Integration of IMU Sensor on Low-Cost EEG and Design of Cursor Control System with ANFIS

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Abstract: *In this paper, an Adaptive Neuro-Fuzzy System (ANFIS) is used for fusion of Electroencephalography (EEG) and Inertial Measurement Unit (IMU) sensors and it is aimed to perform cursor control with this system. The combination of EEG and IMU sensors is intended to perform cursor control by combining cognitive responses and head movements. The system consists of MPU6050 IMU and the NeuroSky Mindwave EEG device. With the prepared recording program for experimental setup, the received data are recorded as separate program tasks with time stamp. Simulator, IMU and EEG tasks prepared for data collection are prepared. During the data collection phase, a cursor simulator was first prepared and the subjects were asked to follow this cursor setup for five minutes. The simulator task records cursor position and velocity. With the IMU task, 3 axis acceleration and angular rotation are recorded. The data collected with the EEG are raw values and extracted feature values. In the ANFIS learning process, IMU features and EEG features were used as input and simulator data was used as output. As a result, ANFIS cursor control is provided with 5% error in cursor movement and 0.3% error for cursor click control.*

Keywords: *ANFIS; EEG; IMU; Human Computer Interaction; Signal Processing.*

I. INTRODUCTION

Human-computer interaction is an area of research involving interaction between people and computers, and the development of technologies used for this purpose. Human computer interface devices are generally composed of hardware and software aiming to give commands to computers according to the input information obtained from human beings. A human computer interface device basically consists of processor, communication and sensor units. The measurements taken from the sensors are interpreted in the processor and translated into commands in a meaningful way and transmitted commands to the machine through the communication unit. Sensor and positioning techniques used in electronic systems can be realized by using relative and absolute systems [1–4]. Absolute systems produce very precise and accurate results; but the infrastructure costs are high and the installation is difficult. Examples of these systems are eye tracking systems [5], motion capture systems such as VICON or Microsoft Kinect [6]. Relative sensor systems are cheap and simple systems. However, since these systems are placed on the body to be measured, faults due to in-sensor friction and other noise sources cannot be fixed and cause error accumulation according to the running time. Examples of such systems are a mouse using an encoder or an optical flow sensor, voice recognition and IMU sensor (Nintendo Wii) [7–9].

The cursor indicates the current and dominant position on the window or images on the user's screen. The biggest advantage offered to the user is; complex, difficult and time-consuming command input and time saving [10]. The cursor control is accomplished very successfully with typical human computer interface devices. However, typical human computer interface system designs and operating principles do not always provide the appropriate use for disadvantaged users. For this reason special human computer interface devices are designed for various disadvantaged groups. For people who cannot use their limbs due to spinal cord injury, cursor control is performed with the help of fuzzy logic according to the change of air flow amount by breathing / blowing [11]. For persons with physical and cognitive impairments, a wearable headset system with IMU sensors was designed and cursor control performed with the help of head movements[12]. With this headset, only the head movements of the person were measured and the movement of the cursor was controlled by the mathematical model which was taken according to the measurements. Biopotential sensors have been added to relative sensors in recent years. These sensors aim to measure the physiological changes of the organism on which the conventional sensors are placed differently than perceiving the changes resulting from the physical environment and providing an interaction with them. Electroencephalography (EEG), Electrocardiography (ECG), Electromyography (EMG) and Electrooculography (EOG) are the best known of sensors. These sensors are used in many areas like attention, stress, meditation and physical activity measurement [13–18]. The most commonly used systems are EOG based systems, which are based on eye movements and are provided by cursor movement control according to signal changes [19,20]. In the cursor control operation with EEG, when a predefined cursor movement sequence run, blink detection is performed with a single channel NeuroSky Mindwave device and the action of clicking the desired letters from the virtual keyboard is performed [21]. The commands generated by the human computer interface devices developed for various purposes are implemented in machines with the help of a control system. For control purposes, Proportional Derivative Integral control (PID), Fuzzy Control (FC), Artificial Neural Networks (ANN), or Adaptive Neuro-Fuzzy Inference Systems (ANFIS) may be preferred [11,22–27].

