AN IMPLEMENTATION OF REGIONAL DESCRIPTOR AND LINE ROI IN DEVELOPMENT OF SEMI-AUTOMATED STRABISMUS DETECTION SYSTEM

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To my beloved family, thank you.

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ABSTRACT

The strabismus (squint) is one of children's most common vision disorders. It can cause discomfort and have a significant detrimental effect on daily life. A timely diagnosis is needed to prevent it from getting worse. However, the traditional diagnosis screening is usually done manually and requires expertise, time and high cost due to the equipment. Thus, the proposed semi-automated strabismus detection using computer-aided diagnosis can help to reduce the time for the ophthalmologist to diagnose the strabismus and the misalignment measurement. This research aims to propose the image processing approach for detection and diagnosis of strabismus. This research proposes three phases: pre-processing, feature extraction, and classification. Initially, the image in pre-processing undergoes Viola Jones algorithm, red channel extraction, contrast adjustment and median filtering to reduce the noise and enhance the image. In feature extraction, binarization and morphological operations are implemented to identify the location of the iris and the misalignment measurement. Finally, the classification is divided into two, where the coordinates of the iris and misalignment measurement are carried out using regional descriptor and line ROI, while the strabismus and non-strabismus are classified using Convolutional Neural Network (CNN). The experimental results have proven that the proposed method has successfully detected the strabismus and the misalignment measurement with an average accuracy for the Eye Disease dataset (0.9167), Google Images (0.9217), CAVE (0.9167), and SiblingsDB (0.9167). In conclusion, by utilizing the image processing approach, this system will be able to assist the ophthalmologist and health care practitioners as strabismus pre-screening tools.

ABSTRAK

Juling adalah salah satu gangguan penglihatan yang paling biasa pada kanak-kanak. Ia boleh membawa ketidakselesaan dan kesan negatif yang serius terhadap kehidupan seharian. Diagnosis tepat pada masanya diperlukan untuk mengelakkan daripada menjadi lebih teruk. Walau bagaimanapun, pemeriksaan diagnosis tradisional biasanya dilakukan secara manual dan memerlukan kepakaran, masa dan kos yang tinggi disebabkan oleh peralatan. Oleh itu, pengesanan juling semi-automatik yang dicadangkan menggunakan diagnosis berbantukan komputer boleh membantu mengurangkan masa untuk pakar oftalmologi mendiagnosis juling dan ukuran salah jajaran. Matlamat penyelidikan ini adalah untuk menyiasat pendekatan pemprosesan imej untuk pengesanan dan diagnosis juling. Penyelidikan ini mencadangkan tiga fasa, yang terdiri daripada pra-pemprosesan, pengekstrakan ciri dan pengelasan. Pada mulanya, imej dalam pra-pemprosesan menjalani algoritma Viola Jones, pengekstrakan saluran merah, pelarasan kontras dan penapisan median untuk mengurangkan hingar dan meningkatkan kualiti imej. Dalam pengekstrakan ciri, operasi perduaan dan morfologi dilaksanakan untuk mengenal pasti lokasi iris dan ukuran salah jajaran. Akhir sekali, klasifikasi dibahagikan kepada dua di mana koordinat iris dan ukuran salah jajaran dijalankan menggunakan deskriptor serantau dan garisan untuk kawasan yang ada daya tarikan, manakala juling dan bukan juling dikelaskan menggunakan Rangkaian Neural Berlingkaran. Keputusan eksperimen telah membuktikan bahawa kaedah yang dicadangkan telah berjaya mengesan juling dan ukuran salah jajaran dengan ketepatan purata untuk dataset Penyakit Mata (0.9167), gambar Google (0.9217), CAVE (0.9167), dan SiblingsDb (0.9167). Kesimpulannya, dengan menggunakan pendekatan pemprosesan imej, sistem ini akan dapat membantu pakar oftalmologi dan pengamal penjagaan kesihatan sebagai alatan awal untuk saringan juling.

