Computers And Electrical Engineering Template

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Abstract

Biometric signal processing has many of its applications in health care, rehabilitation research, and security systems. Nonetheless, over the last couple of decades, the biometric signal has encountered a new niche in educational research. In this work, the development of an eye-tracking device intended to be used for educational monitoring tasks is presented and learning studies. The device is based on the Electrooculography technique in contrast to the most common approaches that are based on image processing and computer vision devices and techniques. The proposed eye tracking device makes use of machine learning algorithms to detect the movements of the user's eye and in this way serve as a way of monitoring the cognitive activities of subjects or students. Moreover, a brief analysis of the cognitive skills related to the learning process of students that can be measure with the proposed system is presented. Also, a general comparison of other systems available in the current literature is made to compare the capabilities and areas of opportunity of the presented system. It is concluded that the device can recognize basic eye movements that can monitor basic cognitive behaviors like reading, writing, copying, or watching multimedia content through electronic devices. With further development and the generation of study cases, the eye-tracking system can be enhanced for further research related to the educational field.

Introduction

Since 2010 many companies started to incorporate biometric technology in educational platforms or services that are delivered to educational institutions [1]. One of the most common types of biometric signals that are used in research education and applications are ocular trackers. A good example of it is Tobii Technology, a high-technology company focused on developing and selling products related to eye tracking and eye control activities [2]. Some of their products have also been used for educational applications and research around the world [3], in fact, his eye-tracking products have been used extensively in eye-tracking research for education. Nevertheless, most of their products require a high investment, and therefore, they are not accessible to everyone. On the other hand, Electrooculography (EOG) has been mainly used for eye tracking and eye recognition movements interfaces focused only on rehabilitation purposes or oriented for people with restricted mobility, examples of these are found in electric wheelchairs, Human-Machine Interfaces, and sleep monitoring applications [4]; [5]. Moreover, it is important to remark that electrooculography has demonstrated to be a feasible way to monitor cognitive skills that are related to the learning process such as writing, reading, and watching by monitoring only saccadic eye movements and fixation [6]; [7]. Nonetheless, the development of interfaces or devices that use EOG as a manner to study the learning process of the student and improve it, is scarce. Another drawback of the available EOG devices and interfaces is the use of specialized software and hardware to generate a high-performance recognition system that can be embedded into interfaces or applications with lower costs [8]. This drawback is shared with the other eye-tracking devices available in the market which require a high investment on part of the professor, student, or educational institutions.

Taking the above into account, the main goal of this work is to present the design and development of an eye-tracking device for educational research purposes. The eye tracking device is made of open-source hardware and software to make it available for both students and professors and maintain it accessible for them. Therefore, this work is organized as follows: Section 2 presents a literature review of the eye-tracking studies focused on educational research and assessment. Section 3 presents the development process of the proposed eye-tracking device based on electrooculography as well as the materials and techniques used to generate the device. Section 4 shows an analysis of the learning outcomes that could be studied according to Bloom's Taxonomy with the proposed system. Section 5, presents the relationship between emotion recognition, learning, and the role or potential of electrooculography. Section 6 makes a brief comparison of the advantages and disadvantages of the proposed system in comparison to the ones used in the literature. Section 7 presents an analysis of the results. Finally, Section 8 presents the conclusions of this proposal and its further work.

Eye-tracking and education

Eye-tracking is a method that enables the gathering of information and data to make an empirical analysis of human cognition, behavior, and perception [9]. These characteristics have enabled that over the last couple of decades, the eye-tracking devices or methods used for education applications or research related to the learning process have started to grow. Some of the fields of education in which this technology has been applied are in text reading for language learning, mathematics understanding, and science knowledge learning [10]. Eye-tracking research focused on education has also been concerned in improving the design of computer-based learning, in the visual areas such as medicine or chess, and more recently to promote visual proficiency by eye movement modeling [11].

