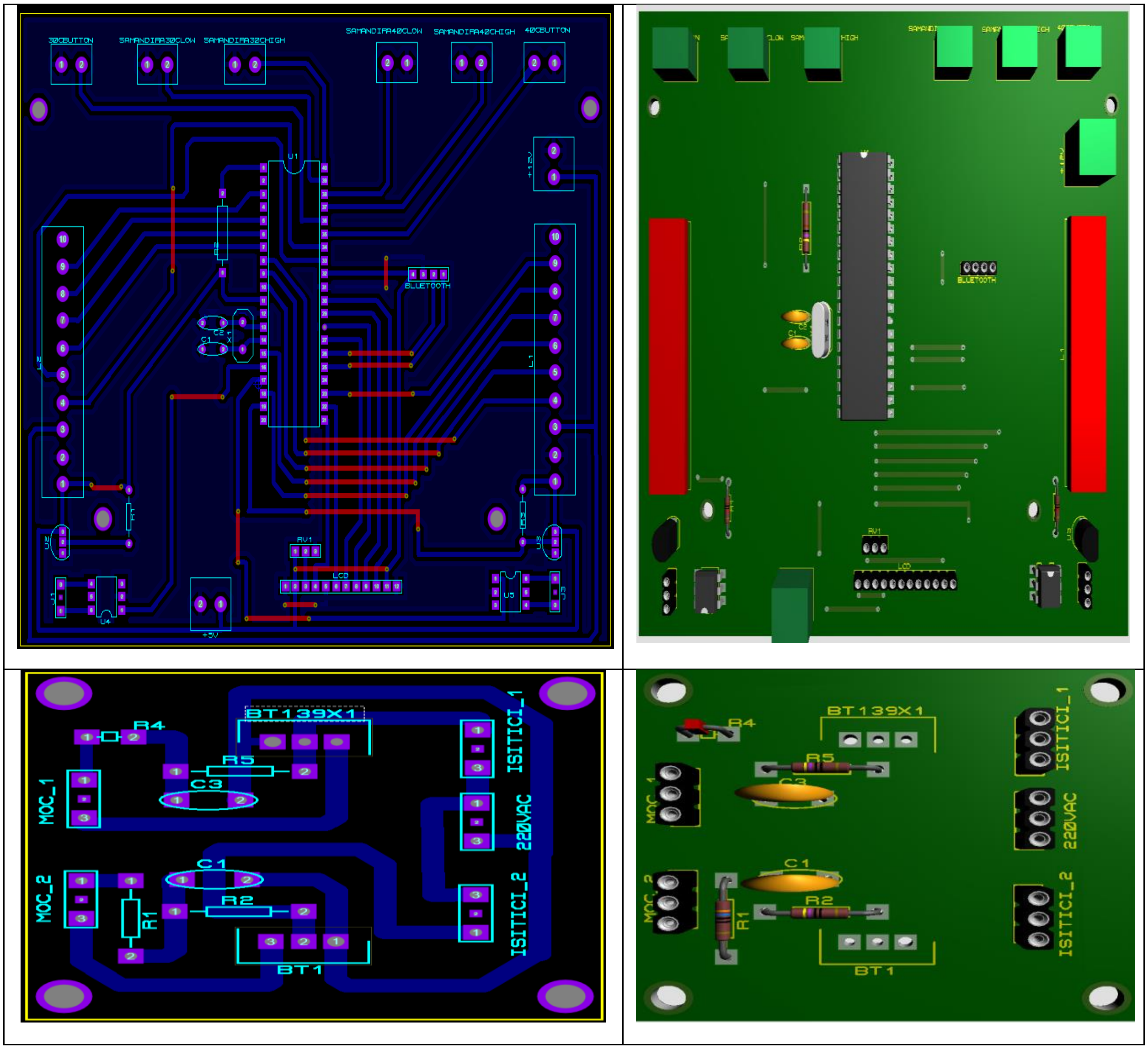


Figure 8: Microprocessor Controlled Bitermal Liquid Caloric System Circuit Diagram and Ares Drawings