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LIST OF SYMBOLS AND ABBREVIATIONS

CCLRR	–	Central Corneal Light Reflex Ratio
AUC	–	Area under the ROC Curve
MSE	–	Mean Square Error
PSNR	–	Peak Signal to Ratio
D_D	–	Distance Different
I_L	–	Left Iris
I_R	–	Right Iris
Tp	–	True Positive
Tn	–	True Negative
Fp	–	False Negative
Fn	–	False Positive
Acc	–	Accuracy
Sen	–	Sensitivity
Spe	–	Specificity

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CHAPTER 1

INTRODUCTION

1.1 Background of the Study

The structure of the human eye is unique and complex. It consists of the eyelid, sclera, iris, pupil, and tear duct on the outer structure of the eyes, as shown in Figure 1.1. The eyelids are two movable structures that help protect the eye from foreign things and limit the amount of light entering the eyes. Next, the sclera is the dense connective tissue of the eyeball that forms the white part of the eye. In conjunction with the eye's intraocular pressure, the sclera is responsible for maintaining the eyeball's shape. It also provides a sturdy attachment for the extra ocular muscles that control the movement of the eyes (Gary Heiting, 2017). Iris is a circular disc of muscle containing pigments that determine eye colour. While the pupil is the central aperture of the iris. The muscles control the pupil’s size in the iris, controlling the amount of light entering the eyes. The iris's muscle fibres also decrease the pupil's size to accommodate for near vision and dilate the pupil when far vision is needed. Lastly, the tear duct (Nasolacrimal duct) is part of the tear drainage system. It drains the tears through the nasal bone and into the back of the bone (American Academy of opthalmology, 2018).

Figure 1.2 displays the illustration of how our eyes are working when seeing an object. Firstly, when a person looks at an object, the object's light will enter the eye through the cornea. Then, it will go through the iris. The iris will change the pupil's size, depending on the brightness of the object. The brighter the light, the narrow the pupil must dilate to let in the minimum light. The light that goes through the pupil is then redirected again to the eye’s lens, which it focuses on and sends the light information to the retina at the back of the eye. The image sent is upside down. Next, the retina will translate the light information into an electrical signal and send it to the brain via the optic nerve. The brain will process the signal and will turn the right image way up. Having pair of eyes gives us a wider field of view and greater depth of perception. The images send by both eyes are slightly different, and the difference is proportional to the relative depth. The visual processing areas in the brain will measure these differences and adjust the sight perception accordingly.

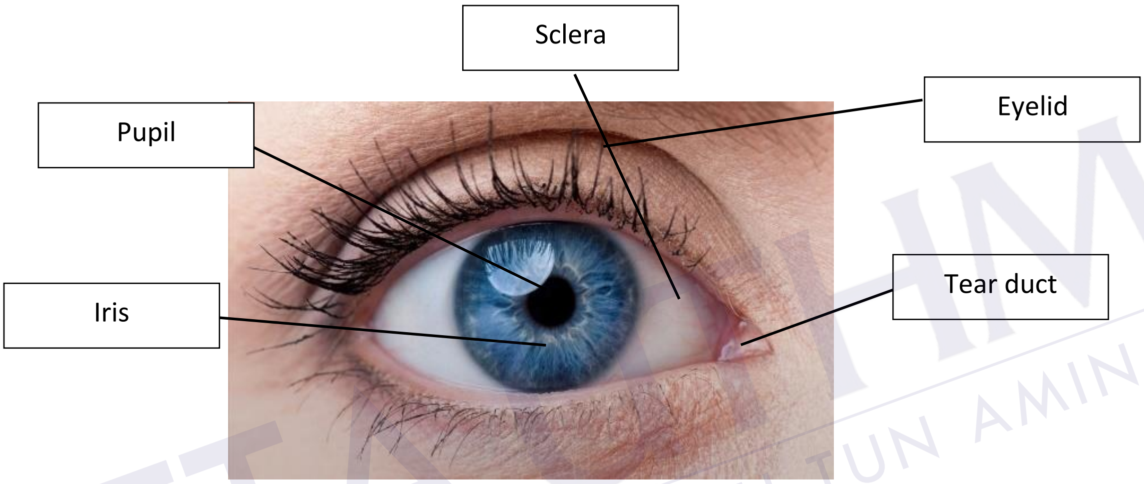

Figure 1.1: The external structure of the eye (Vision Eye Institute, 2017)