There is a significant gap in the literature regarding systems which combine multiple actions, especially for disadvantaged groups. In this study, it is aimed to develop a system for filling the gap in the literature and introducing new alternative human computer interface devices. In the goal direction, it is aimed to perform cursor control by using head movements and blinking actions. It is aimed to provide cursor movement control with head movements and cursor click control with blink actions. In addition, it has been tried to produce a solution to the problem of how students brain activities change while looking at which point in the classroom environment [28,29]. The rest of this paper is organized as follows; the material and method used are presented first. Then, the findings obtained in the experimental results are shared. Finally, the results of the proposed system and the findings are presented. Finally, the conclusions and future work on the system and the findings obtained are presented.

II. MATERIALS AND METHODS

In this section, firstly the experimental setup and the working principle designed to collect the input and output data to be used in the ANFIS system are explained. Finally, the feature extraction and selection are explained. For the purpose of the study, the desired system should interpret the IMU and EEG sensor data with ANFIS and perform cursor move and click operations. For this reason, the operation of the system consists of two parts, cursor movement and click control. Figure 1 shows cursor movement control. The 3-axis Gyro and 3-axis acceleration measurements taken from the IMU sensor are filtered first and then filtered attributes such as filtered mean value, standard deviation, RMS value, frequency and amplitude of the highest frequency peak, Crest and Kurtosis factors are extracted. A frame of 1 second length is used for attribute extraction. The IMU sensor operates at 75 Hz, the EEG sensor at 512 Hz and the cursor simulator at a sampling rate of 23 Hz. The features are tested in combination into the exhaustive search process (exhsrch) which is predefined in MATLAB and the least-error-generating combination is used in ANFIS to generate the velocity vectors in the X and Y axes. The generated velocity vectors are finally applied with PID and the relative position data is generated. The cursor movement control part here is only to generate the movements of the cursor object according to the desired cursor velocity vector.

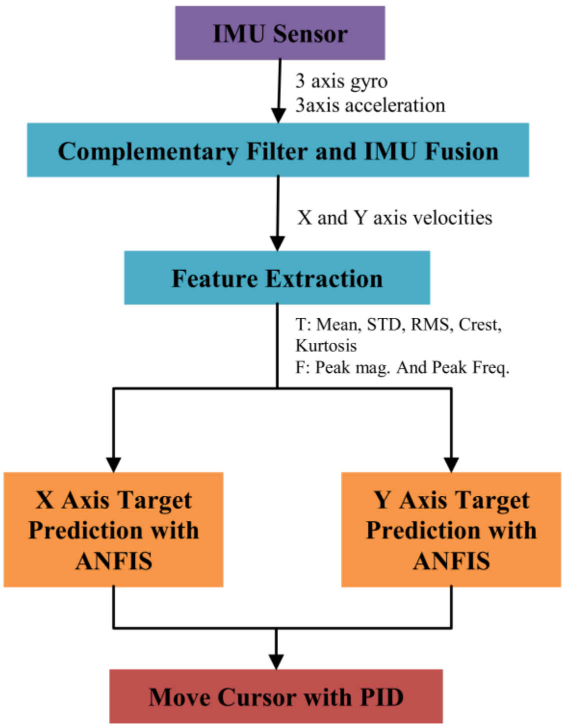

Fig 1.Cursor Movement Control

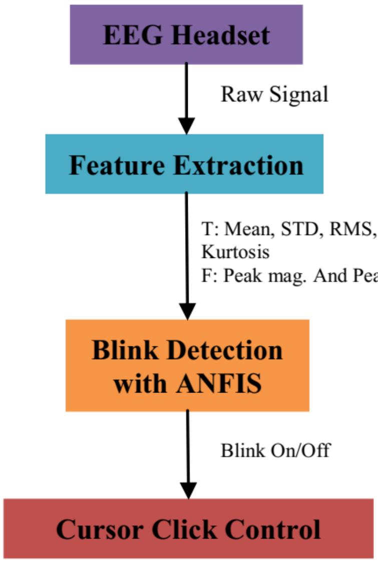

Fig 2. Cursor Click Control

The cursor click control is shown in Figure 2. Here, the raw data is inserted directly into the feature extraction from the EEG. At this stage, the features used in the IMU sensor data are extracted from the raw value without any filtering. Fuzzy control is applied by selecting three of these features. Thus, control is provided by associating blink detection and click action.

