



Strabismus Diagnosis and Angular Deviation Calculation Based on Artificial Intelligence Approaches: A Review

Madior Gueye^{1,2,3,4}(✉), Ousmane Khoum^{5,6}, Mandicou Ba^{1,2,3,4}, Idy Diop^{1,2,3,4}, Alassane Bah^{1,2,3,4}, Doudou Dione^{1,2,3,4}, Regina Esi Turkson⁷, and Aly Mb Kã⁸

¹ Cheikh Anta Diop University (UCAD), Dakar, Senegal
{madior1.gueye, doudou2.dione}@ucad.edu.sn, {mandicou.ba, idy.diop, alassane.bah}@esp.sn

² Department of Computer Science, Polytechnic Institute (ESP), Dakar, Senegal

³ Laboratoire d'Imagerie Médicale et de bio-Informatique (LIMBI), Dakar, Senegal

⁴ UMI UMMISCO UCAD, Dakar, Senegal

⁵ Amadou Mahtar Mbow University (UAM), Diamniadio, Senegal
ousmane.khouma@uam.edu.sn

⁶ Sciences and Engineering Techniques Institute (ESTI), Dakar, Senegal

⁷ University of Cape Coast, Coast, Ghana

rturkson@ucc.edu.gh

⁸ Ophthalmology Department, Abass Ndao Hospital, Dakar, Senegal

Abstract. In Senegal, there is 1 ophthalmologist per 507,000 inhabitants whereas the World Health Organization (WHO) standard is 1 ophthalmologist per 250,000 inhabitants. In addition, out of the country's 14 regions, 6 regions have no ophthalmologist. 84% of ophthalmologists are stationed in the capital, Dakar. Rural areas lack qualified human resources. WHO estimates that 88.4 million people worldwide are visually impaired as a result of uncorrected refractive errors such as amblyopia (irreversible visual impairment). It is a cause of children dropping from school. One of the causes of amblyopia is strabismus. Strabismus is a defect in the parallelism of the eyes. WHO estimates the worldwide prevalence rate of strabismus at 2 to 5% in Caucasians and 0.37 to 1.5% in African melanoderma. It is important to diagnose children at an early age so that they can be treated quickly. The objective is to spare them a visual handicap in the future. To assist ophthalmologists, automatic diagnostic methods for strabismus based on artificial intelligence approaches have been proposed in the literature. In this article, we provide an overview of projects that involve the use of image processing basic techniques, machine learning and deep learning approaches for strabismus diagnosis and angular deviation calculation.

Keywords: Strabismus · Amblyopia · Angular Deviation · Artificial Intelligence · Hirschberg Test

1 Introduction

World Health Organization estimates that more than 2.2 billion people are affected by visual impairment or blindness, 5.9 million people in Africa [1]. The prevalence rate has exceeded the 2% in some sahelian countries [2]. In Senegal, the prevalence rate of blindness is 1 to 1.5% [3]. The loss of productivity due to visual impairment is estimated at USD 411 billion in the world [4]. In sub-Saharan Africa, it is estimated that 0.5% of GDP will be lost annually in the absence of intervention [5]. Among the causes of the visual impairment, there is the uncorrected refractive errors (88.4 million) [4]. One cause of uncorrected refractive errors is strabismus. This disease is an eye misalignment. This deviation can lead to diplopia (double vision) in adults or amblyopia (irreversible decrease in visual acuity) in children [6]. It is a cause of children dropping out from school. Deploying Artificial Intelligence (AI) in this branch appears to be a viable and long-term solution. Machine Learning and Deep Learning algorithms have recently demons-trated exceptional performance on a variety of tasks, particularly the diagnosis of ophthalmology diseases such as strabismus.

This research critically examines current method for automatic diagnosis of strabismus based on artificial intelligence. Following that, we will identify the limitations of existing solutions and potential challenges that will allow to improve the disease management.

After the introduction, Sect. 2 delves into the landscape of ophthalmology in Senegal. Section 3 is dedicated to exploring the application of AI in ophthalmology. Section 4 outlines automatic diagnosis techniques for strabismus, while Sect. 5 delves into the various methods of automatic diagnosis employed. Finally, Sect. 6 synthesizes the findings and draws conclusions.

2 Ophthalmology in Senegal

According to the Senegalese Medical Association, there are 35 ophthalmologists in the public health service and 40 ophthalmologists in the private health service for 17 738 795 residents in 2022 [7, 8] (Fig. 1).

