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## Development of a Multichannel Bioinstrumentation System for Human-Computer Interface Applications

Poyraz Alper ÖNER<sup>1</sup>, Serkan GÜRKAN<sup>2\*</sup>, Mustafa KARAPINAR<sup>2</sup>, Seydi DOĞAN<sup>1</sup>

**ABSTRACT:** A multi-channel measurement system used to measure electrocardiogram (ECG), electroencephalogram (EEG), electromyogram (EMG) and electrooculogram (EOG) biosignals has been designed and prototyped. The designed system has 16 configurable measurement channels. Of the 16 channels the developed system has, 8 have been designed for EEG, 2 for EMG, 2 for EOG, 1 for ECG measurements, the remaining 3 have been reserved as backup channels. In circuit design, biosignal amplifier design principles have been applied by taking into account the characteristics of the biosignal to be measured for each channel, such as bandwidth, frequency, amplitude, noise level. Modules such as instrumentation amplifier, filter, DC suppression unit, amplifier, DC level determination unit, analog-digital converter, optical isolation unit, power supply have been designed to perform biosignal measurements through these channels. Biosignals measured by the developed system can be shifted to the desired threshold level with the help of the analog output reference voltage, converted to digital data 10-bit resolution and transferred to the computer environment in real time. The data transferred to the computer can be used in C#, Excel, MATLAB, and LabVIEW platforms. The novelty of the developed system is that any of the four desired biosignal types can be measured from any channel. In addition, another feature of the system is that it can work with real-time data without being dependent on the databases serving for human-computer interface applications. In experimental studies with some researchers for the performance tests of the system, ECG, EEG, EMG and EOG signals have been recorded with different module configurations, and signal processing stages were carried out to be used for human-computer applications.

**Keywords:** Biomedical engineering, biosignal measurement, biomedical instrumentation, human-computer interfaces, human-machine interfaces, embedded systems

<sup>1</sup> Poyraz Alper ÖNER ([Orcid ID: 0000-0001-5490-4599](https://orcid.org/0000-0001-5490-4599)), Seydi DOĞAN ([Orcid ID: 0000-0001-9785-4990](https://orcid.org/0000-0001-9785-4990)), Balıkesir University, Faculty of engineering, Department of Electrical and Electronics Engineering, Balıkesir, Türkiye

<sup>2</sup> Serkan GÜRKAN ([Orcid ID: 0000-0003-2229-3361](https://orcid.org/0000-0003-2229-3361)), Mustafa KARAPINAR ([Orcid ID: 0000-0002-1953-6804](https://orcid.org/0000-0002-1953-6804)), National Defence University, Army NCO Vocational School, Department of Electronics and Communication, Balıkesir, Türkiye

\*Corresponding Author: Serkan GÜRKAN, e-mail: sgurkan@msu.edu.tr

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## INTRODUCTION

Human-computer interface (HCI) refers to a general expression used for methods that allow people to interact with computer programs (Zhang, 2010). When HCI concept is examined in detail, research areas such as the human-machine interface (HMI) and the brain-computer interface (BCI) are also important topics encountered in the literature (Usakli and Gurkan, 2010).

HCI applications are mainly carried out with electroencephalogram (EEG), electromyogram (EMG) and electrooculogram (EOG) based biosignals (Gordleeva et al., 2020; Li et al., 2020; Martínez-Cerveró et al., 2020; Ramakrishnan et al., 2020; Teng et al., 2020). Especially in EEG-based HCI systems, studies of the detection of ECG, EOG and EMG components (artifacts) and their removal from the EEG signal have been reported in the literature (Hu et al., 2015). By means of HCI applications using biosignals, paralyzed patients who have lost their speaking and movement abilities can be offered the opportunity to meet their basic needs on their own (Usakli et al., 2018; Chang, 2019). In addition, prostheses can be developed to replace the damaged limbs of some patients (Farooq et al., 2019), and channels can be created through which motor neuron patients (amyotrophic lateral sclerosis - ALS) can communicate with their environment (Usakli and Gurkan, 2010; Bozomitu et al., 2019). In parallel with the increase in the average human life expectancy, both the number of paralyzed patients in the society and the number of HCI applications aimed at improving the quality of life of patients are increasing. For example, wheelchair control, computer game applications, computer mouse control applications, virtual keyboard applications are some of the biosignal based HCI applications that have been implemented in recent years (Usakli and Gurkan, 2010; Usakli et al., 2011; Li et al., 2020).

A researcher working in the field of HCI applications may have to use different measurement equipment for the biosignals to be measured. For example, in a wheelchair application, the equipment/hardware needed to evaluate EEG and EMG signals together will be different from the equipment/hardware needed to evaluate EOG and EMG signals together. As a result of this, the costs of the studies to be carried out will increase and extra time will be spent solving the compatibility problems between the equipment/hardware.

Although there have been given EEG, EMG, EOG, EEG-EMG, EOG-EMG-based biosignal data capture applications developed for commercial or academic purposes in the literature, there isn't any study that allows the simultaneous evaluation of EEG, EMG, EOG and ECG biosignals together (Collins et al., 2016; Balamurugan et al., 2020; Teng et al., 2020). Researchers working in the field of biosignal processing and HCI may also prefer to work with data they have purchased from database banks or accessed from open-source databases, due to difficulties and costs of obtaining biosignals from different sources (Cavanagh et al., 2017).

