Improvement of Eye Tracking Based on Deep Learning Model for General Purpose Applications

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Abstract

The interest in the Eye-tracking technology field dramatically grew up in the last two decades for different purposes and applications like keeping the focus of where the person is looking, how his pupils and irises are reacting for a variety of actions, etc. The resulted data can deliver an extraordinary amount of information about the user when it's interlocked through advanced data analysis systems, it may show information concerned with the user's age, gender, biometric identity, interests, etc. This paper is concerned about eye motion tracking as an unadulterated tool for different applications in any field required. The improvements in this area of artificial intelligence (AI), machine learning (ML), and deep learning (DL) with eye-tracking techniques allow large opportunities to develop algorithms and applications. In this paper number of models were proposed based on Convolutional neural network (CNN) have been designed, and then the most powerful and accurate model was chosen. The dataset used for the training process (for 16 screen points) consists of 2800 training images and 800 test images (with an average of 175 training images and 50 test images for each spot on the screen of the 16 spots), and it can be collected by the user of any application based on this model. The highest accuracy achieved by the best model was (91.25%) and the minimum loss was (0.23%). The best model consists of (11) layers (4 convolutions, 4 Max pooling, and 3 Dense). Python 3.7 was used to implement the algorithms, KERAS framework for the deep learning algorithms, Visual studio code as an Integrated Development Environment (IDE), and Anaconda navigator for downloading the different libraries. The model was trained with data that can be gathered using cameras of laptops or PCs and without the necessity of special and expensive equipment, also It can be trained for any single eye, depending on application requirements.

Keywords: Eye tracking, Artificial intelligence, Machine learning, Deep learning, CNN.

تحسين تتبع العين استنادًا إلى نموذج التعلم العميق القابل للتدريب للتطبيقات ذات الأغراض العامة

احمد عامر سلمان ، محمد حسين علي

الخلاصة:

نما الاهتمام بتقنية تتبع العين في العقدين الأخيرين لكثير من التطبيقات مثل التركيز على المناطق التي ينظر لها الشخص,كيفية ردة الفعل لقزحية العين لكثير من الفعاليات الخ. البيانات المستحصلة يمكن الاستفاده منها بطرق شتى عند استعمالها وربطها بنظام تحليل بيانات متطور,قد تتمكن من اظهار معلومات مختلفة عن الشخص تتعلق بعمره,جنسه واهتماماته الخ. في هذه الورقة البحثية تم اقتراح عدد من النماذج تم تصميمها بناءً على الشبكات العصبيه الالتفافية وتم اختيار النموذج الاكفأ والادق.بالاعتماد على ١٦ نقطة ارتكاز تألفت البيانات المستخدمة من ٢٨٠٠ صورة للتدريب و ٨٠٠ صورة للاختبار.اعلى دقة تم الحصول عليها بلغت ٩١,٢٥٪ واقل خسارة بلغت ٠,٢٣٪ للنموذج الادق الذي يتألف من ١١ طبقة.تم استعمال لغة البايثون لبناء الخوارزمية , مكتبة كيراس للتدريب, VSC كبيئة تطوير متكامله و

اناكوندا(ANACONDA) لتحميل مختلف المكاتب. تم تدريب النموذج على البيانات التي يمكن جمعها باستخدام كاميرات أجهزة الكمبيوتر المحمولة أو أجهزة الكمبيوتر الشخصية وبدون الحاجة إلى معدات خاصة ومكلفة ، كما يمكن تدريبه لأي عين واحدة حسب متطلبات التطبيق.

1. Introduction

Eye tracking is the process of measuring the position that the eye is focusing on it, or measuring the motion of an eye with taking the head as a fixed base [1]. Many techniques and algorithms for automatically tracking the location and direction of the gaze have been developed, that are very helpful for different fields and applications. Eye-tracking researches are growing as a result of its guaranteeing the ability to make various tasks easier, especially for users with special needs or old people. [2], in addition to the evolution of the deep learning techniques that nowadays are used in a lot of researching fields such as robotics, self-driving vehicles and biomedical [3]. The features that can be obtained from eye tracker techniques can be used for different types of applications. Different features such as pupil size, mouse position, and gaze point can be read out and can be employed using different techniques of visualization [1]. Companies using these technologies have the ability to analyze large amounts that may reach thousands or more of patterns that contain the eyes of the customers with making decisions for marketing according to the data. The output data of these technologies extracted from the eyes may show different and impressive information about the user, such as age, gender, body weight, emotional state, drug addiction level, personality traits, abilities and skills, etc. Furthermore, they can process the parameters of the eyelids, watching how far the eyes are open, take note of redness and see how watery or dry the eyes are through reflections, the rate of blinking, and time periods that the eyes are staying shut during the blink [2]. The technology has the ability of analyzing the level of stress for patients, Business process outsourcing, banking, accounting, front office, etc. At the present day, laptops, smartphones, and tablets with 3G, 4G, and 5G technologies are widely used. the evolution has gone through the control by using touch technologies in various manners and devices. So a similar path, eye-tracking technology is also going to pass it and take off into the new technical revolution. One of the most important reasons for this evolution in this field is that almost all devices nowadays own cameras with relatively high resolution.