For instance, the use of eye-tracking technology has been applied to analyzed student reading behavior while reading electronic books. In the study of Kao [12], eye-tracking technology was used to understand the reading process of students while visualizing online materials. On the other hand, image processing devices have also been used to analyze the studying behavior of mathematics content at elementary school one example of this is the work of Sun in which a software interface that employs eye-tracking technology was developed to improve the teaching framework [13]. Eye-tracking devices have started to pick up certain attention in the involvement of people that suffer from some type of disability in educational processes an example of the above is presented in the work of Moreva [14] in which an eye-tracking platform was used to study the attention process of students while visualizing a web page-oriented for people with disabilities, in this same work it is also mentioned the growth or presence of students with some type of restricted health condition. The study of [15], tried to analyze how information is processed and learned and what is the role of visual attention in both activities. To do the above, Cuesta used eye-tracking to capture the visual behavior of the student and electroencephalography (EEG) to keep track of information processing. Moreover, Molina [16] studied the process of how electronic books are read and the importance of its design to keep the engagement of the student. To do the above, the eye movements of sixty-five students were tracked, the results indicated the importance of having a good integration of written and pictorial information in e-books. In another work of Molina [17], it is analyzed the importance of the design of multimedia materials in the process of teaching and learning. Instead of using traditional feedback from the students such as surveys and questionaries, the work of Molina employed eye-tracking since it is a more objective method to extract information related to the attention of multimedia learning materials.

According to Hajra medical educational field can also be enhanced with eye-tracking technology [18]. In his work, a literature review was made in which seventeen studies on clinical assessment and six focused on eye-tracking used as an assessment tool were studied, demonstrating the usefulness of the methodology in medical practices. Beach [19] shows a study in which it is determined that eye-tracking methodologies can give an insight into teachers' engagement about learning material, reading behaviors, or sensemaking strategies. In this same study, it is remarked that these methodologies can show educational stakeholders' opportunity areas related to learning outcomes and environments. Besides, [20] provides a review of how eye-tracking technology has been employed directly or indirectly with e-learning platforms and it is described the development process of an e-learning platform to collect eye data with the intention of know the emotional state of the student. Finally, in the study of Lin [21], 38 computer science students were monitor through eye-tracking devices while debugging C language program codes, to understand the cognitive process of the student while reviewing software. It is important to notice that most of the presented studies are mainly focused on using eye-tracking devices based on computer vision techniques, but it is not mentioned any other type of solution.

In the case of electrooculography (EOG) and its potential used in the educational field, there have been some works that have addressed the subject. For example, the study of Shipulina[22] reports the potential that electrooculography could have educational neuroscience research in the field of mathematics. According to Shipulina EOG could provide feedback into the cognitive functions of the students by analyzing the eye-related behavior (ERB). In fact, there are studies that demonstrate that blink rates could decrease significantly during demanding cognitive tasks[23]. Besides, Bonfiglio[24] explains that blink and saccades can be used to punctuate the shifting focus of the attention of an individual from one object to another (exogenous shifts) or the reflections of one through to another (endogenous shifts). A more recent study developed by Muller [25] intended to use the EOG technique to evaluate the usefulness of this technique in the measurement of sentence comprehension duration, the technique was compared with the traditional eye-tracking systems with the authors claiming that both techniques achieve similar results in their study. Moreover, Banerjee [26] tried to recognize cognitive activities form the analysis of eye movements measured through the EOG technique, eight cognitive activities were studied, activities such as reading, writing, web searching, copying, video watching, word search, relaxation activities, and game-playing were analyzed. To recognized these activities machine learning techniques were employed. Furthermore, Marandi [27] presented a study for the quantitative assessment of the decision-making process through the implementation of the gaze tracking by using electrooculography measurement technique, in this study subjects were asked to select between two different objects of the same class within a specific period of time. The results of this work remark that there is a statistical significance related to the gaze direction and decision-making process of the subjects.

From this brief literature review, it is possible to notice the great areas of opportunity that eye-tracking technology can have in educational applications and research related to teaching strategies. Nonetheless, most of the proposals are enabled through commercial image processing devices to collect data from the eye. In addition, there are is a lack of research or proposals that have tried to develop its own eye-tracking technologies or devices, that can serve the specific need of researchers or the experiment that is tried to be carried out by the investigators. The above led to the design of an alternative Eye-tracking technology based on electrooculography that has shown some potential used in educational research, especially in the learning cognitive process analysis. Nevertheless, the potential of eye-tracking devices based on Electrooculography has not been extendedly explored in the current state of the art, therefore it is an opportunity area that could be explored more deeply. In the next section, the process of development of the eye-tracking device is presented.