It is obvious how useful the fixed platform-variable module structure is encountered in Arduino and Raspberry Pi platforms which their usages have become widespread in the last decade (Montironi et al., 2017; Papazoglou, 2018; Uyanik and Catalbas, 2018; Perenc et al., 2019). It is possible to develop a wide range of applications from simple to complex with these platforms used in many fields from student level to engineer level. In addition, it is possible to implement a large number of applications in many different fields at low cost with the help of modules that work in harmony with these platforms and perform different functions. The main motivation in this study is the idea that the fixed processor-variable module structure will also be useful for other HCI studies.

In this study, a system using a fixed measurement platform and a configurable module structure was proposed in which EEG, EMG, EOG, ECG biosignals can be measured and transferred to a computer environment simultaneously and in real time. In this way, it has been possible to develop a

large number of HCI applications by using biosignals obtained from different sources. It is generally encountered two basic elements such as biosignal data capture and signal processing, when HCI studies are examined. In this study, it has been mainly focused on a multi-channel biosignal data capture part rather than signal processing. It is possible to obtain real biosignal data at low costs and quickly by using this developed measurement system. Of the 16 channels the developed system has, 8 have been designed for EEG, 2 for EMG, 2 for EOG, 1 for ECG measurements, the remaining 3 have been reserved as backup channels. Although such a channel allocation has been made, the desired biosignal measurement can be performed from the desired channel by making appropriate electrode connections and module configurations.

In circuit design, biosignal amplifier design principles have been applied by taking into account the characteristics of the biosignal to be measured for each channel, such as bandwidth, amplitude, noise level, etc. The safety of the person whose biosignal measurement will be done has been taken into consideration as the main priority at each stage of the design. The analog data received from the amplifier outputs are sent to an analog output unit to be used in applications. This analog data is also sent to another unit to give digital output when it exceeds a reference value set by the researcher. In this unit, the analog data is converted to 10-bit digital data and sent to the digital output terminals. The digital data obtained from the channels are evaluated with the help of a microcontroller and transferred to the computer by optical isolation. Using this prototype, many types of data can be obtained that researchers may need in biosignal based HCI applications. The data transferred to the computer can be used in C#, Excel, MATLAB, and LabVIEW platforms. As a result, bio-signals can be sent to another external unit in digital format or in original analog form by using various transferring methods such as fiber optic, USB, or Bluetooth. Although the definitions are made for HCI applications in this study, the proposed system can also be used for HMI and BCI applications.

## MATERIALS AND METHODS

The block diagram and some images of the developed system for multi-channel HCI applications have been given in Figure 1 and Figure 2, respectively. As can be seen from the block diagram given in Figure 1, it can be easily understood that the signals received by the electrodes are amplified to the required levels by the biosignal amplifiers, transferred to the microcontroller unit by providing optical insulation, and the data collected from all measurement channels are transferred to the computer with time sharing. The original (analog) signals of each channel are also transferred to the system output panel with Bayonet Neill-Concelman (BNC) connectors. In the system, analog outputs without optical insulation are applied to voltage comparators, providing digital outputs above the desired threshold level, and the resulting threshold outputs are transferred to the system panel with BNC connectors. The analog outputs of all measuring channels are connected to parallel type analog to digital converters. The digital data corresponding to the analog level of the desired channel can be used with a resolution of 10 bits, thanks to the address path and bus created in the D-type connector on the system panel.

For user safety, measurement circuits and recording-imaging units are isolated from each other using an optical insulator. Analog data obtained from the optical isolator output are transferred to BNC connectors for each channel and are also connected to the fiber optic (F/O) outputs by the developed analog-to-optical converter. Optically isolated analog data obtained from all channels are evaluated in the microcontroller unit and transferred to a computer with time sharing. In addition, digital and optical data of all channels are serially transferred to two different outputs with the help of the microcontroller unit. Thanks to this developed system, it is possible to access many data types that will be needed in HCI

applications via any connection type. The developed system can be used in computer aided applications as well as in applications that do not require computer support.