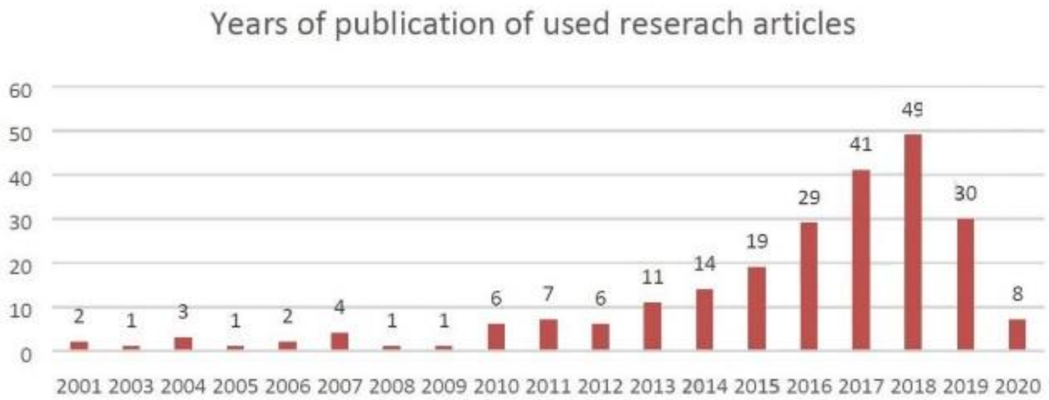

Figure 1: Number of research articles published between 2000 and 2020 [2]

This modern hardware can form in companionship with eye motion-tracking technology for gathering data concerns with the vision of the user while doing his routine tasks. As eye tracking popularity is growing in a rapid manner, it has become more accessible and easier to deal with, producing an ocean of information. The number of research papers released during the period from 2000 to 2020 reached 180 research (128 during the last three years from 2018 to 2020), as shown in Figure 1.

Most of the methods used depend on a camera installed on glasses or an internal camera in a helmet that the user wears, but it is possible to benefit from a camera that depicts the face in general, and the images of the eyes are extracted from the video stream.

Extracting the eyes areas from the video stream is done using several libraries such as:

OpenCV: is an open-source software library concerns with machine learning and computer vision which contains a large number of algorithms that deal with computer vision. It was built to accelerate the use of machine perception in commercial products and for providing a common infrastructure for computer vision applications [4].

Dlib: is a modern toolkit build with C++, containing algorithms concern with machine learning and complex software creating tools for solving problems in the real world. it can be used in a lot of applications because it is an open-source license and does not require any payment. It is used in both academia and industry for a wide range of domains including robotics, smart mobile phones, and embedded devices [5].

Although of the large number of functions and algorithms that have been used for dealing with this field of eye tracking, most of them share the same parameters especially the main parameters such as:

Gaze Position: From each data frame gaze position can be extracted as a coordinate (x, y), which can give a view of the location that the person is looking at on the screen. As a second benefit of this parameter is can be used for blinking identification [6].

Pupil Diameter: emotions and condition of a person in various activities can be detected using Pupil diameter, for instance, exhaustion or negligence while driving a vehicle can be detected using this property [7].

So, according to the above, each application has its preferred technologies and each technique has its performance limits, here we would present a simple model that uses deep learning for gaze detection and moving the mouse according to it, this model can be trained by the user himself in order to accomplish the largest accuracy according to his eye(s) shapes.

Here, there is an important point to be clear, which is the data used for trained gathered by the user himself for his own eye in order to make the model specialized to his eyes. Data can be imported from the Internet but a lot of parameters should be taken into counts such as the large similarity of the shape of eyes imported from the Internet to the shape of users eyes and other parameters, any unuseful data not only will be useless but also may harm the performance of the model and reduce the accuracy.