The ds18b20 programmable digital thermometer of the Dallas company was used to control the temperature of the bitermal caloric test setup to reach 30 and 44 degrees and to fix the automatically determined temperature value. The time required for the temperature values measured with a digital thermometer to reach a fixed temperature of 30 degrees, were measured with an electronic chronometer and seconds were converted. For the simultaneous temperature accuracy values of the same measurements, the liquid temperatures were checked with the Fluke brand 724 model temperature calibrator and the time required for the liquid temperature to be ready was recorded with the same method. It is seen that the times required for the preparation of the recorded temperatures are randomly distributed. The Bland-Altman method was used because the mean of the differences in the time data spent for the desired temperature values should spread around the zero value. Bland – Altman charts were used to establish the lower limit and upper limit. The lower limit values of the elapsed time values are determined in Equation 2.1 and the upper limit values are determined by the equation shown in Equation 2.2.

$$Lower\ Limit = (Average) - (1{,}96\ x\ Standard\ Deviation) \quad (2.1)$$

$$UpperLimit = ((Average)) + (1{,}96\ x\ Standard\ Deviation) \quad (2.2)$$

The definitions of the parameters used in the above equations,
Average = Average of Elapsed Time Differences
Standard Deviation = Standard Deviation of Differences
This stabilization process is achieved by constantly controlling the temperature of the liquid. Ambient conditions were set at 25 degrees ambient temperature and initial liquid values were set at 20 degrees. The time required to raise the liquid, which is 20 degrees in ambient conditions, to 30 and 44 degrees was measured repeatedly with a chronometer.Fluke Brand 724 model temperature calibrator was used in order to measure the time to reach the value shown on the screen of the system and the temperature accuracy of the liquid temperature value taken from the same point.

2.5. Evaluation of Nystagmus Test and Measurement System for BPPV with Boxplot

There are Dix-Hallpike, gaze, head thrust, optokinetic nystagmus, pursuit tracking, bithermal caloric, head shaking, saccadic motion test modules within the BPPV-related nystagmus test setup interface. In order to check the validity and reliability of the system tests, the box plot method was used. The boxplot method in Figure 9 includes minimum value, 1st quartile, mean, third quartile and maximum value information [8].
Minimum Value: The first value obtained after subtracting outliers found in the system test.
Quarter 1: The portion corresponding to the 25% in the system test.
Average: The portion corresponding to the midpoint in the system test.
Quarter 3: The portion corresponding to the 75% of the system test.
Maximum Value: The highest value obtained after subtracting outliers found in the system test.

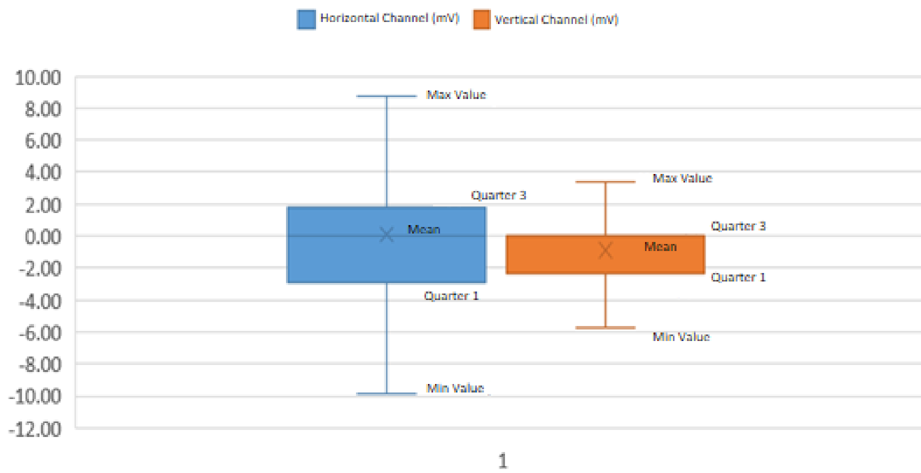
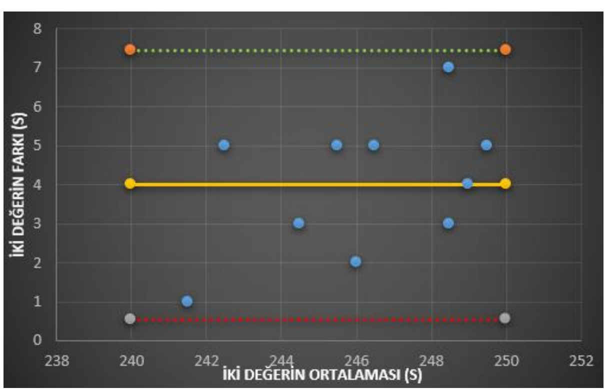
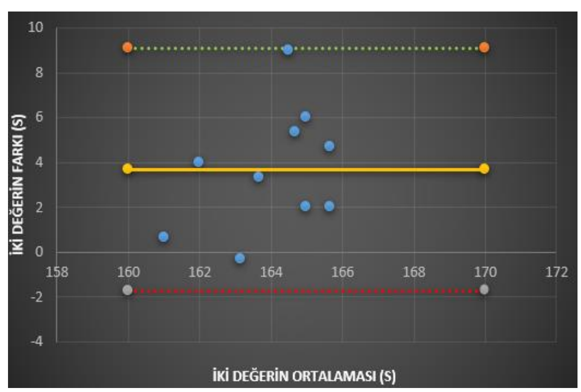