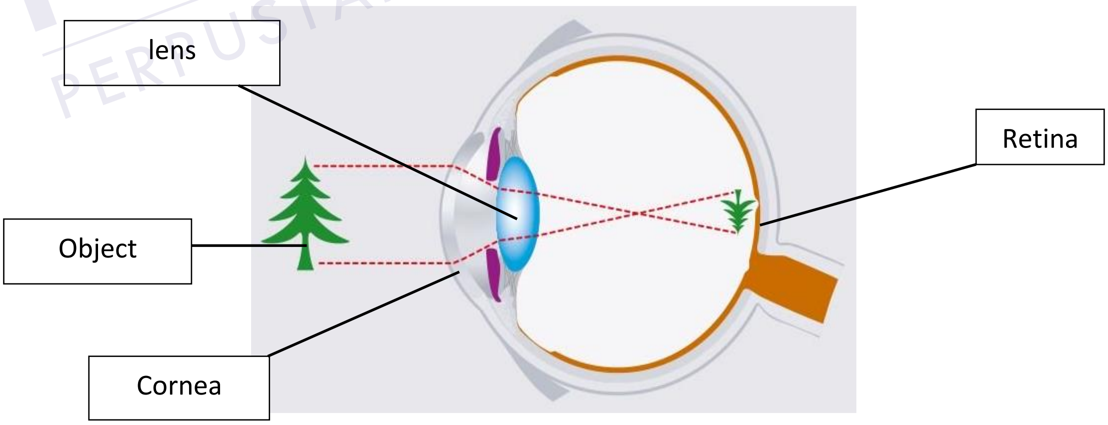

Figure 1.2: How do eyes work when seeing an object (Seibel Vision Surgery, 2020)

Strabismus, also known as crossed eyes, is an eye condition in which the eyes do not look in the same direction due to the misalignment. The nerves that transmit information to the eye muscles are most likely to be affected. Children with poor eye muscles or those who are farsighted are more likely to develop strabismus (Association, 2021). There are four types of strabismus which are esotropia (inward turning), exotropia (outward turning), hypertropia (upward turning) and hypotropia (downward turning), as shown in Figure 1.3.

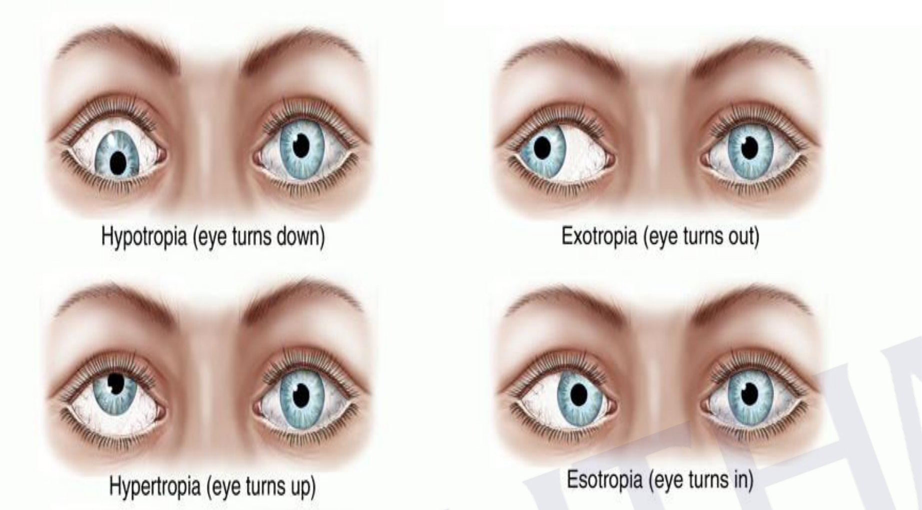

Figure 1.3: Types of strabismus (Taylor & Elliott, 2014)

Strabismus is usually caused by a family history of the condition, a refractive error in which people with uncorrected farsightedness tend to focus more energy on the other eye to keep the objects clear, and lastly, the medical condition such as if the person has down syndrome, cerebral palsy or injuries related to head. According to Meghan Endicott of the American Optometric Association (2019), “An undetected and untreated eye and vision disorders, such as amblyopia and strabismus, too often can become the barriers to learning, leading to delayed reading and poorer outcomes in school” (Golden, 2019).