Methods

Electrooculography pre-processing circuit

Electrooculography is an electrophysiological technique in which the biopotential generated between the cornea and the retina is measure using silver/silver chloride electrodes [28]. Compared with electroencephalography (EEG) techniques or Brain-Computer Interfaces (CBI), it is less invasive and requires a less quantity of electrodes. An illustration of the placement of the electrodes needed to measure the EOG signal around the eyeball can be seen in Figure 1. With this configuration, saccadic eye movement and blinks can be easily detected through EOG and provide a measurement tool for eye-related behavior, nonetheless, there are some important problems that need to be addressed in order to perform a good eye-tracking system based on EOG. In general, this biopotential is susceptible to a great quantity of noise and variations making it rarely deterministic even for the same person in a different environment. To counterweight this problem, it is important to implement adequate processing of the signal both in hardware and software to assure a good performance of the device. The first step consists in the acquisition of the signal, then a preprocessing process is needed to remove noise and artifacts from the signal. These artifacts or noise could come from the muscle activity around the face (electromyography), the power electric line, or electromagnetic interference. The third step is related to the feature engineering of the EOG signal, this process is crucial since depending on the selected features the classification process can be done more precisely or could worsen the classification process. After the classification algorithm was selected the last step is the implementation of the whole system in an embedded processor that could process the information fo the sampled EOG signal in real-time.

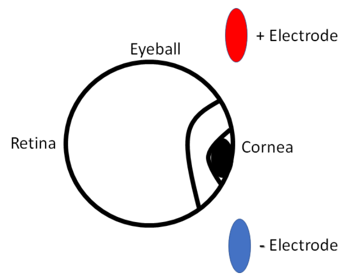

Figure 1: Corneo-Retinal Potential of the eyeball and electrode placement.

To generate a low-cost device, the preprocessing of the signal needs to be performed with the less quantity of components. To achieve the above, it is important to consider that the EOG has a very low amplitude ranging from 50 to 3500 µV and its bandwidth is limited from 0Hz otherwise known as the D.C. component and 30Hz according to the International Society for Clinical Electrophysiology for Vision (ISCEV) [29]. However, these signals are susceptible to very low-frequency noise commonly referred to as based line drift. Therefore, an amplification stage needs to be performed with the use of an instrumentation amplifier (AD620) and a decoupling the D.C. stage achieve by using a high pass filter with a cut-off frequency of 0.5Hz to 1Hz. Later, a low pass filter with a cut off frequency of 30 Hz is placed in cascade to the high pass filter. This low pass filter also serves as an antialiasing filter for the sampling of the signal with a microcontroller (MCU) capable of communicating with any type of computer or electronic device. To enable the communication of the MCU with any type of electronic device, a Bluetooth communication module (HC06) was used for this purpose. Finally, bipolar to unipolar conversion circuit is placed between the output signal of the low pass filter and the analog channel of the microcontroller to limit the amplitude of the signal in a range of 0V to 5V and avoid damaging the analog channel of the microcontroller. This pre-processing circuit can be appreciated in Fig 2.

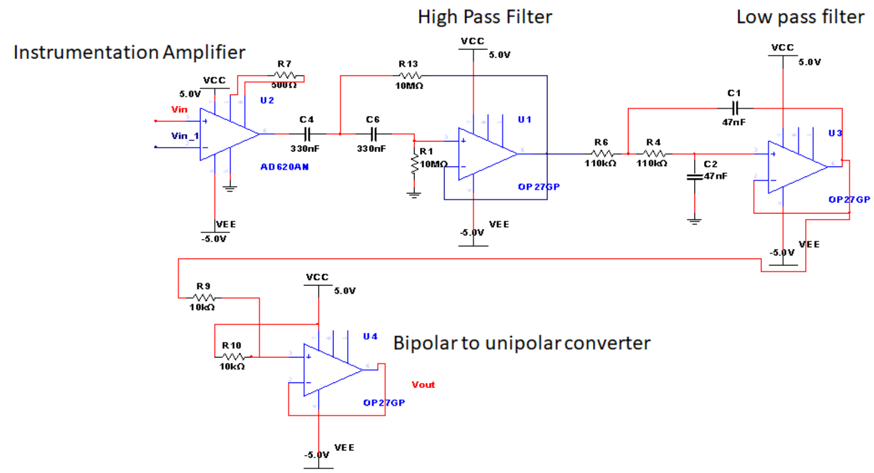

Figure 2: Preprocessing circuit of the eye tracking device composed of a instrumentation amplifier, a unipolar to bipolar converter , and a bandpass filter with a bandpass of 0.5Hz to 30Hz.