The designed system is shown in Figure 3.The system consists of a computer, a low-cost (75$) EEG headset (NeuroSky Mindwave Mobile), an IMU sensor (MPU6050), a microcontroller (Arduino Nano-V3), a mouse and a projector. The important issue is that the modified measuring device enables the use of combined EEG and IMU sensors on a headset. Modified headset and connections are shown in Figure 4. The MPU6050 sensor is connected to the Arduino Microcontroller via the I2C communication protocol. The Universal Asynchronous Receiver Transmitter (UART) is used to transmit 3 axis angular position to the computer after the complementary filter and fusion of 3-axis acceleration and angular rotation values. The complementary filter is used from TKJ Electronics Arduino Library. The Mindwave EEG device is directly connected to the computer via Bluetooth communication. With the prepared recording program, the received data are recorded as separate program fragments and with time stamps. For data collection, a cursor simulator was prepared first, and the subjects were asked to follow this cursor setup for five minutes. Experimental data collected from 10 participants consisting of 4 female and 6 male.

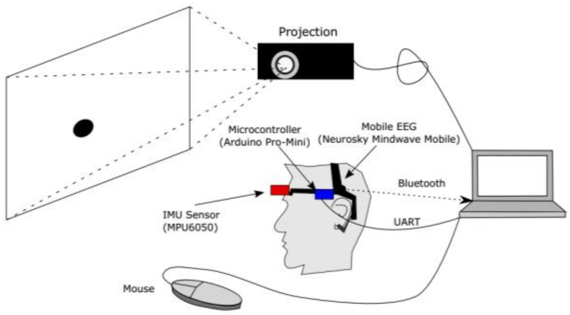

Fig 3.Experimental Setup for Data Collection

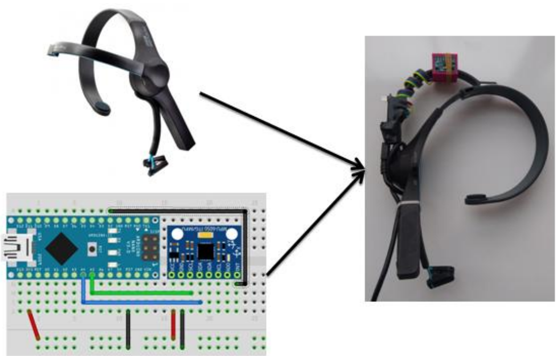

Fig 4.EEG Headset Modification

It is aimed to perform cursor movement simulation in the designed experimental system. A program has been prepared in order to have an object representing the cursor moving randomly on the reflected screen in the aimed direction and to change the shape of the object randomly. The cursor control program is written in the Python programming language, and the program uses the Pygame library. In the designed software, PID control is used to move the object to the target and a natural path is obtained. This software not only manages cursor object motion but it is also multi-threaded prepared for EEG and IMU measurement. The program's algorithm and subtasks are shown in different colors in Figure 5. When the experimental measurement and simulation program starts to work, it starts the EEG and IMU recording threads, randomly applies the cursor targets during the simulation period and stops the whole program with threads at the end of the simulation period.