The remainder of this paper is organized as follows. Section 2 provides some background about Eye-tracking related work and previous experiments for tracking techniques. Section 3 shows a number of applications that need Eye-tracking techniques. while section 4 presents the procedure used for gathering the data and the steps of the algorithm. Section 5 shows the model used with its details. In section 6 the result is shown, discussed and summarized. Section 7 contains the conclusions drawn from the results. While section 8 is built on ideas that can be implemented for further future work to make more use of the proposed model. Finally, section 9 consists of the resources that have been read and used for writing this article.

2. Related work

The importance and popularity of motion analysis have led to several previous works and surveys:

In 1999, K. N. Kim and S. R. Ramakrishnan presented a vision-based method for gaze-tracking, proposing eye gaze as an input for an eye movements computer interface with high efficiency. [8].

In 2002, Kaufman, Bandopadhay, and Shaviv proposed that electrodes that are placed with different locations on the skin and close to the eye are changed with the orientation of the electric field as a result of the rotation of the eyeballs. changings in the electric field due to eye movement are measured by these electrodes then, these estimations are passed through amplification and analyzed to predict the eye position [9].

In 2006, A. Poole and L. Ball, proposed that the point-of-regard can be determined using the position of the reflections relative to the pupil, which is the predicted position that the user is looking at [10].

J. Griffin and A. Ramirez proposed that using CNNs as a fast classification method, and apply it to a dense dataset within the use of different interpolation methods might produce similar accuracy and speed [11].

In 2016, Divya Venugopal, Amudha J, C. Jyotsna illustrated the advantages and applications of eye tracking, its usable fields, and workable manners for developing applications by using a commercial eye tracker [1].

In 2017, P. A. Punde, Dr. Mukti E. Jadhav and Dr. Ramesh R. Manza discussed eye tracking technology and its different implementations and that it is being used in nearly most of important fields including computers that have human interactions techniques, psychology, marketing, medical modern infrastructure, etc. [12].

In 2020, I. Rakhmatulin and A. T. Duchowski, presented an analysis with details about modern techniques that used a webcam for gaze-tracking, details about the practical implementation of the populist methods for gaze-tracking, and an introduction of a new eye-tracking approach that significantly increased the effectiveness of using a deep learning method [13].

In 2020, Ahmad F. Klaib, Nawaf O. Alsrehin, Wasen Y. Melhem, Haneen O. Bashtawi, Aws A. Magableh, Wrote a study aimed to explore and review eye-tracking rules, algorithms, methods, procedures, types, and techniques with further and deep details on the most effective and efficient modern processes such as machine learning, Internet of Things, and cloud computing. which have been growing in use for the last two decades and especially for the development of recent applications [2].

In 2021, Mohd Faizan Ansari, Pawel Kasprowski, and Marcin Obetkal presented in an Article titled "Gaze tracking using an unmodified web camera and convolutional neural network", a gaze estimation using a CNN that can be applied under various circumstances and platforms without additional special hardware requirements. It made an approve that Gaze estimation is possible with acceptable accuracy [14]. This paper is the basis of the comparison mentioned later.

The interest in this field has been increased for a while, a lot of old methods of image processing were used, but they were not based on deep learning for tracking. After the evolution of deep learning and becoming familiar with dealing with different scientific fields, the interest grew up, but this time depending on AI. Just like any different specialist, different experiments and researches had their chance for optimizing the performance of the model used. Here, a new model based on deep learning is proposed to get better performance than the past researches had, with developing data gathering method.

3. Applications

Stress Analysis: The analysis of a large amount of data say a thousand of eye motion tracking of different users in different circumstances, allows the technology to analyze the stress level that the user feeling in the present time [15].

Website Usability: This application helps websites designers to know what the user wants in the website, what he is concern to deal with, and where his eyes move along at the first look. The designer becomes familiar with all of these parameters in different ways with different aspects. In order to help with this issue and increase the accuracy of users concerns predictions and make it automated, Eye motion tracking is used by recording the movement of user's eyes to identify the important and attractive elements and sections in the website [16].

Advertising and Marketing Research: A- electronic way: get an amount of data for the first reaction implemented by the eye movements for the Ad's on the online websites, B- Real life: By gathering the data of the position pointed to by the gaze to which product in the showcase of the shop [17].