EOG signal conditioning and samples acquisition

For the sampling stage, an Atmega 328p microcontroller was chosen, this microcontroller is embedded in the Arduino Uno development board. The microcontroller was configured to sample the EOG signal coming from the pre-processing circuit at a rate of 2 milliseconds. To remove the noise, generated due to electromagnetic interference a first-order Infinite Impulse Response (IIR) digital filter with a cut off frequency of 10 Hz was designed and implemented. It is important to have a deterministic sampled rate to assure that the IIR filter performs correctly, therefore the 500 Hz sampling rate was generated through the interrupt service routine of one of the timers of the Atemga 328p. To design the digital filter first, the analog low pass filter is designed with the required cut-off frequency leading to the next transfer function (Equation 1).

$$LP = \frac{62.83}{s \ + 62.83}$$

Then the continuos low pass filter is converted to the digital domain with the use of the bilinear transform or Tustin method. The discrete transfer function taking into consideration a sampling rate of 2 milliseconds is presented below and a bilinear transformation (Equation 2).

$$LPD \ = \ \frac{0.05912z + 0.05912}{z - 0.8818}$$

To program in a microcontroller the discrete transfer function it is necessary to express it in the form of sums and multiplications leading to the next expression (Equation 3).

$$y\left(n\right) \ = \ 0.8818y\left(n-1\right) + 0.05912x\left(n\right) \ + \ 0.03912x\left(n-1\right)$$

Where **y(n)** represents the actual output of the filer, **x(n-1)** represent a one delay input value of the analog to digital converter of the microcontroller, while **x** represents the actual input of the ADC. Finally **y(n-1)** is one delay output value of the difference equation.

Since the difference equation depends on values from past inputs and particularly past output values, IIR filters are commonly known as recursive filters. When the microcontroller is first to turn on, the past input and output values are set es zero and in this way, the filter starts to calculate the output signals. Each time the microcontroller enters the interrupt service routine of the timer, the microcontroller triggers the analog to digital conversion unit of the Atmega 328., then the sampled data is sent through serial communication through a single board-computer for further processing. During the above process, the difference equation must compute the output value that will be seen through serial communication. The Universal Asynchronous Receiver Transmitter Protocol was the selected communication protocol to enabled the connection with other external devices. With the help of Python 20 samples for up movements, 20 for down movement, and 20 blink movements were recorded.

Later, time analysis of the sampled signals was performed to extract observations or characteristics of the EOG signal, in this case, the root means square (RMS) value (Equation 6), the average value (Equation 5), (AVR), and the distance between the positive peak and negative of the signals were chosen as characteristics (Px), this calculation is express in the equation 7. This process is commonly known as feature extraction. The expressions used to calculate the mentioned features are shown below.

$$AVR \ = 1/N \sum_{i=1}^{N} |x_i|$$

$$RMS \ = \sqrt{1/N \sum_{i=1}^{N} x_i^2}$$

For the relation of the Average Rectified Value (AVR), and the Root Mean Square (RMS) $\boldsymbol{N}$ represents the sample size of the recorded eye movement and $\boldsymbol{x_i}$ is the value on each data index $\boldsymbol{i}$ in the size of the sampled eye movement signal.

$$P_X \ = \ P2 - P1$$

The distance or number of samples between the maximum peak value (P1) of the EOG signal and the minimum peak value (P2) was the final predictor (Px)chosen to classify the movement of the EOG signal. The distance between peaks is simply calculated by subtracting P1 from P2. Figure 10.4 illustrates this process for and blink movement of the EOG signal.

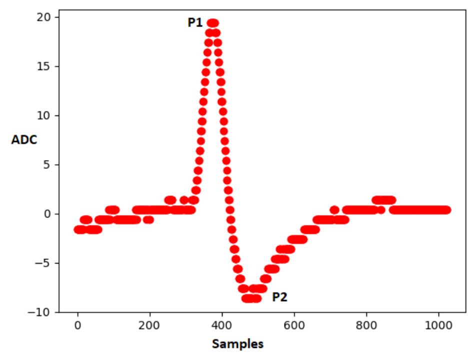

Figure 3: Blink Movement of the electrooculography signal.

Linear Discriminant Analysis

Linear discriminant analysis (LDA) is a dimensional reduction technique in which it is sought to maximize the variance between classes and minimizes variance within the class. In other words, the idea behind LDA is to find the projection in space that maximizes the mean between the classes and minimize the variance within the classes. This machine learning method can be used for both binary classification and multiclass classification. Similar to the previous machine learning models that have been tested, 5-fold cross-validation was used to avoid overfitting problems with the generated model. Table 1, shows the classification performance metric based on the confusion matrix.