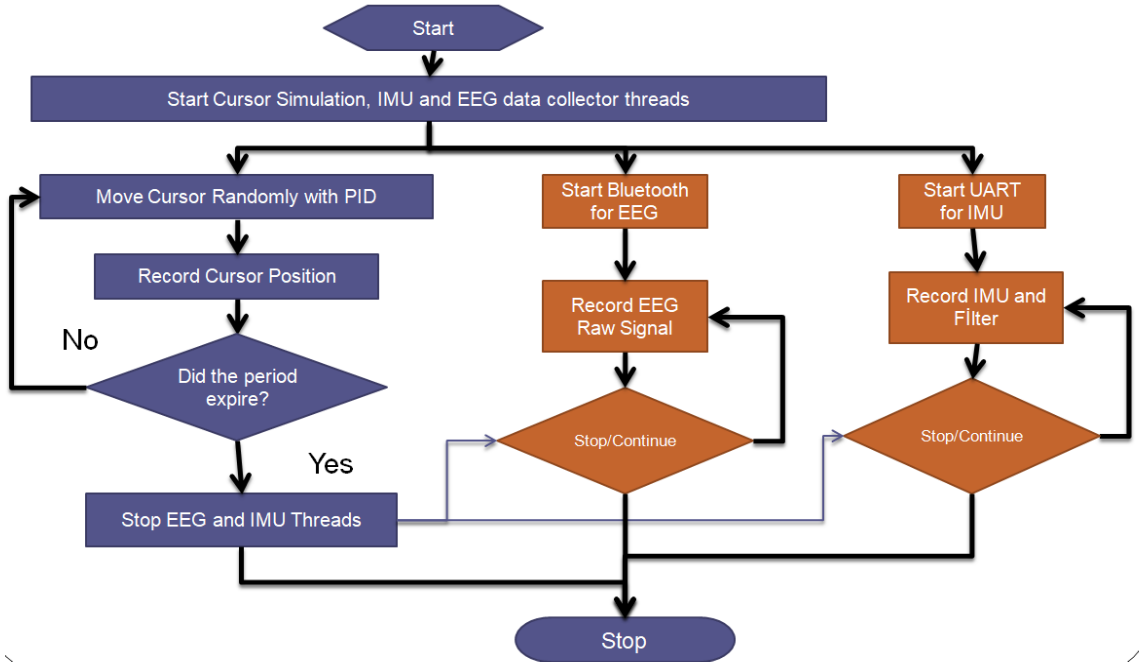

Fig 5. Algorithm for Data Collection in Experimental Setup

A. *ANFIS IMU Sensor Fusion and Cursor Movement Control*

The features of the IMU sensor that are used individually as a result of the cursor speed being used as output are shown in Figure 6 for the X axis and Figure 7 for the Y axis. In case of using two pair combinations of these features, the lowest error value for X axis movements is obtained at X and Y RMS values, and the lowest error value for Y axis movements is obtained at X and Y mean values. In the ANFIS configuration, the FIS properties are selected as grid partition, Sugeno type FIS, and five triangle membership functions for input and output is constant. In the ANFIS learning configuration, the optimization method is hybrid, error tolerance is 0 and epochs are 500. The ANFIS model of the X axis, the input and output membership functions of which these attributes are used as inputs is shown in Figure 8. As a result of the learning process for X axis motion control, 3.2849 error tolerance was obtained. In FIS tests, the train data error was 3.2845 and the checking data error was 3.3542. The Y-axis ANFIS model, input and output membership functions are shown in Figure 9. For the Y axis motion control, 5.1255 error tolerance was obtained as a result of the learning process. In FIS tests, a mean trial error of 5.1251 for train data and 5.2798 for checking data were obtained.