Assistive Technology: This technology can be done using either monitor mounted or Wearable types of eye motion trackers for disabled persons to control computers. Thanks due to these applications classical held with hand devices are getting replaced by eye-tracking [18].

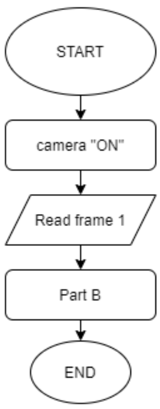

Figure 2: Main part of the model concerns with reading the consequently frames from the camera video.

Digital and Operational Training Scenarios: many types of simulators used Eye tracking for tracking trainees' eye movements, such as flying training, driving, etc. [19].

Human Behavior: Eye tracking has an important application, which includes analyzing movements patterns of the pupils of the eyes. Eye-tracking has the ability to recognize the emotions of human beings [20].

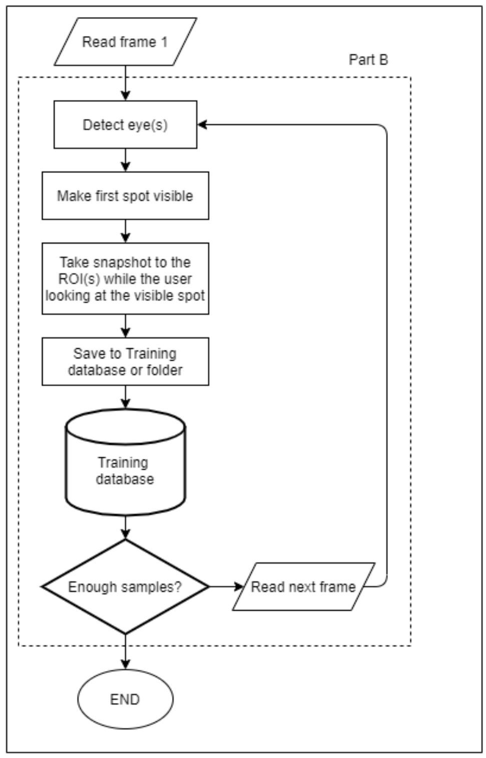

Figure 3: Flowchart containing eye(s) detection, change the visibility of the spots, take a snapshot for the detected eye(s) and save them to the training database or folder.

Developmental Psychology: This application field looks at the behavior of Infants using Eye tracking and how far visual attitude impacts their growth and the realization of their surrounding environment, as they interact and receive information using their eyes when they haven't the ability to talk yet [21].

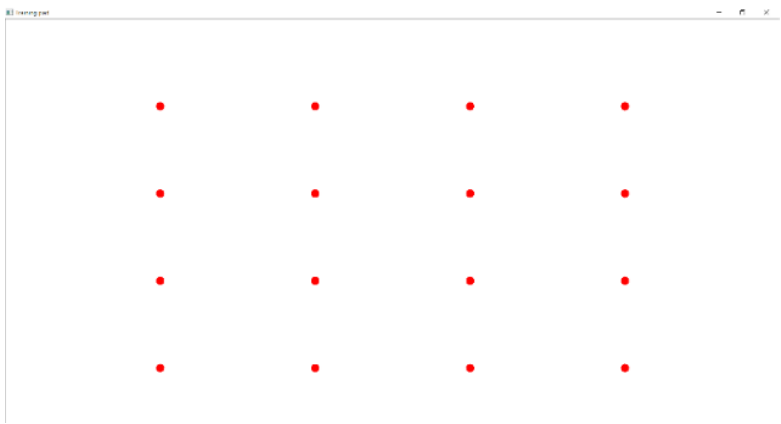

Figure 4: Screenshot for the computer display shows the (16) spots visible all together to declare the idea

Assistive tool for ALS (Amyotrophic Lateral Sclerosis) Patients: An interface can be built controlled based on an eye motion tracking technique for ALS patients to help the patients for controlling the computers using eyes movement. This application is quite helpful for patients who don't have the ability to use the mouse, keyboard, etc. [18].

Early detection of some diseases: Applications on smartphones can be designed so that they are available to everyone in order to check children at home using the smartphone application if the child suffers from autism as an example [22].