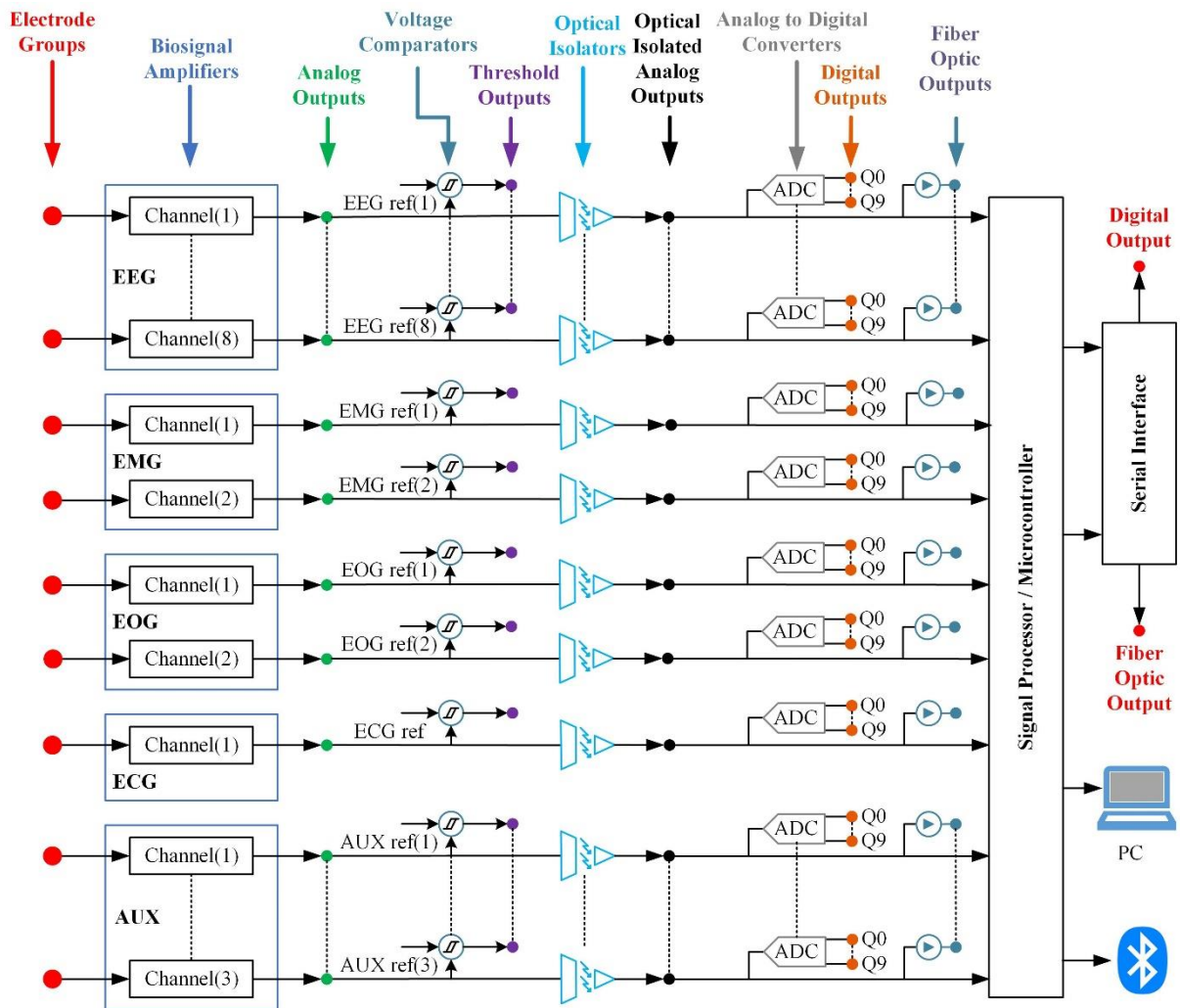


Figure 1. The block diagram of the developed system



Figure 2. Some images of the developed system for multi-channel HCI applications

As can be seen in Figure 2, the system back panel has been arranged for electrode connections and energy input. All signal outputs and computer connection sockets are available on the front panel. When the inside of the system case is examined, there are three main units in it. The first of the units is the power circuit that converts the mains voltage into DC voltage levels to be used in the system. The second unit, called "application development unit" where biosignal measurement applications can be developed,



contains 20 cascaded sockets. The energies of the application modules and their connections between each other are made with the help of these sockets. Biosignal amplifiers can be developed by mounting portable circuits developed in this study to module sockets, and these can be used for bioinstrumentation studies. The third unit is the microcontroller unit.

The most commonly preferred instrumentation amplifier being used in biosignal amplifiers, 2<sup>nd</sup> order low pass filter (LPF), 4<sup>th</sup> order LPF, 50 Hz notch filter, non-inverting amplifier, DC coupler, DC drift remover and optical transmitter modules have been designed for use in the application development unit.

### Design Principles of Application Development Modules

There are some similarities in the processes such as EEG, EMG, EOG, ECG to get biosignals with the help of electrodes and making useful data by amplifying them. The methods given in the literature for the measurement of these signals have been searched and eight different modules have been designed to be used in experimental studies. The circuit schematic diagrams of the designed modules have been given in Figure 3.

One of the most critical and important components for biosignal measurement systems is undoubtedly instrumentation amplifiers. In the designed system, AD620 instrumentation amplifier has been preferred. The circuit diagram and appearance of the instrumentation amplifier module has been given in Figure 3a. The voltage gain of the module (G) can be calculated by Equation (1). Since R1 is a constant value resistance (1 KΩ), the G value varies between 5.49 and 50.4 according to the value that RV1 takes between 0 and 10 KΩ.

$$G = \frac{49400}{R_1 + RV_1} + 1 \quad (1)$$

A 2<sup>nd</sup> order (20 dB/dec) LPF module that circuit diagram and appearance are given in Figure 3b has been designed to be used in the system. The cutoff frequency (f<sub>c</sub>) of the module is calculated to be 49.41 Hz using Equation (2).

$$f_c = \frac{1}{2\pi\sqrt{R_1 R_2 C_1 C_2}} \quad (2)$$

A 4<sup>th</sup> order (40 dB/dec) LPF module that circuit diagram and appearance are given in Figure 3c has been designed to be used in the system. The f<sub>c</sub> of the module has been calculated to be 49.41 Hz as done in the previous LPF.