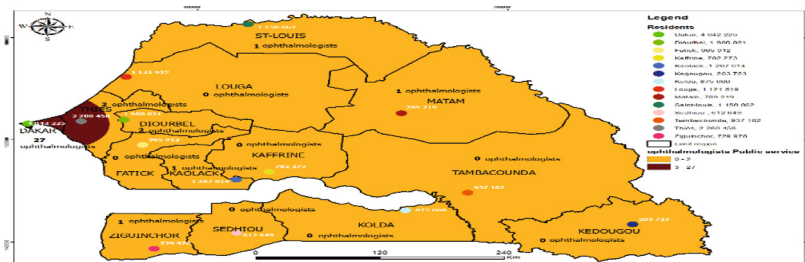


Fig. 1. Number of ophthalmologists in public service by region

Many regions such as Louga, Tambacounda, Kaffrine, Kedougou, Sedhiou, Fatick and Kolda do not have an ophthalmologist [7]. So, the patients travel miles to have a

consultation in ophthalmology. Sometimes, without money, the patients stay at home without diagnosis and treatment. This situation can have serious consequences on people's health (visual impairment and blindness). In addition, the public health clinic of ophthalmology have no enough equipment to properly support the patients. It is therefore essential to find solutions to this lack of staff and equipment. One cause of visual impairment (amblyopia) is the strabismus. It is important to diagnose children at an early age so that they can be cared for at an early stage, in order to spare them a visual handicap in the future. The artificial intelligence could provide solutions for the early diagnosis of eye diseases.

3 Artificial Intelligence in Ophthalmology

Medical diagnosis assisted by AI using images are evolving rapidly. In Ophthalmology, deep learning techniques can be applied to diagnose in order to predict variations in the visual prognosis of patients. Intelligent systems are an important means of revolutionizing eye care [9–11]. As a result, the costs associated with eye care could be reduced [4, 5]. Supervised learning is the most widely used in AI applications. This methodology is used to classify, segment images and predict scenarios for diagnosing ophthalmic diseases such as Diabetic Retinopathy, Glaucoma, and Age-Related Macular Degeneration etc.

3.1 State of Art of Detection and Classification Algorithms for Ophthalmic Diseases

Some eye diseases such as Diabetic Retinopathy (DR), Age-Related Macular Degeneration (AMD) and Glaucoma (GLC) can be diagnosed using artificial intelligence.

IDx-DR is the first algorithm used to diagnose the Diabetic Retinopathy (DR) and approved by the FDA (Food and Drug Administration) in USA [9]. It applies a set of CNN-based detectors to analyze the retinal images in order to detect the signs of the DR. The accuracy and the specificity are under 90%. Google DeepMind has developed an algorithm to diagnose the DR with 96.1% of sensibility and 93.9% of specificity. The neural network used is the Inception-v3 architecture [10]. P Saranya and al. Have proposed an automatic method to detect DR [11]. Advanced Convolutional Layer Architecture in U-Net was used to support pixel-level class labeling. The images obtained was used as input to feed the CNN to train and classify the type of DR depending on severity. This techniques have an accuracy, a specificity and sensitivity of 94%, 93.8% and 92.3% respectively. Neil Vaughan and al. Have reviewed the various moderns techniques using smartphone to detect the DR [12]. Smartphone funduscopy devices are comprised of lens devices connecting with smartphones. Software applications integrated in the smartphone analyze the mobile retinal image captured to diagnose DR. These devices are a modern diagnostic tools and help ophthalmologist for diagnosing and monitoring of disease.

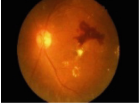
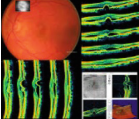

The diagnosis of the Age-Related Macular Degeneration (AMD) know progress. with AI. Nakhim Chea and al. Have developed a method to detect Diabetic Retinopathy (DR), Glaucoma (GLC) and Age-related Macular Degeneration (AMD). This methods have an accuracy rate of 85.79% and a specificity of 99.63%, 99.82%, and 91.90%,

respectively for GLC, AMD and DR [13]. He and al. Have proposed a deep learning model using OCT images to detect AMD (neovascular and non-neovascular) with a sensitivity of 95% and a specificity of 95%, [14]. In the same way, Lee and al. Have used an architecture VGG-16 of CNN model to classify the OCT images between AMD and healthy. This method has an accuracy rate of 87.6% [15].