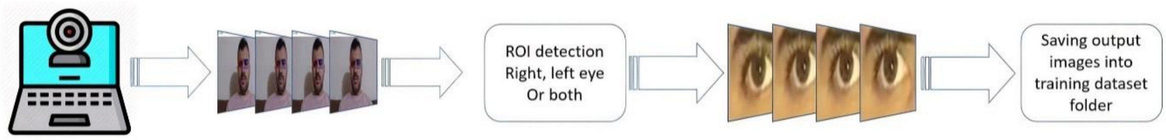

Figure 5: Shows the extraction of ROI(s) from the video stream frames and feed them to the training algorithms to produce the output model.

4. Research method:

As previously mentioned above this procedure aim to be as much easy as possible to make it a simple user interface, and to make it simple to understand the algorithm flowchart parts will be explained individually. As the model is based on computer vision implemented by the video frames captured by the camera, the main part is reading the frames consequently from the camera video input to our model as shown in Figure 2.

Then, different algorithms can be used to detect the right, left eye, or even both (individually) as the parts that the model dealing with. In order to separate them, the names of them were suggested as ROI (Region Of Interest) as "ROI" or "ROI1" and "ROI2" (or "LROI" and "RROI" as Left and Right ROI) as explained above and shown in Figure 3.

As the model aims to be user trainable by himself, he can decide how accurate the model he wants, by choosing the number of spots that interact with, in this paper, 16 spots will be taken into account as shown in Figure 4 which are all been visible in the figure but not in the practical work. To begin the training, the first spot will be visible and the user should focus on it till it become invisible and the next spot is visible. In order to make the system more automated, the visibility time period of the spots can be modified as required, in this experiment (5) seconds was chosen, and in the third second a snapshot is taken for ROI(s) (not the entire face) and saved into the training folder with a name format contains all information and will be as shown below:

NameFormat=CONCATENATE(ROI,Spot,Random) ... (1)

A-ROI character :
"R" for the right eye
"L" for the left eye
B-Spot number:
For '1' to maximum choose number (16 in this experiment as mentioned above)
C-Random number: in order not to make any similar names.

In order to increase the accuracy, this experiment may be repeated as much as the accuracy satisfies the user's requirements. After gathering the required amount of data represented by the images of eye's snapshots, a new stage begins which is the deep learning model training which can be briefly said that is fed with the gathered data and as a result of this it supplies us with an output model that can be used for detecting the position of eyes. This model has the structure and parameters shown below in Figure 5.

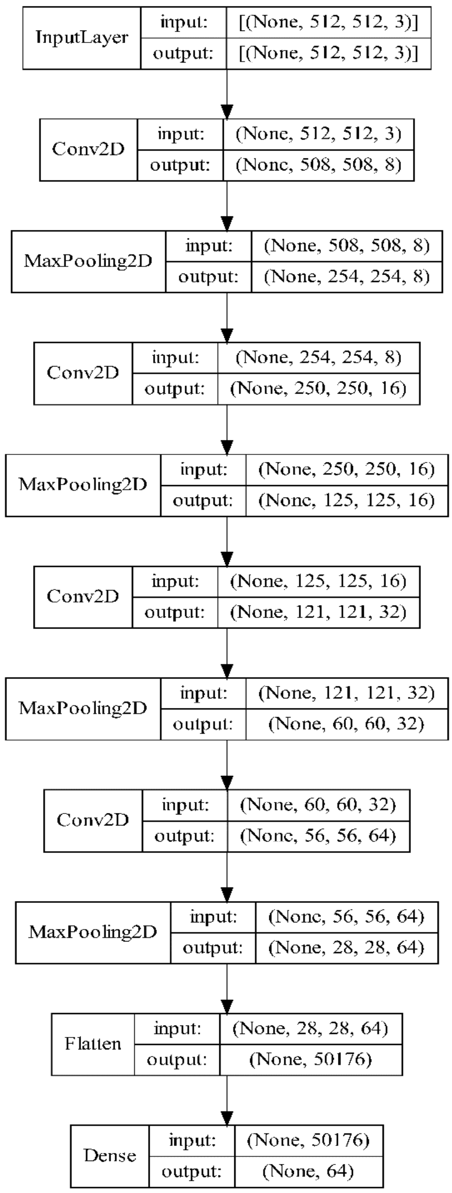

Figure 6: The architecture of the fourth (proposed) model.