Class	Accuracy	Precision	Recall	F1 Score
Blink	0.97	1	0.91	0.95
Down	100	1	1	1
Up	0.97	0.9	1	0.95

Table 1: Metrics results for the linear discriminant analysis classifier

To generate and implement a low processing classifier that can be executed in a low-cost and portable processor, linear discriminant analysis was the selected classifier with an overall accuracy of 96.67%. Since there are a total of three classes, Linear Discriminant Analysis generates three linear equations (y1, y2, y3) for each of the classes, when there is a new observation and it is evaluated into the three linear equations, the new observation will correspond to the equation of the class that produced the greatest value of the three. These equations are later programmed in the Python classification program that is loaded into the Raspberry.

$$y_1 = \begin{vmatrix} -3.7388 \\ 1.7168 \\ 0.0664 \end{vmatrix} x_F + 3.4469$$

$$y_2 = \begin{vmatrix} -3.9733 \\ 0.0625 \\ -0.0683 \end{vmatrix} x_F + 8.8381$$

$$y_3 = \begin{vmatrix} -7.7121 \\ 1.7793 \\ -0.0019 \end{vmatrix} x_F + 12.2850$$

From the above equations, y1 is the linear discriminant function of blink movements, y2 is the discriminant function of down eye movements, y3 is the linear discriminant function of up eye movements, xF is the feature input vector (Equation 11) of the EOG signal that is composed of the AVR value, the RMS, and Px value of the sampled EOG signal.

$$\begin{vmatrix} ARV & amp; RMS & amp; PX \end{vmatrix}$$

Eye-tracking implementation in an embedded device.

Now that the algorithm has been developed for the classification of the eye movements, it is necessary to implement the same algorithm and the whole processing methodology in an embedded system that can process the EOG signal in an easy manner. Since it is important to achieve both portability and easy usability in order that students or professors can make proper use of the eye tracking device, the selected embedded system was a Raspberry Pi 4 Model B Plus. The Raspberry Pi also denominated as a single-board computer or microcomputer is a small size electronic card that has the necessary hardware to perform capabilities similar to desktop computers or laptops but with the exception of not including peripherals such as a keyboard, display, or mouser, nonetheless, all these peripherals can be substituted with a small touchscreen display. The Raspberry main purpose is the promotion of the teaching of computer science in schools of developing countries, nonetheless, because of its low price and portability, this microcomputer has been used in research educational projects in the past [30]; [31].

As mentioned before, the processing of the EOG was done in Python. This programming language was selected due to its multiplatform nature, which allows a Python program to be run in different types of operating systems such as Windows, IOS, and Linux, been Linux the operating system in which Raspbian the operating system of the Raspberry is based on. Therefore the implementation can be done in a transparent manner without developing delays. The Python program was developed within the Thonny development environment target for beginners and educational purposes, this decision was made in order to facilitate the professor and students to use in a straightforward manner the code of the eye-tracking system and consequently make adjustments to it, according to their specific needs.

One of the hardware characteristics of the Raspberry is that it comes with an integrated Wifi chip as shown in Table 6 that allows a connection to the internet or network in a wireless manner. Besides, the Raspberry comes with a VNC server that allows users to enable remote control of the software and hardware that is embedded or connected to the Raspberry, in this way the professor can enable remote monitoring of the eye-tracking by enabling the remote desktop capabilities of the single-board computer. Therefore, the professor could have remote analysis o the eye movements while performing an experiment without the need of been physically present during the experiment. This functionally could be helpful when it is intended to generate a study case where it is important that the student must not be perpetuated during the experiment. Also, this characteristic is suitable when the student or professor cannot have some degree of physical contact or direct interaction with each other by no means like in online courses. On the other hand, since the majority of the electronic hardware that is used in the eye-tracking has been used for educational purposes in the past, it is a feasible activity to used this system to introduce the students or even the professor to topics related to computer programming, electronics engineer, and artificial intelligence. Figure 7, shows the application developed in Python to monitor remotely the eye-tracking device.