For diagnosing Glaucoma, Chi Li and al. Proposed a machine learning (ML) method. This study has used two OCT images datasets (Asian and Caucasians datasets). For the Asian dataset, the model has an accuracy rate of 92%. However, in the Caucasian dataset, the model trained with compensated data has an accuracy rate of 84%. This poor reproducibility of the ML model is due to the difference between the ocular characteristics of Asian test dataset and the Caucasian test dataset [16]. With 99% of accuracy rate, Qaisar Abbas had developed a deep learning model to detect the glaucoma using retinal fundus images [17]. In this method, a CNN unsupervised architecture, the deep-belief network (DBN) model and softmax linear classifier were used to differentiate between glaucoma and non-glaucoma retinal fundus image.

In brief, deep learning and machine learning algorithms have always helped ophthalmologists to automatically diagnose the retinal disease such as diabetic retinopathy, AMD and Glaucoma using retinal images (Table 1).

Table 1. Some examples of methods based on Deep Learning and Machine Learning Approaches for diagnosing DR, AMD and GL

References	Disease prediction	Accuracy	Architectures	Disease retinal image / OCT image
[11] 2023	Diabetic Retinopathy	94%	U-NET + CNN	
[14] 2022	Age-Related Macular Degenerative	sensitivity of 95.0% and specificity of 95.0%	CNN	
[16] 2023	Glaucoma	92%	ML model	

Such as retinal diseases, AI algorithms can help ophthalmologists for diagnosing strabismus early.

3.2 Strabismus

Strabismus is a defect in the parallelism of the eye [6]. In adults, the disease is manifested by a diplopia (double vision). For children, this diplopia can be inhibited by the phenomenon of suppression. Indeed, the child has the ability to neutralize the image of the eye whose vision is abnormal and promote normal eye. Over time, the abnormal eye

becomes weak and creates what we call amblyopia. The latter is defined as a unilateral or bilateral, functional or organic reduction of certain visual functions, mainly the discrimination of forms [6]. The tests used for diagnosis include the Hirschberg test. The test, as illustrated in Fig. 2, is performed as follows:

- The examiner projects a light 20 cm from the eyes;
- He analyzes the position of the corneal white reflection in relation to the center of the cornea.

The diagnosis will be positive if the two centers do not coincide or the angular deviation is higher than 5DP (Prismatic Diopter).



Fig. 2. Clinical diagnosis of strabismus

There are many causes of strabismus. It can be a neurological problem [early strabismus (convergent or divergent)], an ametropia (accommodative strabismus) or a partial or permanent paralysis of an oculomotor muscle (intermittent divergent strabismus) [18]. The treatment of strabismus depends on the cause. It can range from a simple optical correction to surgery to straighten the eye [18]. However, to diagnose, monitor and surgically treat the deviation, the ophthalmologist needs to know the angular deviation. In hospitals, the angular deviation calculation requires patient's cooperation, an experienced examiner, use of prisms and requires lots of time. Artificial intelligence (AI) offers intelligent solutions to these problems (Fig. 3).



Fig. 3. Objective method for measuring angular deviation with the prism

4 Strabismus and Automatic Diagnosis Techniques

4.1 Detection of Strabismus Using Image Processing Approaches

Oren Yehezkel and al. [19] proposed an automatic system for diagnosing strabismus and calculating angular deviation. They used a system named EyeSwift System created by the company NovaSight Ltd based in Israel. It is an eye tracking system and a near infrared illumination for detecting corneal reflection and the pupil center. An infrared camera detects the angle between the cornea and the pupil reflection. An image processing algorithm is used to estimate the position of the eye and the point gaze. The correlation coefficient between this method and manual calculation was 0.9 ($P < 0.001$) for the horizontal deviation, 0.91 ($P < 0.001$) for the vertical deviation, with 100% correct for diagnosing the type of the strabismus. The system developed by Yang Zheng and al. [20] based on the cover test to diagnose the strabismus has 91% accuracy rate. They created a video database using a recording device. The video is fed into the proposed algorithm that consists of six stages: (1) eye region extraction, (2) iris boundary detection, (3) key frame detection, (4) pupil localization, (5) deviation calculation, and (6) evaluation of strabismus. It is a complex method which requires the patient's pre-sence and an electronic data collection device. Valente and al. [21] proposed an eye tracking system using image processing algorithm for diagnosing strabismus. This method has 93.33% accuracy rate to diagnose the patients with exotropia. But, this technique has globally 87% accuracy rate to diagnose the other types of strabismus and does not calculate the angular deviation. Xilang Huang and al. [22] have proposed a pre-trained convolutional neural network-based face-detection model. Then, they used a detector for 68 facial landmarks to extract the eye region for a frontal facial image. Otsu's binarization and the HSV color model are applied to the image to eliminate the influence of eyelashes and canthi. The aim is to calculate the distance between the pupil center and canthi using the least square method to obtain the coordinate of the pupil center. The sample mean and sample standard deviation of the positional similarity of the normal and strabismus images were 1.073 ± 0.014 and 0.039, as well as 1.924 ± 0.169 and 0.472, respectively. This method seems very interesting in diagnosis strabismus. However, it does not calculate the angular deviation. Po-Han Yeh and al. [23] also proposed a method using an eye-tracking virtual reality (VR). This method have an interclass correlation coefficient of 0.897 with the alternative prism cover test (APCT). This system is a commercial-grade VR-based and the difference between VR and the APCT reveals a large standard deviation (0.88 ± 5.77 PD) which is not negligible.