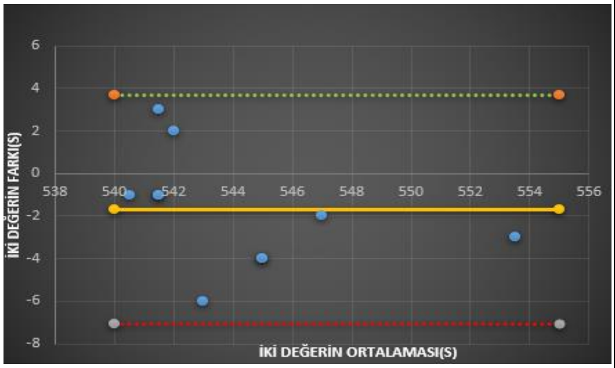
Figure 9: Box Plots Used in System Testing

The tests were obtained with 10 repetitive results in 5 healthy individuals and the system reliability was checked with the box plot method.

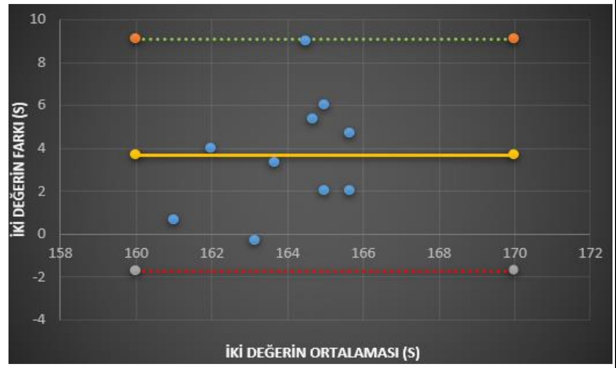
3. Result

The times required for the preparation of the liquid values prepared at 30 and 44 degrees of the bitermal caloric test were obtained as a result of repeated tests. It was analyzed with the Bland Altman method with repeated results and compared with the Fluke brand 724 model temperature calibrator. Bland Altman graphs obtained from the comparison results are shown in Figure 10.

	
a- Bland Altman Chart of 30 degrees temperature value in a bitermal caloric test setup, 3900 ml liquid level and automatic preparation time compared to the Fluke 724 model temperature calibrator	*b- Bland Altman Chart of 30 degrees temperature value, 2600 ml liquid level, and automatic preparation time in a bitermal caloric test setup compared to the Fluke 724 model temperature calibrator*



c- Bland Altman Chart of 44 degrees temperature value, 3900 ml liquid level and automatic preparation time in a bitermal caloric test setup compared to the Fluke 724 model temperature calibrator



d- Bland Altman Chart of 44 degrees temperature, 6600ml liquid level, and automatic preparation time in a bitermal caloric test setup compared to the Fluke 724 model temperature calibrator