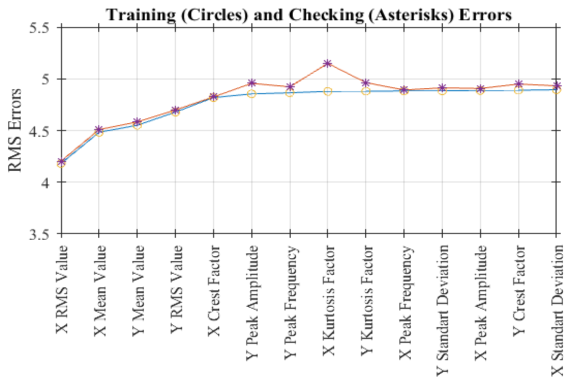

Fig 6. RMS Error Values of Each X Axis Angular Velocity Features

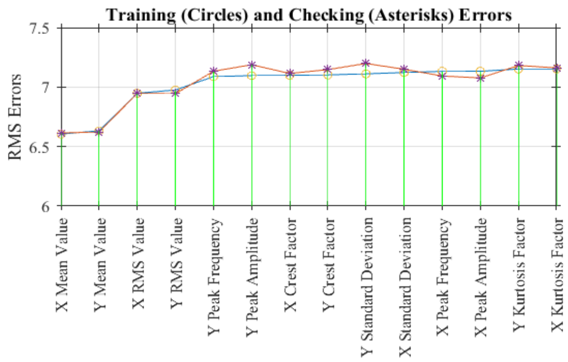

Fig 7. RMS Error Values of Each Y Axis Angular Velocity Features

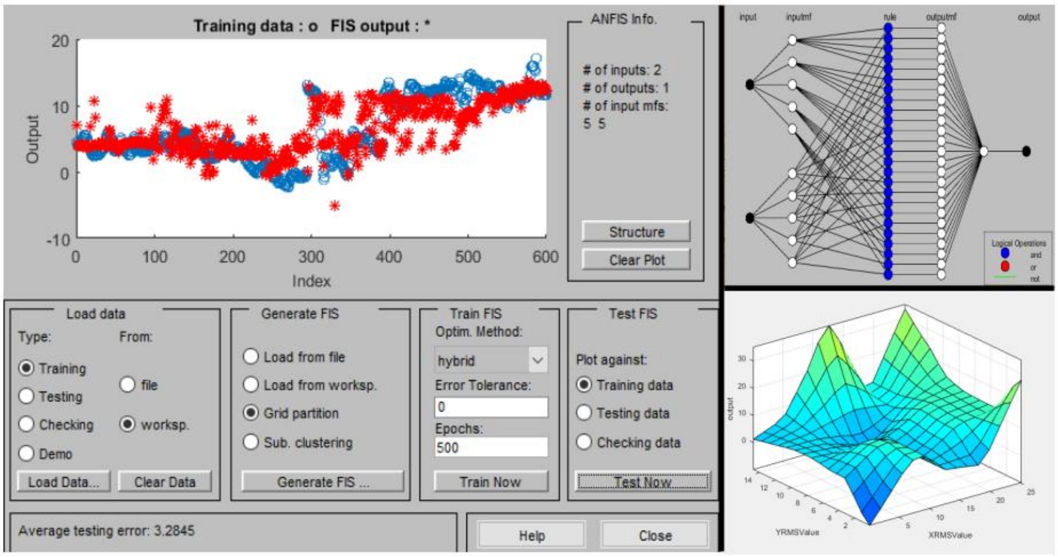

Fig 8. ANFIS for X Axis

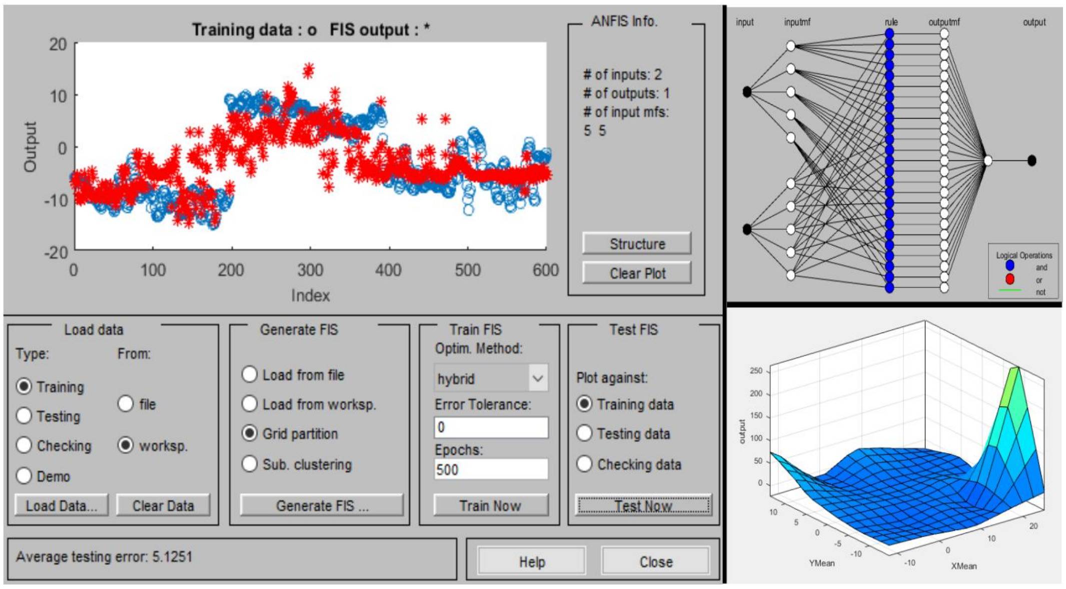

Fig 9.ANFIS for Y Axis

B. *ANFIS Blink Detection and Cursor Click Control*

The error rates obtained when the features obtained from EEG raw data are tested individually are shown in Figure 10. When the triple combinations of the attributes are applied, the combination of attributes with the lowest error rate is the raw value, mean value, and standard deviation. The ANFIS model used for blink detection is shown in Figure 11. In the ANFIS configuration, FIS properties are grid partition, Sugeno type FIS, five triangular membership functions for three inputs and output are constant. ANFIS train options are epoch is 