Shrinivas Pundlik and al. [24] have developed an application integrated in a smartphone to detect a strabismus using the Hirschberg test. This application named EyeTurn App, used image processing algorithms to automatically measure the distance between the corneal reflection position and the eye center. For the latent and manifest deviation, the application measurements were coherent with the comparator clinical methods.

Shorav Singh Suriyal has presented a thesis entitled: Quantitative analysis of strabismus using image processing [25]. He has used the basic techniques of image processing. It is an interesting method that did not use AI for the automatic detection. Dmitri Model and Moshe Eizenman have developed an automatic Hirschberg test for infants [26]. The system requires two cameras and a computer with an integrated calculation system. The

method is used to estimate the Hirschberg Ratio (HR) and the angle Kappa (the angle between the visual and optical axis) for each infant. The objective is to calculate the angle of eye misalignment. The results of the test with five infants show that the 95% limits of agreement between repeated measurements of angle Kappa are $\pm 0.61^\circ$. The maximum error in the estimation of eye alignment in orthotropic infants was 0.9° with 95% limits of agreement between repeated measurements of 0.75° . The method is interesting but the number of tests is small. N. Bushuieva and D. Romanenko have developed a method using a software to assess the angular deviation and the oblique muscle function in strabismus patients [27]. They analyzed the two-dimensional eye globe in diagnostic gaze positions of healthy patients and strabismus patients. The results obtained show that the correlation coefficient between angular deviation measured with the method and Hirschberg test is 0.797, mean difference measurements was 1.1° . The correlation coefficient between angular deviation with the method and Fresnel prim test was 0.881, mean difference between measurements was 3.8 PD. This method has 80% of correlation with conventional scale in the analysis of oblique muscle function. The Table 2 offers an overview of solutions based on image processing approaches.

4.2 Strabismus and Machine Learning Approaches

The method proposed by Mengash and Mahmoud has 95.9% of accuracy rate [28]. A set of training video was used to create a data set. The data set includes videos for eye region before and after cover test for the two eyes. Then, a decision tree (ID3) is built using labeled cases from actual strabismus diagnosis. The model are extracted from the corresponding videos of patients, and an association between the extracted features and actual diagnoses is established. This method require a bigger volume of videos, the cooperation of the patient and a recording device when the patient do the cover test. Rohismadi and al. [28] have proposed a system which has 91.8% of accuracy rate for strabismus detection using a case-based reasoning algorithm. It is a good method to classify strabismus. System developed by Alla Daher and al. [29] has 98.5% accuracy rate for diagnosing strabismus. This method used the electro-oculography (EOG) signal to analyze eye muscle irregularities. They used K-Nearest Neighbors (KNN) and wavelet decomposition method to extract and to classify the features from EOG signal. EOG is an examination that records the position and movements of the eye.

The Table 3 shows an overview of solutions based on machine learning approaches.