Figure 10: Bland Altman Charts of a bitermal caloric test setup compared to the Fluke 724 model temperature calibrator

In Table 1 and Table 2, the time taken to prepare 3900 ml and 2600 ml liquid level at 30 degrees liquid level is compared with the Fluke brand 724 model and the mean values are 4.00 ∓ 1.8 s and 3.67 ∓ 2,8 respectively, as a result of the comparative Bland Altman method. In addition, the values obtained for 44 degrees are given in Table 3 and Table 4. Their average values are -1.70 ∓ 2.75 and -0.70 ∓ 3.09, respectively. When the values are examined, it is observed that the time required for the preparation of 30 and 44 degrees is randomly distributed. The differences and averages of the elapsed time values in the Bland Altman chart are located within the limit values. It has been concluded that there is no relationship between the differences and the averages of the elapsed time values for the result values between the limit values.

Table 1: Results related to the time(s) taken for automatic preparation of 30 degrees temperature value and 3900 ml liquid level in a bithermal caloric test setup using the Bland Altman method..

Elapsed Time	Differences(s)
Average ∓ SS	4,00 ∓ 1,8
Lower Limit	0,54
Upper Limit	7,46

Table 2: Results related to the time(s) taken for automatic preparation of 30 degrees temperature value and 2600 ml liquid level in a bithermal caloric test setup using the Bland Altman method.

Elapsed Time	Differences(s)

Average ∓ SS	3,67 ∓ 2,8
Lower Limit	-1,74
Upper Limit	9,07

Table 3: Results related to the time(s) taken for automatic preparation of 44 degrees temperature value and 3900 ml liquid level in a bithermal caloric test setup using the Bland Altman method.

Elapsed Time	Differences(s)
Average ∓ SS	-1,70 ∓ 2,75
Lower Limit	-7,09
Upper Limit	3,69

Table 4: Results related to the time(s) taken for automatic preparation of 44 degrees temperature value and 2600 ml liquid level in a bithermal caloric test setup using the Bland Altman method.

Geçen Süre	Farklar(s)
Average ∓ SS	-0,70 ∓ 3,09
Lower Limit	-6,76
Upper Limit	5,36

For the liquid transfer times of the bitermal caloric test setup, the output speeds of the system were determined, and the transfer times were calculated at 30 and 44-degrees liquid temperatures. As a result of the tests, one-liter, two-liter and three-liter discharge times were measured in the process starting from the highest liquid level determined and following the readiness of 44 and 30 liquid degrees. The flow rate was determined by mathematical processing of the measured repetitive discharge times. The fluid discharge rates detected are 13.66 cm^3/s (13.6) ± 1.14 cm^3/s (1.14 ml/s) for the thirty-degree caloric test setup. Liquid discharge rates for the forty-four-degree caloric test setup were determined after repeated results of 16.30 cm^3/s (16.30 ml/s) ± 0.23 cm^3/s (0.23 ml/s).

3.1 Nystagmus Test Setup for Benign Paroxysmal Positional Vertigo

Digilent Waveforms Analog Discovery connection control buttons, Dix-Hallpike test, fized gaze test, head thrust, optokinetic nystagmus test, pursuit tracking test, head shaking, saccadic movement test modules can be selected on the interface of the nystagmus test setup due to benign paroxysmal positional vertigo (Figure 11) prepared in Microsoft Visual C#.