The DC coupler module is designed to suppress DC levels occurring between components in the system during measurements. The circuit diagram and appearance of the designed module have been given in Figure 3d. As can be seen in the figure, an active high-pass filter with a cutoff frequency of 0.33 Hz is encountered.

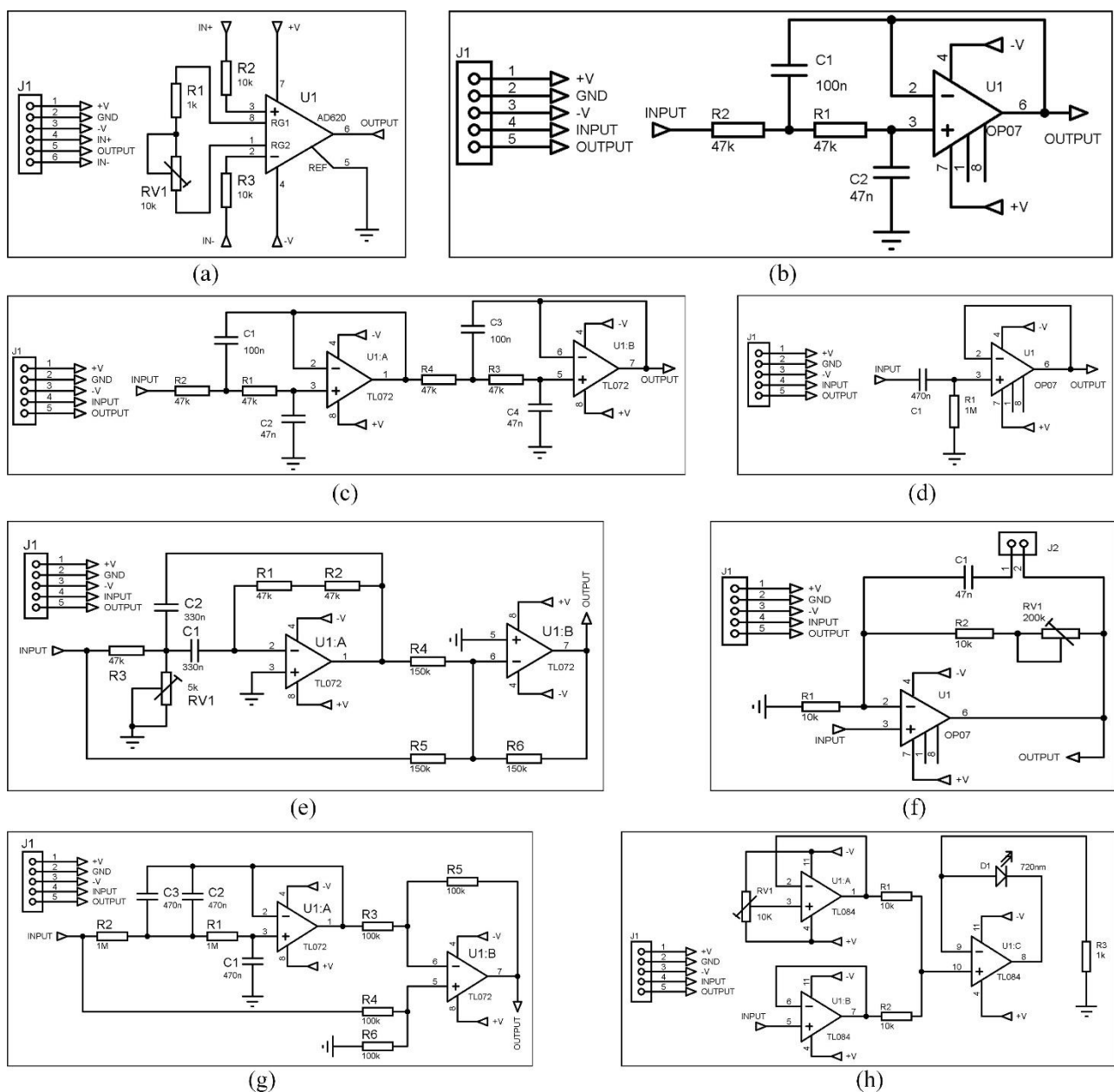
In the system, a narrow band 50 Hz notch filter module has been designed to suppress 50 Hz noises originating from the electrical network. The circuit diagram and appearance of the designed module have been given in Figure 3e. The quality factor (Q) and bandwidth (BW) of the module are 4.87 Hz and 10.26 Hz, respectively.

The designed non-inverting amplifier module has adjustable voltage gain, and this gain value can be changed between 2 and 22. The circuit diagram and appearance of the module have been given in Figure 3f. When the jumper J2 in the module is open circuit, standard non-inverting amplifier operation is performed. When J2 is short-circuited, a non-inverting LPF of which gain can be adjusted in the range of 2 - 22 and the cutoff frequencies between 15.4 Hz - 338.8 Hz is obtained.

The DC drift remover module, like the DC coupler module, has been designed to suppress the DC levels occurred between units during measurements. While the DC coupler module operates on the

principle of high pass filter, the DC drift remover module operates as a low pass filter. The circuit diagram, block diagram and appearance of the designed DC drift remover module have been given in Figure 3g. As can be seen in the figure, it is seen that the input signal is first passed through a 0.22 Hz low pass filter. This signal obtained at the filter output can be described as the DC component in the input signal. Then, the DC component is removed from the input signal with the help of a differential amplifier, and it means that the DC component in the input signal is suppressed.