4.3 Strabismus and Deep Learning Approaches

A system developed by Jiewei Lu and al. [30] has 96.1% accuracy rate for diagnosing the strabismus. R-FCN (Region based Fully Convolutional Networks) is used to extract the eye of the image facial and a pre-entrained convolutional neural network (CNN) classifies the features. The angular deviation is not calculate. Zengai Chen and al. [31] have also proposed an automatic method for diagnosing the strabismus. This method has 95.2% accuracy arte. They used an eye tracker to record a subject's eye movements. A gaze deviation (GaDe) image is then proposed to characterize the subject's eye-tracking data according to the accuracies of gaze points. The GaDe image is fed to a pre-trained convolutional neural network (CNN) and SVM algorithm is used to classify the features

Table 2. Overview of solutions based on Image Processing Approaches

References	Materials	Dataset	Methods	Results	Advantage (A), Limitation (L)
[19] 2019	Eye tracker device, infrared light	69 children	EyeSwift System	Accuracy: 90% for the horizontal deviation, 91% for the vertical deviation and 100% for diagnosis strabismus	A: High accuracy for strabismus diagnosis L: system not adapted to muscle paralysis or patient with nystagmus; The 95% limits of agreement is not negligible ($\pm 11,4$ DP)
[20] 2019	Electronic data collection device	undefined	Images processing basic techniques	Accuracy: 91% in horizontal direction (error of 8 diopters) and 86% in vertical direction (error of 6 diopters)	A: allow an intelligent evaluation of strabismus L: significant error; Accuracy in vertical direction under 90%
[21] 2017	Recording Camera	undefined	Eye-tracking system + image processing basic technique	Accuracy: 93.33% for the exotropia, 87% for diagnosis strabismus	A: high accuracy for exotropia L: doesn't calculate angular deviation
[22] 2021	undefined	iBUG 300-W	CNN + Detector for 68 facial landmarks + Otsu's binarization + HSV color model	Normal eye: $1,073 \pm 0,014$ Strabismic eye: $1,924 \pm 0,169$	A: automatic diagnosis of strabismus L: doesn't calculate angular deviation

(continued)

Table 2. (continued)

References	Materials	Dataset	Methods	Results	Advantage (A), Limitation (L)
[23] 2021	Eye-tracking virtual reality (VR) device	38 strabismus patients	The system eye-tracking virtual reality headset simulate the APCT (Alternative prism Cover Test)	Mean difference between VR and APCT is $0,88 \pm 5,77$ PD ($p = 0,352$) ICC comparing VR and APCT is $0,897$ ($p < 0,001$)	A: calculate deviation without prism or occlude L: system do not correct patient's refractive error; eyeglasses increase measurement error
[24] 2019	smartphone	undefined	EyeTurn Application	Phoria measurements with the app were consistent with MT (slope = 0.94 , $R^2 = 0.97$, $P < 0.001$, $RMSE = 1.7\Delta$). Measurements with the app were higher than with Synoptophore (slope = 1.15 , $R^2 = 0.91$, $P < 0.001$), but consistent with CTPN (slope = 0.95 , $R^2 = 0.95$, $P < 0.001$)	A: automatic horizontal strabismus diagnosis L: Method used only horizontal direction, not evaluate the effect of glasses

(continued)

Table 2. (continued)

References	Materials	Dataset	Methods	Results	Advantage (A), Limitation (L)
[25] 2018	undefined	28 images 100 images	Basic technique of image processing Logistic regression model for training	Accuracy: 78% Accuracy: 93%	A: High accuracy with Logistic regression model L: method using image processing
[26] 2011	computer, two camera	06 children	Eye-tracking technique	The average difference between two independent measurements of eye misalignment was $-0.27^\circ \pm 0.38^\circ$ and the 95% limits of agreement for repeated measurements were $\pm 0.75^\circ$	A: simulate the Hirschberg test L: the number of test is small
[27] 2015	undefined	140 normal patients 148 strabismus patients	Program calculate pupil center shift relative to pupil center position in primary gaze	Accuracy: 80%	A: simplified method L: accuracy under 90%

(strabismus or normal). This technique is used to diagnose only the strabismus but not to calculate the angular deviation. Moreover, it used a complex system. The system proposed by Keli Mao and al. [32] used deep learning for diagnosing strabismus. Indeed, Inception ResNetV2 architecture of CNN is used to locate the pupil center in order to know the position of the eye (strabismus or normal). The accuracy rate is 94.17% using the digital images. However, this method only treats horizontal strabismus (esotropia, exotropia). In addition, their photos were obtained from an Asian population. These studies need to be extended to other ethnic groups. Another system developed by Thayane de Oliveira Simoes and al. [33] has 96.6% accuracy rate for diagnosing strabismus. They calculate the distance between the center of the limb and the point between the corners of the eyes. They used U-NET architectures to segment the image and extract features,