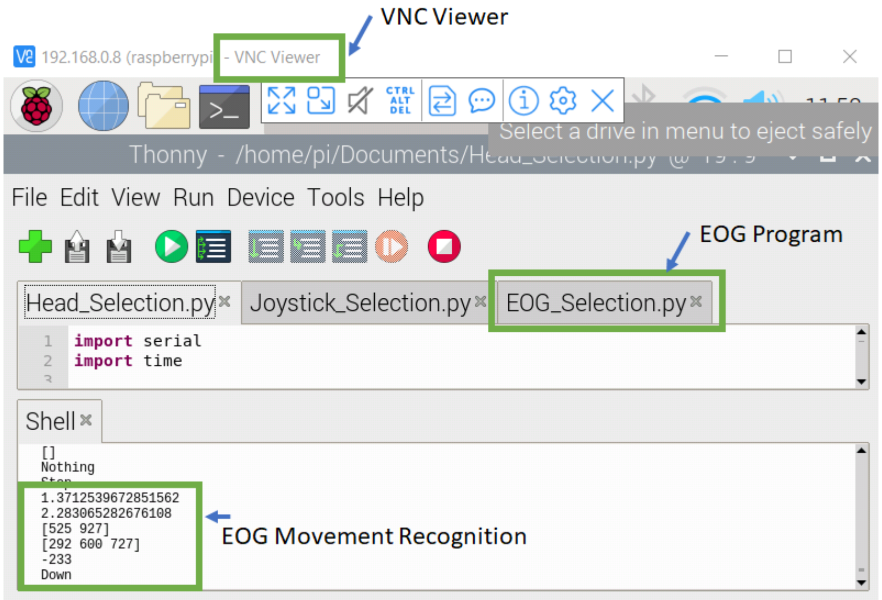

Figure 4: Remote monitoring of the eye-tracking device from the VNC Viewer applicatio

Learning outcomes and eye-tracking

To evaluate the possible impact of eye-tracking in the study and analysis o the learning process of students, this section makes a comparison in which elements of Bloom‘s Taxonomy can be analyzed by implementing the proposed system. Bloom’s Taxonomy is a framework that tries to describe how the process of learning occurs in the cognitive domain, it consists of six stages or levels. An illustration of Bloom’s Taxonomy can be appreciated in Figure 5. The Taxonomy follows a hierarchical construction that depicts the levels of apprehension on learning from the most basic one at the beginning of the illustration to the most complex one at the end as shown in Figure 5. This taxonomy has been used in the past as a model to create assessments, curricular maps, online course syllabus, or defining teaching strategies [32]. Each of the stages or levels of Bloom’s Taxonomy are associated with certain types of actions or activities. In the case of the first stage called Remember, refers to the action of recall or recognize ideas and information. For the second stage, known as understanding, it is associated with actions such as hearing, viewing, and reading with the intention of interpreting or summarising ideas in their own words. The third level is related to the application of theories, ideas, or problem-solving techniques and used them in new problems. The fourth stage consists of the decomposition of concepts in its basic units or parts through examination. Finally, the evaluation and creation stages are the higher learning outcomes that could be achieved according to the Taxonomy of Bloom. In the case of evaluation, it is related to judge opinions or points of view while creation is the action of assembly different parts of knowledge into a new whole to solve a problem [33].