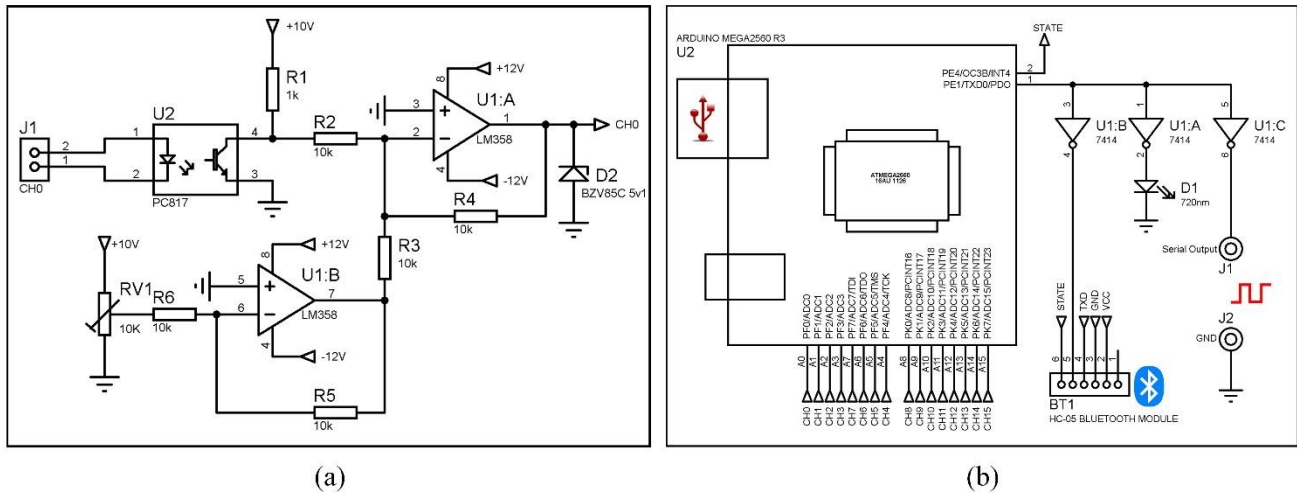
Optical isolator module allows analog signals obtained in measurements to be carried by fiber optic cable by converting them to light. The circuit diagram and appearance of the designed module have been given in Figure 3h. As can be seen in this figure, it is understood that the brightness of the 720nm wavelength light source varies according to the input voltage of U1:B. For  $\pm 5$  V voltage values applied from the module input, the current passing through the 720 nm light source varies in the range of 10 mA - 30 mA. Thus, the analog signal is converted into an optical signal.



**Figure 3.** Circuit schematic diagrams of the designed modules **a)** Instrumentation amplifier, **b)** 2<sup>th</sup> order low pass filter, **c)** 4<sup>th</sup> order low pass filter, **d)** DC coupler, **e)** 50 Hz notch filter, **f)** Noninverting amplifier, **g)** DC drift remover, **h)** Optical transmitter

## Microcontroller Unit

The microcontroller unit collects and evaluates the analog signals obtained in the application development unit and performs the necessary operations for transmission to the computer via the front panel communication terminals. The circuit schematic diagrams of the designed microcontroller unit have been given in Figure 4.



**Figure 4.** Circuit schematic diagrams of the designed microcontroller unit **a)** Optical isolator, **b)** Data format converter