Table 3. Overview of solutions based on Machine Learning Methods

References	Methods	Accuracy	Features extracted	Advantages (A), Limitation (L)
[28] 2021	G-Transform model + Decision Tree (ID3)	95.9%	Distance between the center of iris and the right, left boundaries respectively	A: High accuracy L: require a bigger volume of videos, presence and cooperation of patient, videos recording system
[28] 2023	Case-based reasoning algorithm	91.8%	unknown	A: good for diagnosing strabismus L: did not calculate angular deviation
[29] 2023	KNN + wavelet decomposition tree method	98.5%	Electro-oculography (EOG) signal	A: High level of accuracy. Further research is necessary to explore the potential of these methods

and ResNet to classify them. Laura Alves de Figueiredo and al. [34] proposed a software which has 42% to 92% accuracy rate for diagnosing strabismus by analyzing the 9 eye gaze positions. Their method used ResNet 50 to evaluate ocular motility but requires further research. Method proposed by Haider Shamil Hamid and al. [35] has 95.62% accuracy rate to diagnose strabismus. They used Viola-Jones algorithm to detect eye region and deep learning algorithm to detect and classify strabismus in normal, exotropia and esotropia. But it does not evaluate the vertical deviation. Sukru Karaaslan and al. [36] proposed a method using deep learning and image processing to detect strabismus. Their method has 90% to 91% accuracy rate. It is a good method but can be improved. The Table 4 offers an overview of solutions based on deep learning approaches.

5 Discussion and Potential Challenges

This survey reviews various approaches using eye-tracking system associated with basic techniques of image processing, various machine learning techniques and several deep learning algorithms. These approaches are differentiated by their accuracy, time and complexity. Indeed, the proposed methodologies share steps such as image acquisition or video, image preparation, eye region detection, image segmentation to extract the features, model classification that uses the extracted features and predicts the disease and model evaluation. But, there are some differences between machine learning, deep learning and image processing approaches. In machine learning approaches, features

Table 4. Overview of solutions based on Deep Learning Approaches

References	Datasets	Architecture and Feature extracted	Accuracy	Advantages (A), Limitation (L)
[30] 2018	5685 images including 3409 training dataset (701 strabismus images, 2708 normal images and 2276 testing dataset (470 strabismus images, 1806 normal images)	R-FCN + CNN R-FCN for eye region extraction and CNN for classifying	96.1%	A: high level accuracy L: doesn't calculate angular deviation
[31] 2018	undefined	CNN + SVM classifier Color image feature and bright point of GaDe image (Gaze Deviation image)	95.2%	A: automatic diagnosis strabismus with good accuracy L: not calculate angular deviation and use some equipment that is not accessible to everyone
[32] 2020	5,595 images divided into training (70%), validation (15%) and retrospective test sets (15%)	CNN architecture InceptionResNet V2 Feature extracted: unknown	Retrospective testing: 99.0% Prospective testing: 97.2%	A: high accuracy L: method only treats horizontal strabismus (exotropia, exotropia). In addition, their photos were obtained from an asian population. These studies need to be extended to other ethnic groups
[33] 2019	undefined	U-Net + ResNet Networks	96.6%	A: high accuracy L: did not calculate angular deviation

(continued)

Table 4. (continued)

References	Datasets	Architecture and Feature extracted	Accuracy	Advantages (A), Limitation (L)
[34] 2020	110 strabismus patients	ResNet 50 Networks	42% to 92% according to the eye gaze position (1 to 9)	A: allows the evaluation of ocular motility L: variable accuracy, further exploratory research and validations are required
[35] 2022	285 facial images	Viola-Jones algorithm + CNN algorithm	95.62%	A: High accuracy L: did not calculate angular deviation
[36] 2023	88 strabismic patients	Deep learning algorithm + image processing	90% to 91%	A: good accuracy but can be improved

extraction is the input and the objects classes as output while the deep learning algorithm use the image to classify the objects. The image processing approaches use the image to locate the eye region, extract eye and classify the objet using basic techniques of image processing. Another difference is noted in the image acquisition. Eye-tracking system requires some material to record image facial with their complexity. It requires the cooperation of the patient. In addition, image processing technique requires a good command of eye location techniques, filter and others. Machine learning,