5. Proposed model

In this experiment, the proposed model contains 4 convolutional layers and 3 fully connected layers. A 5-by-5 kernel size was chosen for each convolutional layer with some strides equal to1. The padding was configured as "Same" configuration, which is used for padding the input and force the dimensions of the output shape to be equal to the dimensions of the original input. convolutional layers and max pooling used "ReLU" as an activation function. 2-by-2 kernel size and a stride of 1 were used for Max pooling layers. Categorical cross-entropy was used in the model as a loss function, which is a metric that measures the difference between probability distributions or, as in this case, it measures the difference between the predictions and the ground-truth distribution [23].

Last fully connected layer used the activation function "Softmax". In addition, Adam optimizer was used. A learning rate equal to 0.0001 was used for this implementation. The architecture of the model is shown in Figure 6, it also shows the chosen number of filters, the shapes of inputs and outputs for each layer, and the chosen number of neurons of the fully connected layers.

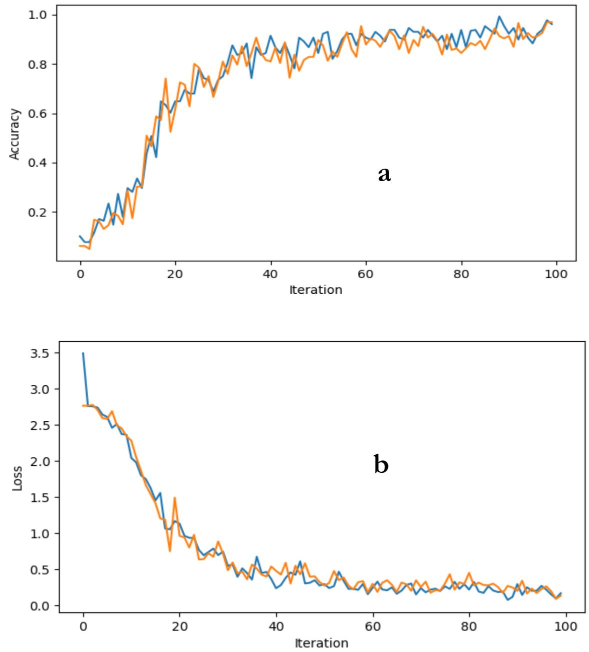

Figure 7: Output accuracy and loss achieved by the final proposed model (Iteration * 10), blue lines for training and the oranges for testing, (A) shows training and testing accuracies and (B) shows training and testing losses.

Table 1: Summarized the experimented models and their details

Model index	1	2	3	4	5	6
Maximum accuracy	88.43	89.98	90.93	91.25	86.32	90.39
Minimum loss	0.3024	0.2688	0.2312	0.2312	0.3344	0.2751
Maximum validation accuracy	89.21	95.31	94.21	97.18	87.65	92.81
Minimum validation loss	0.2666	0.1690	0.2584	0.1686	0.2861	0.2370
Convolution layers (filter sizes)	8,16,32, 64,128, 256	8,16,32, 64,128, 256	8,16,32, 64,128	8,16,32, 64	8,16,32	8,16,32, 64,128, 256
Maxpooling layers (pooling sizes)	6	6	5	4	3	6
Dense layers (no. of units)	128,64, 32,16	64,32,16	64,32,16	64,32,16	64,32,16	128,64, 32,16
Total params	1,627,584	1,357,120	1,455,168	3,281,856	7,392,128	546,488

6. Results

This model was elected after many experiments with a different number of layers and different details, Table (1) summarized some of the experimented models and their details. The model is rationally inspired by the structure of LENET 5 [24] network, with adding, removing layers, and adjusting some parameters after trying and observing the performance enhancement after each try. After all of these experiments, the model that achieved the highest accuracy and the lowest loss was chosen, which is the fourth model in Table (1) below and has the output accuracy and loss shown in Figure 7. The curve can be smoother by increasing the batch size, but of course with noticing the hardware limitation, and the curve can grow faster using a larger dataset. Improving performance can be done by gathering more data or increasing the size of the input data. Proposed model is more accurate than other models as shown in Table (2).

Eye tracer is a camera-based tracking device that makes it able for tracking users' eye movements. Manipulation obtaining of the data is possible for further analysis. Depicting the data can be done by many types of visualization techniques like saccades, fixation, area of interest (AOI), etc. Visualization techniques give a comprehensive view of the seeking behavior. A large number of applications depend on Eye-tracking, like patients and employees' stress analysis, emotions identifying, determination the position where a person is looking on a website, and searching attitude of a user.