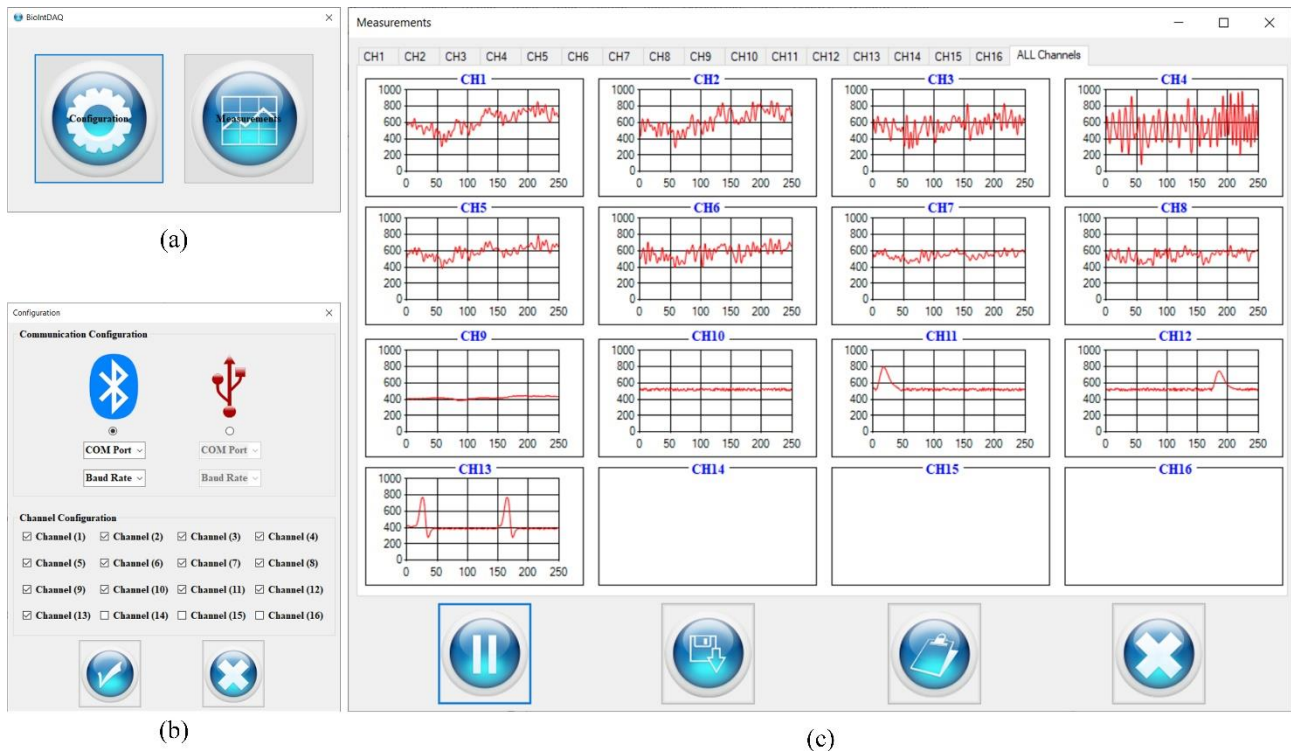
The first function of the microcontroller unit is to optically isolate the analog signals obtained in the application development unit and the communication terminals from each other. All amplified biosignals coming from the application development unit to the microcontroller pass through an opto-coupler based isolator. The circuit diagram of one of the opto-coupler based insulators designed for each channel has been given in Figure 4a. The optical isolator circuit is used together with the optical transmitter circuit, and the D1 light source in Figure 3h and the component J2 in Figure 4a are mutually connected. Thanks to this structure, an optically isolated analog signal is obtained at the CH0 output in Figure 4a.

Another process performed in the microcontroller unit is to produce 10-bit digital data for each of the 16 analog channels. An Atmega2560 has been used in the microcontroller unit for this process. Analog data applied to the A0-A15 analog inputs of the Atmega2560 are converted into 10bit digital data. The digital conversion for which analog input will be determined by the address data applied to the B0-B3 digital inputs. 10-bit digital data obtained as a result of analog-to-digital conversion are transferred to A0-A7 and C0-C1 digital outputs of Atmega2560. There is a D type connector on the front panel of the system for 4-bit address input and 10-bit digital output.

The last process performed in the microcontroller unit is to obtain the data formats needed for the data transfer channels. A circuit part designed for this process in the microcontroller unit has been given in Figure 4b. As can be seen in this figure, isolated analog data of all channels are applied to the analog inputs of Atmega2560. Analog data of each channel is converted to serial digital data format in the Atmega2560 microcontroller and transferred to the USB port and TX0 pin. Serial digital data obtained from the TX0 pin is then applied to three Schmitt Triggers. By using the "U1:A" Schmitt Trigger with a 720 nm light source, the optical form of the serial data is obtained. "U1:C" output is directly transferred to the front panel of the system and provides electrical serial digital data. "U1:B" output is connected to a Bluetooth module. Thus, biosignal data can be transferred to a computer wired or wirelessly using the USB port or Bluetooth module.

## User Interface Software

A user interface software has been designed to transfer the data collected in the system to the computer. Visual C# has been preferred for the interface software and the developed interface has been named as "BioInstDAQ". BioInstDAQ consists of three menus: "Main Menu", "Configuration Menu" and "Measurements Menu" and their screenshot images have been given in Figure 5.



**Figure 5.** User interface software menus (a) Main menu, (b) Configuration menu, (c) Measurements menu

"Main Menu" is the start menu and is used for switching between these menus. "Configuration Menu" is used for determining the connection type, connection port, connection speed and measurement channels. The menu where signals belonging to all channels can be displayed and recorded is the Measurement Menu. In this menu, the signals for the channels can be displayed individually or collectively. The digital data of the obtained biological signals can be saved in the computer in text (.txt) format. This recorded data can be used in platforms such as C #, Excel, MATLAB and LabVIEW.

## RESULTS AND DISCUSSION

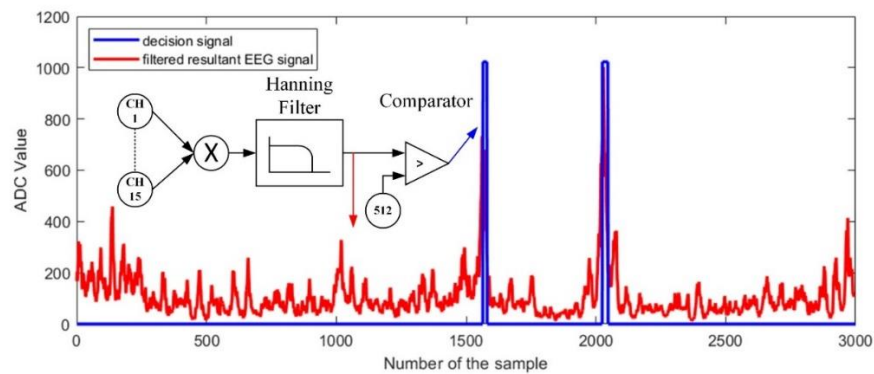
After testing all channels of the designed system, experimental studies have been carried out with a group of researchers working biomedical engineering field to test the system functions. In these studies, researchers carried out biosignal measurement obtained from different sources and have been asked to evaluate the signals they recorded.