methods requires a deep knowledge in image processing domain for extracting features. It is done manually. While in deep learning algorithm, the features extraction is done automatically. In terms of accuracy, machine learning approaches and deep learning approaches offer greater precision to diagnose strabismus than image processing approaches. Machine learning methods and deep learning techniques are roughly equivalent in terms of accuracy. Some machine learning and deep learning techniques detect automatically the strabismus without calculating the angular deviation. These methods are interesting for diagnosing the disease but limited. Indeed, the angular deviation calculation is an additional step that allows the ophthalmologist to confirm the diagnosis, to monitor the disease and to use this value in the event of surgery. These automatic diagnosis methods can be used in African hospital particularly in Senegal. In collaboration with Abass Ndao hospital in Dakar, we plan to create a database of facial images (strabismus patients with angular deviation, normal patients). Then we will create an artificial intelligence model for diagnosing strabismus and angular deviation calculation in order to use it in ophthalmology department especially in remote areas.

6 Conclusion and Future Works

Currently, amblyopia continues to be one of the causes of school drop-out among children. Early diagnosis of strabismus is becoming a key factor in the fight against visual impairment. Artificial Intelligence offers solutions for diagnosing strabismus early.

In this study, we analysed various automatic diagnostic techniques of strabismus such as image processing approaches, machine learning methods and deep learning techniques. All these methods are interesting. However, in Africa, particularly in Senegal, some of the devices used are not available in our hospital unlike the developed countries. The Challenge is to boost the use of artificial intelligence in our hospital. The aim is to help the specialist for early diagnosing and monitoring of the disease. As future works, we plan to collect data at the Abass Ndao hospital in Dakar. We will combine a deep learning model and a classifier prediction model with the value of the angular deviation as input for diagnosing strabismus automatically.

References

1. Rapport Mondiale sur la Vision. ISBN 978-92-4-000297-5 (version électronique), ISBN 978-92-4-000298-2 (version imprimée). Publié le 08 Octobre 2019
2. OMS: Eye Health. <https://www.afro.who.int/health-topics/eye-health>. Accessed on 16 Nov 2023
3. Mémoire de Master de Madior Gueye : Evaluation des effectifs et des dotations du matériel d'Ophtalmologie au Sénégal à la lumière des normes nationales et de l'OMS. Soutenu le 19/12/2020 à l'Université Polytechnique de l'Ouest Africain (UPOA), Dakar, Sénégal
4. OMS : Cécité et déficience visuelle. <https://www.who.int/fr/news-room/fact-sheets/detail/blindness-and-visual-impairment>. Accessed on 10 Oct 2023
5. Frick, K.D., Foster, A.: The magnitude and the cost of global blindness: an increasing problem that can be alleviated. *Am. J. Ophthalmol.* **135**(4), 471–47 (2003)
6. Prince Kwaku Akowuah and al.: Strabismus and amblyopia in Africa – A systematic review and meta-analysis (2022). <https://doi.org/10.1080/09273972.2022.2157023>
7. Tableau de l'ordre national des médecins du Sénégal (2022). <https://www.ordremedecins.sn/>
8. Rapport annuel sur la Population du Sénégal en 2022. <https://www.ansd.sn/>. Accessed on 16 Nov 2023
9. Abràmoff, M.D., et al.: Improved automated detection of diabetic retinopathy on a publicly available dataset through integration of deep learning (2016). *Investigative Ophthalmology & Visual Science* October 2016, vol.57, pp. 5200–5206. <https://doi.org/10.1167/iovs.16-19964>
10. Gulshan V., Peng L., Coram M., et al.: Development and validation of a deep learning algorithm for detection of diabetic retinopathy in retinal fundus photographs (2016). *JAMA* **316**(22), 2402–2410. <https://doi.org/10.1001/jama.2016.17216>
11. Saranya, P., et al.: Detection and classification of red lesions from retinal images for diabetic retinopathy detection using deep learning models (2023). <https://doi.org/10.1007/s11042-023-15045-1>
12. Vaughan, N., et al.: Review of smartphone funduscopy for diabetic retinopathy screening (2023). <https://doi.org/10.1016/j.survophthal.2023.10.006>
13. Chea, N., et al.: Classification of Fundus Images Based on Deep Learning for Detecting Eye Diseases (2021). <https://doi.org/10.32604/cmc.2021.013390>
14. He, T., et al.: Automatic detection of age-related macular degeneration based on deep learning and local outlier factor algorithm. *Diagnostics (Basel)* (2022). <https://doi.org/10.3390/diagnostics12020>