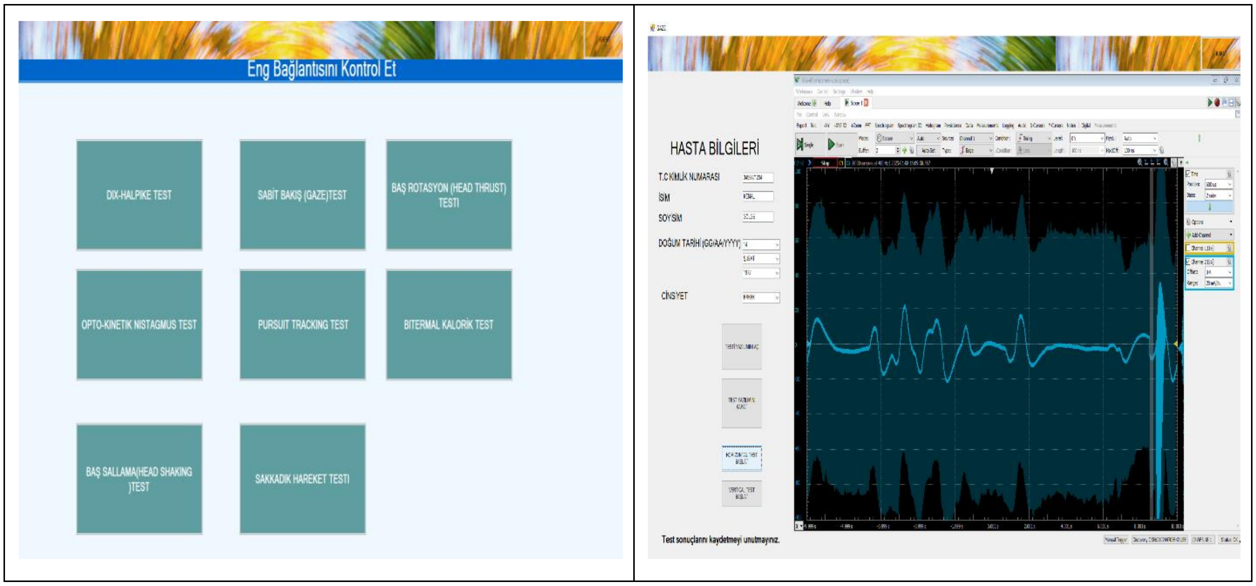


Figure 11: Test Setup Interface of Nystagmus Due to Benign Paroxysmal Positional Vertigo

3.2 Validity and Reliability of the System

The validity and reliability of the implemented system were investigated by repetitive measurement of the data obtained from healthy individuals in the laboratory environment. For this, gaze test, pursuit tracking, saccadic motion, optokinetic nystagmus, passive head rotation, head thrust, head shaking, dynamic positional (Dix-Hallpike), static positional and bitermal caloric test methods were applied to healthy individuals and recorded. Gaze test is the method used to detect both vertical and horizontal axis nystagmus. System gaze test was applied for the individuals in Figure 12. As a result of the tests applied, periodic repetitive regions were found in the horizontal movements of the patient data obtained by the imitation method, and when the graph is examined, the frequency of the repetitive data on the vertical channel is observed more intensely. For this reason, the graphic values suitable for the gaze test in all parts of the healthy individual test are given in Figure 12. However, in Figure 12, it is seen that there are defects in the vertical canal and nystagmus formation. In Figure 13, it is seen that the horizontal and vertical channel distribution densities of the patients are closer to the 0 region in the column graphs, and even though the same test is performed in the horizontal and vertical planes in this region, the distribution is in wider ranges. When these obtained data are examined, when the regions and values of nystagmus are examined, the regions and values of nystagmus of the individual with nystagmus and the reliability of the data are determined by examining the healthy individual and the column and distribution graph with nystagmus. It has been proven that nystagmus can be detected reliably by examining the data of patients and healthy individuals with imitation of both graphs.