### Measurement and Evaluation of EEG Signals

In this experimental study called "Task 1", the researchers were given the task of establishing the necessary configuration for measuring the EEG signals, and they were asked to record the EEG signals obtained as a result of the right-fist clenching movement. Then, they were asked to determine the moment of fist-clenching using signal processing techniques. The filtered resultant EEG signal obtained from the measurement channels and the MATLAB printout showing the detection of the fist-clenching moment are given in Figure 6. In this study, Ag-AgCl electrodes were used for the measurements, three



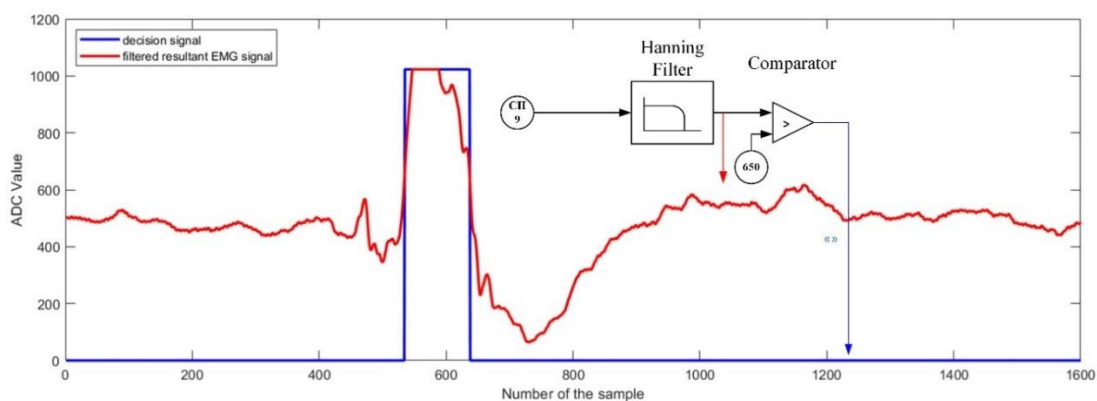
Laplacian derivations were preferred for the placement of the electrodes, and the center electrodes were placed at the C3, C4 and Cz points. The reference electrode was placed in the left mastoid and the ground electrode in the right mastoid. As a result of the measurements conducted via 15 channels, it is observed that the EEG signals can be measured successfully, the obtained EEG signals are compatible with those given in the literature, and the moment of fist-clenching can be detected. Results clearly show that the obtained signals can be used in HCI and BCI systems (Hu et al., 2015; Collins et al., 2016; Cavanagh et al., 2017; Gordleeva et al., 2020; Hooda et al., 2020).



**Figure 6.** EEG signal and detection the moment of the fist-clenching for "Task 1"

### Measurement and Evaluation of EMG Signals

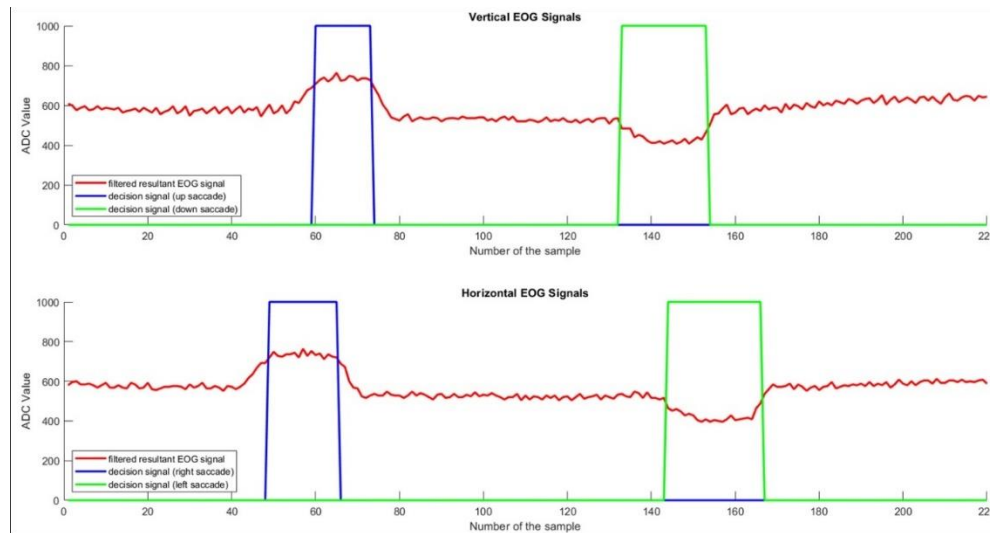
In this experimental study called "Task 2", the researchers were given the task of establishing the necessary configuration for measuring EMG signals, and they were asked to record the EMG signals obtained as a result of the left-fist clenching movement. Then, they were asked to determine the moment of fist-clenching with signal processing techniques. The EMG signal obtained from the measurement channel and the MATLAB printout showing the detection of the fist-clenching moment have been given in Figure 7. As a result of the measurements conducted via single channel, it is observed that EMG signals can be measured successfully. The obtained EMG signals are compatible with those given in the literature, and the fist clenching movement can be detected. Results clearly show that the obtained signals can be used in HCI systems (Hu et al., 2015; Farooq et al., 2019; Gordleeva et al., 2020).