In this paper, two simple applications were attempted to examine the practical implementation of the model. The first application is controlling the mouse using an eye tracking model for using PC, and as shown in Figure 8, in which "folder1" is selected using the mouse controlled by the proposed model. The same experiment is implemented and this time the "folder14" was selected using the same technique as shown in Figure 9.

The second application is a simple calculator contains the Num key, four algebraic operations, Enter and Delete buttons, as shown in Figure 10 without pressing any button, after that button contains the number "2" was pressed as shown in Figure 11, then at last number "8" was pressed on as shown in Figure 12.

7. Conclusion

In this paper, an eye-tracking model was elected from a number of proposed models after many experiments with a different number of layers, different details, and parameters. The model is based on CNN and consists of 4 convolutional layers for feature extraction, 4 max pooling layers for feature maps dimensions reduction, and 3 fully connected layers with a softmax layer for classifying the screen spot is focused on by the eye. The dataset used for the training contained 2800 training images and 800 test images (in case of 16 spots). The proposed model achieved a maximum accuracy (91.25%) and a minimum loss (0.23%).

Table 2: A comparison between the proposed model and other models.

Model	Accuracy	Number of spots	Training dataset
Proposed model	91.25%	16	3600
ARCH-L [14]	88.55%	20	6000
ARCH-R [14]	82.30%	20	6000

Figure 8: "folder1" was selected using mouse controlled by eye tracking model.

The performance of the model can be better by gathering more data, increasing the size of the input data, and changing the number of spots. The model was built with Keras framework based on python 3.7 using Visual Studio as an IDE and Anaconda navigator as a GUI application launcher.

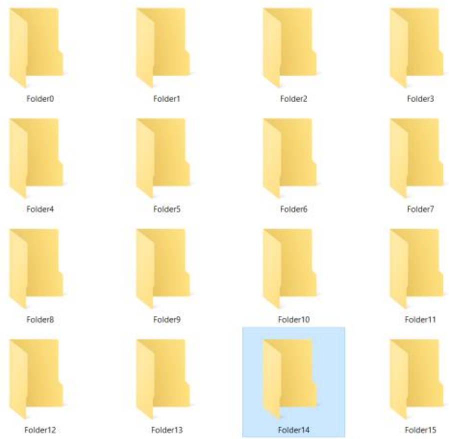

Figure 9: "folder14" was selected using mouse controlled by eye tracking model.

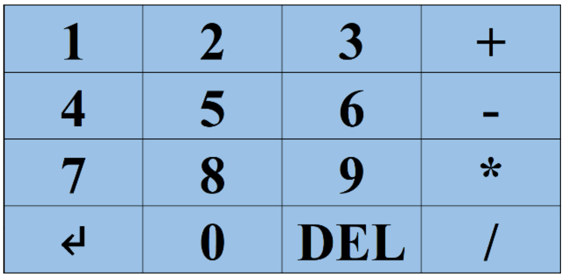

Figure 10: Simple calculator to examine the proposed eye tracking model.

The proposed model does not need special and expensive equipment, just using a laptop's or PC's camera. It can be trained for a specific eye and it is no commitment with a single eye as it has a simple implementation and the model will work depending on the input data of the specified eye. The ease of using the method of gathering data makes it simple to implement for modern software.

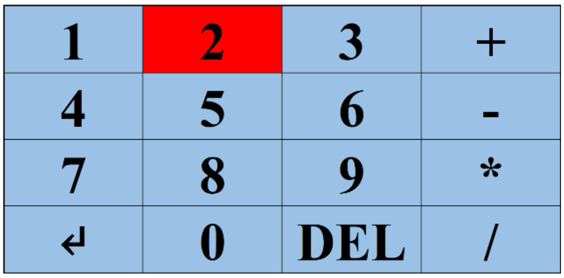

Figure 11: Button containing number "2" is pressed using the proposed eye tracking model.

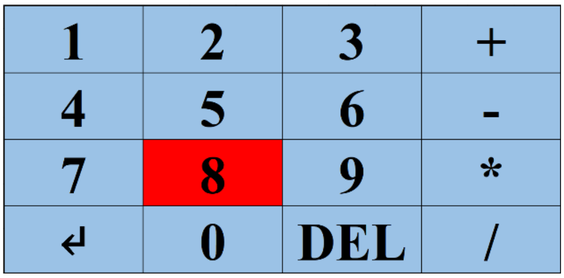

Figure 12: Button containing number "8" is pressed using the proposed eye tracking model.

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