200, neural network type is back propagation and error tolerance is 0. Eye blink detection with ANFIS has been completed with an error rate of 0.3012. In the test part, mean error was 0.3011 for train data and 0.3032 for check data.

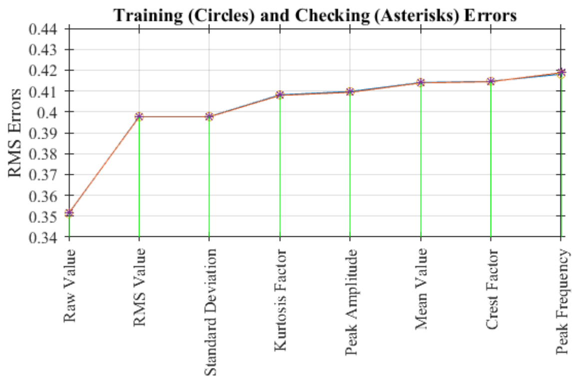

Fig 10.RMS Error Values of Each EEG Features

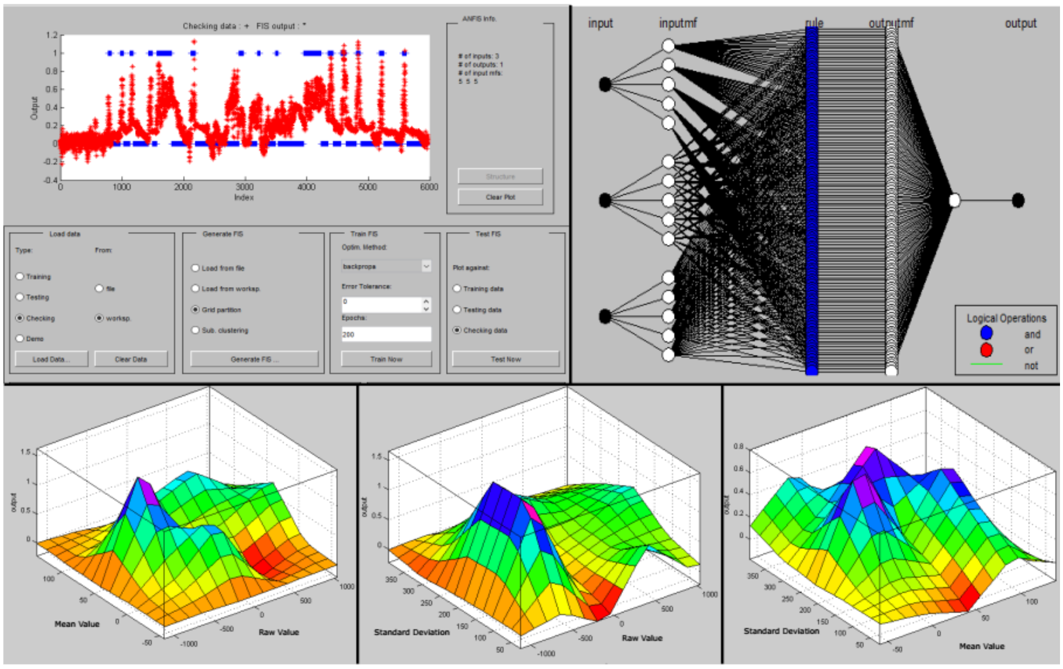

Fig 11. ANFIS for Blink Detection from Raw EEG Values

III.RESULTS AND DISCUSSION

The cursor movement check result on the X axis is shown in Figure 12. X-axis movements are performed with 3% error. The cursor movement control result on the Y axis is shown in Figure 13. Movements on the Y axis are controlled with a 5% error. Since the error obtained is constantly added to the previous error, error accumulation occurs as shown in Figure 12 and Figure 13. Raw data and detection results after blink detection are shown in Figure 14. Blink detection was performed with a 0.3% error.