**Figure 7.** EMG signal and detection the moment of the fist-clenching in "Task 2"

### Measurement and Evaluation of EOG Signals

In this experimental study called "Task 3", researchers were given the task of establishing the necessary configuration for measuring EOG signals, and they were asked to detect upward, downward, left and right movements of the eye using signal processing techniques. The EOG signals obtained from the measurement channels and the MATLAB printout showing the detection of eye movements have been given in Figure 8.

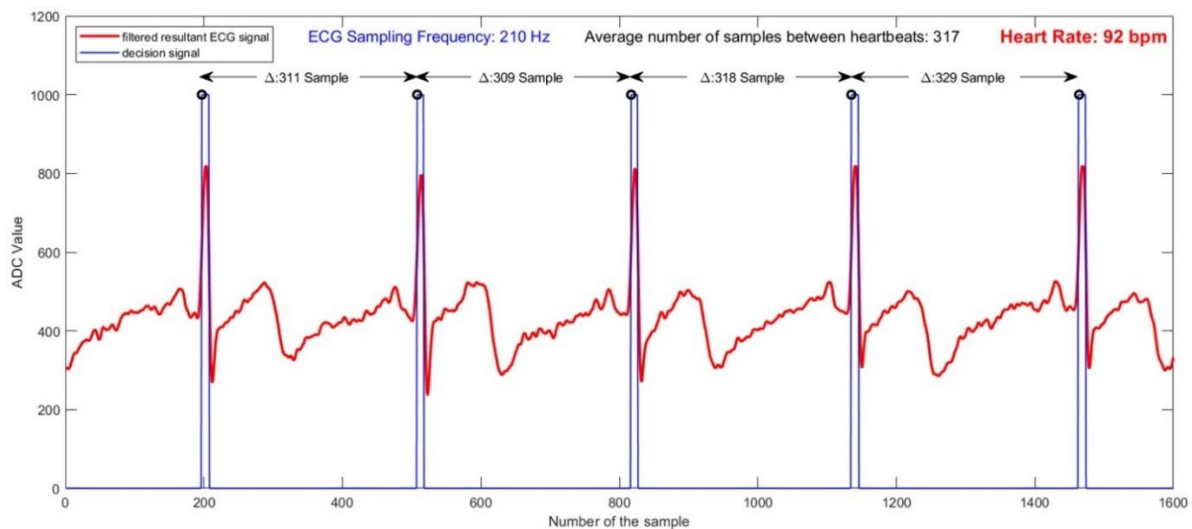


**Figure 8.** EOG signals and detection of the eye moments for "Task 3"

Ag-AgCl electrodes were used for the measurements and as a result of the measurements conducted with these electrodes via two channels, it is observed that the EOG signals can be measured successfully, the obtained EOG signals are compatible with those given in the literature, and eye movements can be detected. Results clearly show that the obtained signals can be used in HCI systems (Usakli and Gurkan, 2010; Hu et al., 2015; Usakli et al., 2018; Martínez-Cerveró et al., 2020).

### Measurement and Evaluation of ECG Signals

In this experimental study called "Task 4", the researchers were given the task of establishing the necessary configuration for measuring ECG signals, and they were asked to determine the heart rate per minute using signal processing techniques. The ECG signals obtained from the measurement channels and the MATLAB printout showing the heart rates have been given in Figure 9. Left foot was taken as reference in measurements, and right and left arm derivations were used. As a result of single channel measurements, it is observed that ECG signals can be measured successfully, heartbeats can be detected, and the obtained ECG signals are compatible with those given in the literature. Results clearly show that the obtained signals can be used in HCI systems (Kashou et al., 2020; Panganiban et al., 2021).



**Figure 9.** ECG signals and detection of the heartbeats for "Task 4"

## CONCLUSION

In this study, a multi-channel biosignal measurement system has been designed and prototyped to be used in biomedical engineering schools and laboratories where HCI researches are conducted. Experimental studies have been conducted with a group of 6 researchers using this designed system. It has been shown that the measurement of basic biological signals such as EEG, EMG, EOG and ECG is possible by this system having 16-channels. Of the 16 channels the developed system has, 8 have been designed for EEG, 2 for EMG, 2 for EOG, 1 for ECG measurements, the remaining 3 have been reserved as backup channels. The designed system has the output types needed for the development of HCI, HMI and BCI systems. All channels have a configurable hardware structure with the designed development modules, and it is possible for develop HCI applications. The fact that biosignals recorded in experimental studies with a group of 6 researchers are compatible with those given in the literature shows that the system works correctly and fulfills its function. In addition, it is possible that many new studies can be published in the literature both by evaluating the relationships between biosignals obtained from different sources and by developing new HCI applications.

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## Conflict of Interest

The article authors declare that there is no conflict of interest between them.

## Author's Contributions

The authors declare that they have contributed equally to the article.

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