15. Lee, C.S., et al.: Deep learning is effective for the classification of OCT images of normal versus age-related macular degeneration. *Ophthal. Retina* (2017). <https://doi.org/10.1016/j.oret.2016.12.009>
16. Li, C., et al.: Assessing the external validity of machine learning-based detection of glaucoma (2023). <https://doi.org/10.1038/s41598-023-27783-1>
17. Abbas, Q.: Detection of Glaucoma Eye Disease on Retinal Fundus Images using Deep Learning (2017). *(IJACSA) Int. J. Adv. Comput. Sci. Appl.* **8**(6) (2017)
18. Loba, P., et al.: Guidelines for the management of strabismus in children (2022). 3/2022, vol. 124, pp.127–130. <https://doi.org/10.5114/ko.2022.118848>
19. Yehezkel, O., et al.: Automated diagnosis and measurement of strabismus in children (2019). *Am. J. Ophthalmol.* **213**, 226–234 (2019). <https://doi.org/10.1016/j.ajo.2019.12.018>
20. Zheng, Y., et al.: Intelligent evaluation of strabismus in videos based on an automated cover test. *Appl. Sci.* **9**, 731 (2019). <https://doi.org/10.3390/app9040731>
21. Valente, T.L.A., et al.: Automatic diagnosis of strabismus in digital videos through cover test (2017). *Comput. Methods Programs Biomed.* **140**, 295–305 (2017). <https://doi.org/10.1016/j.cmpb.2017.01.002>
22. Huang, X., et al.: An automatic screening method for strabismus detection based on image processing (2021). <https://doi.org/10.1371/journal.pone.0255643>
23. Yeh, P.-H., et al.: To measure the amount of ocular deviation in strabismus patients with an eye-tracking virtual reality headset (2021). *BMC Ophthalmol.* **21**, Article number 246
24. Pundlik, S., et al.: Development and Preliminary Evaluation of a Smartphone App for Measuring Eye Alignment (2019). <https://doi.org/10.1167/tvst.8.1.19>
25. Suriyal, S.S.: Quantitative analysis of strabismus using image processing (2018). A thesis, presented to the Department of Electrical Engineering California State University, Long Beach, August 2018
26. Dmitri Model and Moshe Eizenman: An Automated Hirschberg Test for Infants (2011). *IEEE Trans. Biomed. Eng.* **58**(1) (2011). <https://doi.org/10.1109/TBME.2010.2085000>
27. Bushuyeva, N., Romanenko, D.: Assessment of deviation angle and oblique muscle function in strabismus patients using analysis of two-dimensional eye globe pictures in diagnostic gaze positions (2015). <https://doi.org/10.1111/j.1755-3768.2015.0446>
28. Amirul, M., et al.: An automated strabismus classification using machine learning algorithm for binocular vision management system (2023). <https://doi.org/10.1109/ICSECS58457.2023.10256291>
29. Daher, A., et al.: Artificial Intelligence Powered System for Detecting, Diagnosing and Rehabilitating Strabismus Disorder (2023). 10.1109/ICABME59496.2023.10293014
30. Lua, J., et al.: Automated Strabismus Detection for Telemedicine Applications (2018). <https://www.researchgate.net/publication/327571320>
31. Chen, Z., et al.: Strabismus recognition Using Eye-Tracking Data and Convolutional Neural Networks (2018). *Hindawi, J. Healthcare Eng.* Article ID 7692198, 9 p. <https://doi.org/10.1155/2018/7692198>
32. Mao, K., et al.: An artificial intelligence platform for the diagnosis and surgical planning of strabismus using corneal light-reflection photos (2020). Submitted Jul 22, 2020. Accepted for publication Dec 18, 2020. <https://doi.org/10.21037/atm-20-5442>
33. Simoes, T.O., et al.: Automatic ocular alignment evaluation for strabismus detection using U-NET and ResNet networks (2019). 8th Brazilian Conference on Intelligent Systems, Salvador, Brazil, pp. 239–244 (2019)
34. Alves de Figueiredo, L., et al.: Strabismus and Artificial Intelligence App: Optimizing Diagnostic and Accuracy (2020). <https://doi.org/10.1167/tvst.10.7.22>

35. Hamad, H.S., et al.: An Intelligent Strabismus detection method based on convolution neural networks (2022). <https://doi.org/10.12928/TELKOMNIKA.v20i6.24232>
36. Karaaslan, S., et al.: A new method based on deep learning and image processing for detection of strabismus with Hirschberg test (2023). 10.1016/j.pdpdt.2023.103805