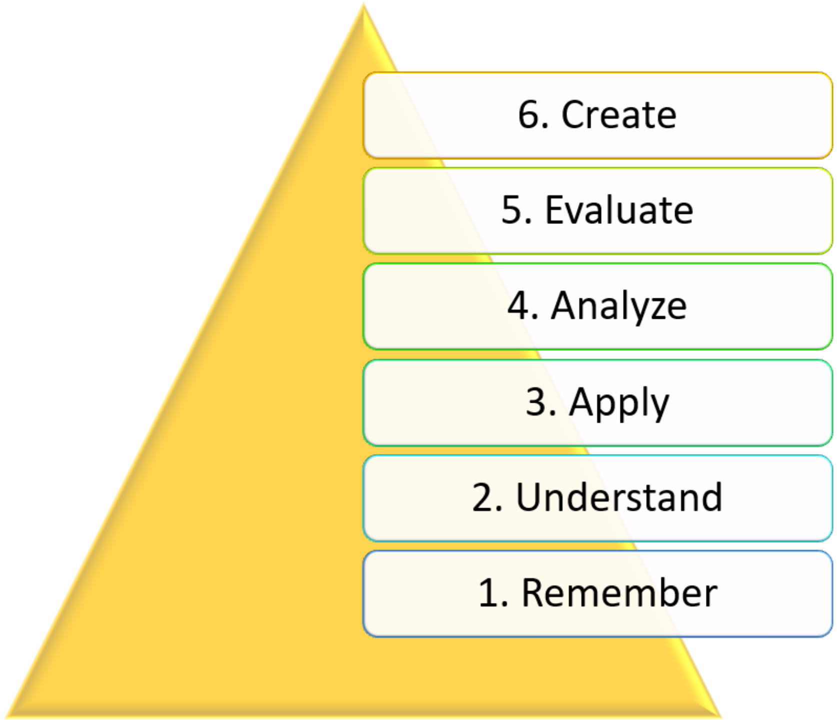

Figure 5: Bloom's Taxonomy stages representation.

As presented in the work of Banerjee, [26] some cognitive skills that can be associated with eye movement and also be tracked with electrooculography. In that study, it was noticed that is was possible to detect or discriminate activities such as reading and writing. Fogarty [23], also notice that blinks have a relation with cognitive function by analyzing that the rate of blinking decreases while making visually demanding activities. Taking these studies as a reference it is possible to infer that the proposed eye-tracking system can be used to study levels 1 and 2 of Bloom's Taxonomy since reading and writing are often associated with the process of remembering or recall ideas and understanding concepts. Another work that sustains the above is the one presented by Lagodzinski [34] in which it tried to found the features associated with the EOG signal and certain cognitive activities such as reading, writing, or watching television. This raises the potential of using the eye-tracking device to not only study the cognitive behavior while reading but also while seen videos on a computer or television in an objective manner instead of applying questionnaires to the student after watching a video or interacting with some type o multimedia material. Besides, Eckstein [35], mentioned that eye-tracking and eye-gaze could be crucial to access important characteristics of the cognitive process such as attention, memory, and decision making. This suggests that the eye-tracking system can be used to study aspects of the third (Apply) and fourth (Analyze) stages of Bloom's Taxonomy especially in decision-making experiments. Moreover, Shipulina[22], also remarks that many of mathematics activities are related to the eye-related behavior that can be recorded through electrooculography. For instance, Hegarty [36] realized a study in which it was determined that unsuccessful arithmetic word problem solvers tend to fix their eyes on relational terms or numbers while more successful solvers fix their eyes on variables. The work of Hegarty, suggest that the analysis of eye movement can have a way of measuring or acquiring feedback on the learning outcomes related to the applying and analyzing stages of Bloom's Taxonomy while exams or test are applied that are related to mathematics. Table, present a list of activities or experiments that can be carried out to study the cognitive process of the student according to the stages that are presented in Bloom's Framework. Notice that these activities are limited to only the first four stages of the model of Bloom, higher-order learning outcomes as evaluation and creation demand, and analysis of the judgment and creativity of the student.

Bloom's Taxonomy Levels	Activity
Remember	Copy some text of a book or presentation. Elaboration of tests or exams
Understand	Write a summary or report of certain topic. Write or retell a text in your own words.
Apply	Exercise or problems resolution
Analyze	Read a text about a topic and identify certain ideas to contrast and compare them.

Table 2: Example of activities that can be studied through the propsoed eye-tracking device taking as reference Bloom's Taxonomy.

Emotions, Learning, and Electrooculography

Another application in learning that an eye-tracking device based on electrooculography could have is in the development of a system for emotion recognition and assessment. It has been studied that emotions and learning have a strong relationship, according to King [37], studies in disciplines such as neuroscience, physiology, and education have generated research that supports the association of emotions and learning. There have been several types of approaches to detect or classify emotions that go from electroencephalography, facial images processing, and even speech analysis through voice recordings, nonetheless, according to Lim [38], the used of eye-tracking to classify or detect emotions is a field that is currently starting to be researched. In the case of EOG signal measurement, there has been some interest in the detection of emotions through this technique special since emotions play a crucial part in human communications [39]. For instance, Paul [40], elaborate a machine learning classification algorithm for emotion recognition based on EOG. It is concluded that EOG based emotion recognition techniques have some potential in generating real-time emotion evaluation system. Another similar work was presented by Soundariya[41] and [42] in which the relationship between electrooculography and emotions was also studied. Despite, there is a great number of studies that have tried to find a correlation between emotions and education or eye-tracking (EOG) and education, there is no research that has tried to merge education, electrooculography, and emotions. Therefore, this is an area of opportunity that must no be underestimated that could be implemented with a low-cost device as the one presented.