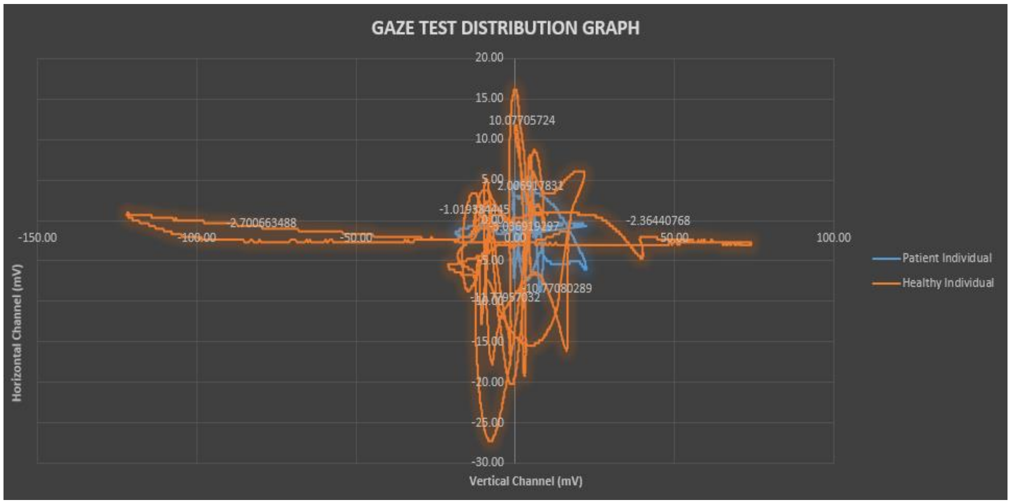


Figure 12: Distribution chart of gaze test data of healthy and BPPV individuals with nystagmus

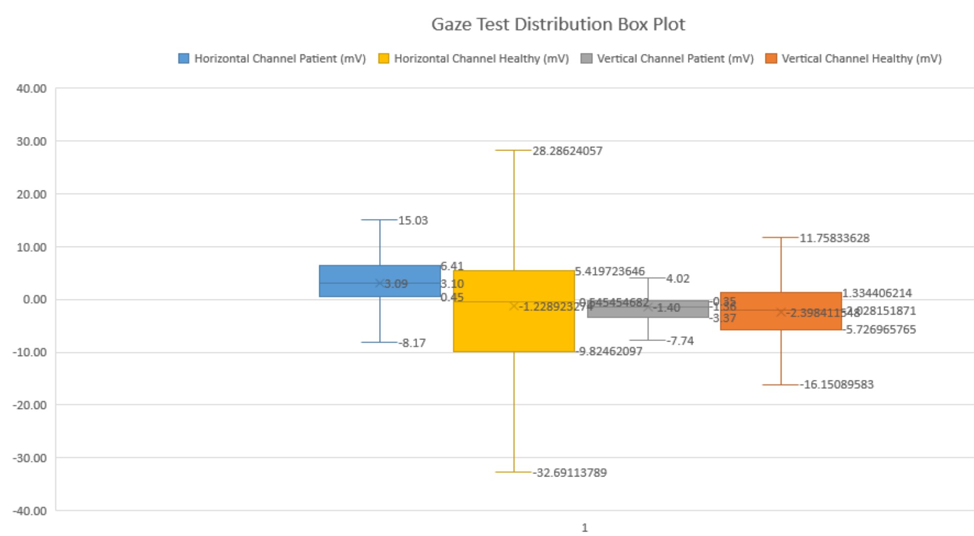


Figure 13: Distribution box plot of gaze test data of healthy and BPPV individuals with nystagmus

4. Discussion and Conclusion

In this study, it was aimed to develop a test and measurement system for nystagmus due to benign paroxysmal vertigo. This study, unlike other studies, is that it has a single interface software and hardware compatibility that prepared all treatment methods. At the same time, adaptive monitor screen compatibility and presenting the appropriate diagnostic methods to the physician's information increase the diagnostic success rate. There are studies in the literature showing that visual stimuli have positive effects on diagnosis, and therefore visual stimuli are transferred to the patient with the help of a monitor. The data obtained from the developed system has been transformed with the help of Digilent Waveforms Analog Discovery, whose reliability has been accepted, and it has been determined that the system is reliable. In addition, the operation of the system as a whole, its portability, production cost balance, patient and specialist ergonomics have been discussed and applied. As a result, it is seen that the developed system will enable the diagnosis of patients with benign paroxysmal positional vertigo to be determined in accordance with integrated visual stimuli in correct and ergonomic environment conditions. However, in order to add treatment modules to the system and to determine its field validity, ethical committee decisions should be taken and control and test groups should be formed and repeated tests of the system on sick individuals are required.

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