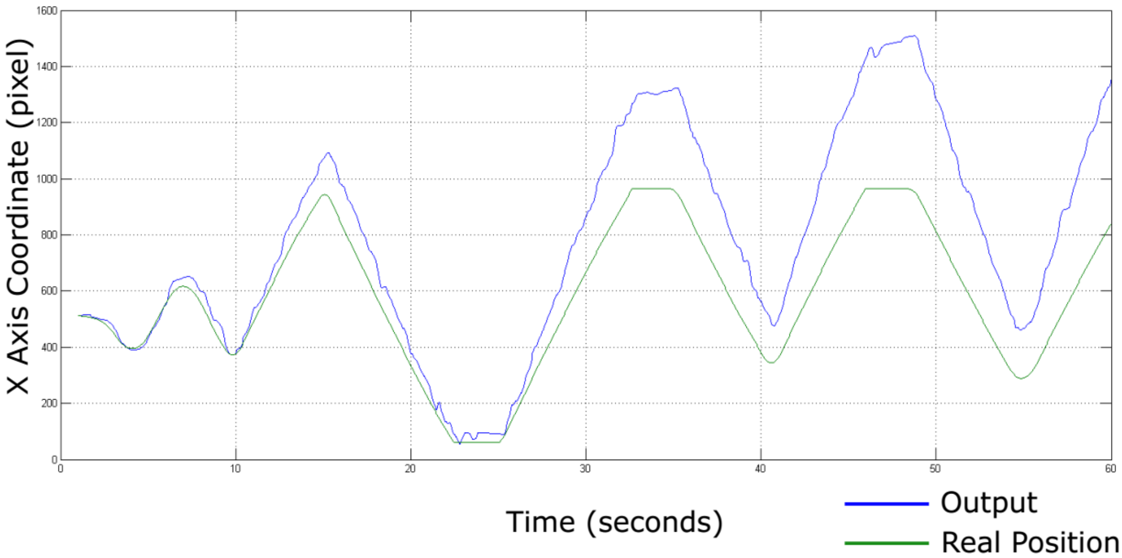

Fig 12.X Axis Cursor Control Experimental Results

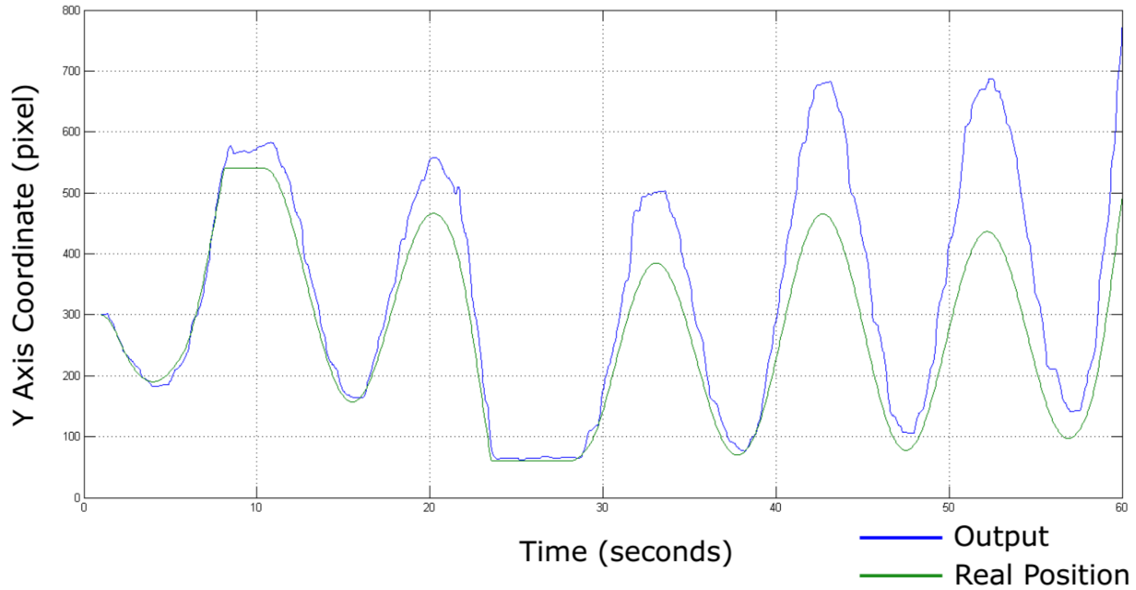

Fig 13. Y Axis Cursor Control Experimental Results

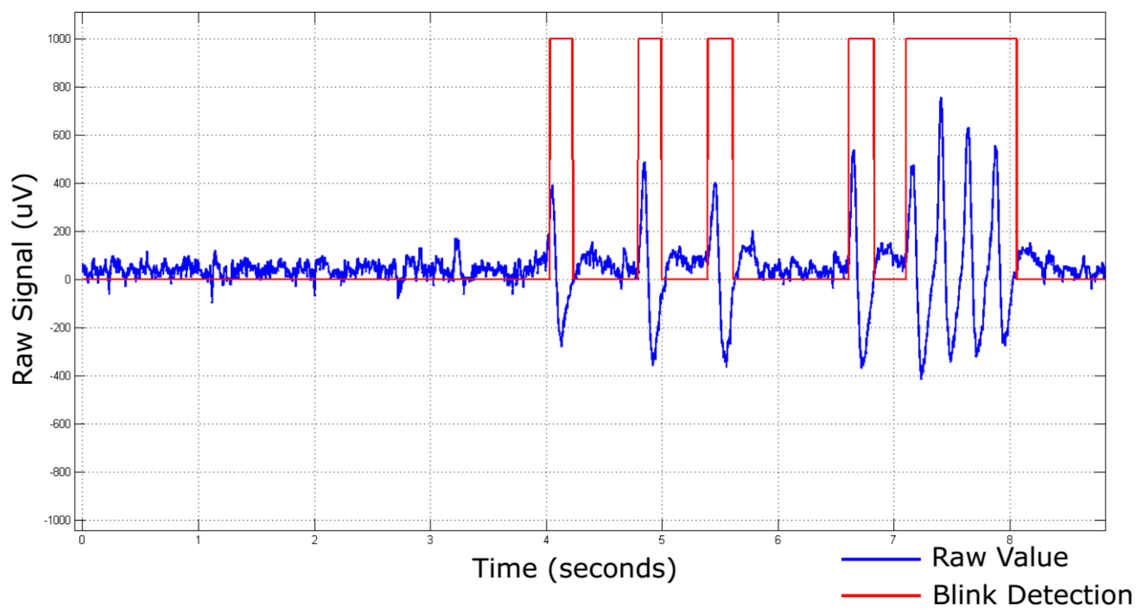

Fig 14.Blink Detection Experimental Results

IV. CONCLUSIONS AND FUTURE WORK

As a result of this study, a system which is composed of IMU and EEG sensors was created for cursor movement and click monitoring and inspection software was created with the help of ANFIS for the operation of the system. In the study, an experimental setup for the ANFIS learning process was established and various features were taken from the collected data and selected pairs were applied to the fuzzy controller. Results for control systems are:

- The system has successfully linked cursor move and click actions with head movements and blink actions respectively.
- It has been observed that the amount of error in the system increases in case of long usage. The increase in the amount of error is due to the influence of the IMU placed on the EEG from the friction. However, resetting the cursor reference with short intervals will help to avoid error accumulation.
- The prototype system presents a new alternative in the literature for the use of a single probe EEG device for active cursor control and combining with an IMU sensor.

The system created within the scope of the study is important in terms of design of low cost and high performance human computer interfaces. It is aimed in the future studies:

- Original circuit and mechanical design should be created instead of ready to use systems.
- The number of EEG probes should be increased for the development of the EEG system
- It is aimed to add a heat map like eye / gaze tracking system heat map outputs for cursor-EEG relationship and flow analysis.

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CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this paper.

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