Advantages and disadvantages of the eye-tracking system.

It this section a brief comparison of the proposed eye-tracking system with the conventional ones and commercial is made to display its core characteristics and areas of possible improvement. The first disadvantage of the proposed eye tracking device is that it is more invasive than camera-based recognition systems. This is because the EOG technique requires the use of electrodes that must be placed on the user's skin, while the camera only requires that it be aimed at the user's eyes. In addition, the electrode placed on the skin must be replaced every time it is used, so a component of the system must be changed every time it is planned to use. Likewise, the manufacture of the electrode, design, and quality becomes important and deterministic points when using the electrooculography technique. Also, since the EOG is a physiological signal it is susceptible to artifacts, ambient, and body noise which sometimes makes the behavior of the EOG technique unpredictable in different environments or persons. Nonetheless, the majority of these problems can be avoided or corrected by applying the proposed signal processing methodology described in the previous section, where it is important to have a filtering stage, the feature extraction process, and a classification model.

On the other hand, because the processing method used to classify or monitor biopotentials turns out to be computationally less expensive than to process video or image, the proposed eye-tracking system can be implemented at a more accessible cost and without the need to require specialized components or parts that make it impossible to implement them independently by teachers or students. Therefore, it is possible to implement the processing techniques in other electronic embedded systems without the need for specialized hardware and software. This is supported by the software that was proposed in the previous sections of this in which Python was selected as the programming language that has an open license ar has a multiplatform development environment. Also, the microcontroller used for the sampling of the EOG signal is an Atmega328p with is the microcontroller in which the Arduino development platform is based. The Arduino platform, similar to the Raspberry has been widely used in educational institutions and research to motivate the learning of electronics and programming topics into the students [43]. By taking into account the above, it could feasible for students or professors to implement the eye-tracking device by only following the presented methodology and in this way enhance the development of other skills in the field of programming and electronics engineering. Also, EOG can be used as a substitute for Brain-Computer Interface since it can assess in some degree cognitive activities as established in the previous section of this work, but with a less quantity of electrodes, it can be adjusted by the user, and require less specialized hardware and software to make a the eye-tracking processing and classification.

Results

The whole intention of the methodology process was to developed a system that could monitor en some extend the movement of the eye. Therefore, it was necessary to employ a machine learning algorithm that could achieve the task with a certain degree of accuracy. As it was mention before Linear Discriminant Analysis (LDA) was the selected classifier due to its overall accuracy 96.67%, also this classifier it less propensity to overfitting and it can be implemented with less computational requirements since the model only requires to evaluate three linear functions to make the classification of the EOG signals.

On the other hand, it was presented to possible applications of the eye-tracking device in educational research. In fact, there is a great is an opportunity in the analysis o cognitive process related to learning that could be better understood by using eye-tracking technology specifically by using electrooculography as suggested the comparison made with Bloom´s Taxonomy. anther area of interest that has not been fully explored is the relation between EOG system, educations, and emotions, despite briefly explore in this work, the current literature has not provided enough attention to this particular feel. Besides, It could be a great opportunity for the study of the cognitive learning processes and emotions through eye-tracking devices is the near future. Nevertheless, there are some disadvantages as point out in the previous section that need to be addresses in order to apply this type of system in an experiment that could help to gather significant conclusions and results related to the educational learning process of students.

Conclusions

From the literature review presented in this work, as well as the development process of the eye tracking device, it is possible to notice that eye tracking is a suitable technology for educational research, nonetheless, the equipment needed to perform this type of research is not accessible for many students or professors due to the image processing technology and hardware required to perform and accurate tracking of the eye. Therefore, the proposed eye-tracking device could be a solution to generate low-cost hardware and software, that can be accessible to anyone and made educational research through eye-tracking reachable. Besides, the use of machine learning techniques such as linear discriminant analysis can help to recognize basic eye movements through electrooculography with very low processing requirements in comparison with image processing methods. This makes the interface suitable to be implemented in any electronic device compatible with Python and with Bluetooth connectivity. Nonetheless, it is important to mention that is imperative to ensure the efficiency of the eye tracking device in a real setup scenario and development experience or case studies that help to this objective. Taking into account that the literature related to electrooculography as an educational research method is scarce, as future work it will be important to generate feasible study cases of the technology to gather significant data related to the usefulness of the device in different setups. One first step would be to run similar experiments like the ones shown in the presented literature and compare them with the performance of the proposed device.

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