For children, if the strabismus is not treated early, it will lead to another eye problem called amblyopia is, commonly known as lazy eye. It is a problem in which one or both eyes' vision is reduced (Taylor & Elliott, 2014). Dr Sharon Napier, a pediatric ophthalmologist, said, “The earlier you treat them, the better the brain will learn to see” (2019). Previous strabismus diagnoses include cover tests, corneal light reflex tests (Hirschberg test), Maddox test, and others requiring eye care to conduct it manually (Z. H. Chen., 2018). However, all these devices are expensive, time-consuming, and need to be manually done, which is not suitable for a big event (e.g.

health campaign) (Khumdat, Phukpattaranont, & Tengtrisorn, 2013). Therefore, a semi-automated strabismus detection can help to provide a valuable computer-aided diagnosis with less time and less cost. Thus, it enables the ophthalmologist to analyses and diagnose the patient's eye image more quickly and to provide appropriate treatment as soon as possible.

Four online sources will be used to evaluate the system's performance, with several images from each source serving as research elements. There are three online datasets: the Columbia gaze dataset (CAVE), the Kaggle: Eye Disease dataset, and the Siblings Database (SiblingsDB). While other sources are from Google Images.

1.2 Problem statement

Research on the strabismus diagnosis has been widely studied, with various methods of detection being used. Several tests are conducted to diagnose, such as the cover test, Hirschberg test and others (Ibarra et al., 2018; Yamin, Khan, & Yasin, 2013; Yumang et al., 2019). However, this previous type of research consumes time and cost. Also, some of the previous research only focuses on detecting whether the patient has strabismus and no information on the strabismus eye is given when no tests are done, although the system are fully automated detection system (Lu et al., 2018; Zheng et al., 2021). Therefore, in this proposed research, strabismus will be detected and an iris misalignment measurement will be provided to aid orthoptists and ophthalmologists in their work. The detection of strabismus at an early age is required because it is easier to treat before their visual pathway from the eyes to the brain are fully formed, and it will be difficult to change. Hence, pre-screening is recommended. However, it is usually done manually requires expertise, time and high cost due to the equipment. Thus, this research proposed developing a semi-automated strabismus detection to help the orthoptist and ophthalmologists diagnose and analyse the patient's result from the computer-aided system and can come out with the treatment faster. The information also can be recorded by the ophthalmologist to see the result of the patient during the treatment.

1.3 Aim of the Study

This research aims to propose the image processing approach for detection and diagnosis of strabismus. The system will detect the strabismus based on the sample images available on the online sources.

1.4 Objectives of the Study

There are several objectives to be achieved in order to complete the purpose of this research:

a) To develop a pre-processing on the first stage of the work to reduce the noise and enhance the eyes image.
b) To propose a segmentation algorithm in identifying the position of the iris and the misalignment measurement.
c) To develop a semi-automated digital image processing technique for the detection of strabismus.

1.5 Scopes of study

The scopes of the research are:

a) This study focuses on creating a system that can detect the strabismus and provide information on the iris's coordinates and distances between the centre of the iris to the inner corner of the eyes.
b) The experimental is conducted and evaluated on selected samples of dataset's images from four online sources: Eye Disease dataset, Google Images, CAVE, and SiblingsDB. Only the Eye Disease dataset and Google Images contain images of individuals with strabismus while CAVE and SiblingsDB consist of images of individuals with no strabismus.
c) The image selected need to be a frontal view image with distance between camera and the individual is around 0.5m to 1m to get a clearer image of the eyes.

d) The system is semi-automated, where the coordinates and distance of the iris require user interaction to provide the information.
e) The research utilizes MATLAB R2020a as the main software to develop the system for strabismus detection.

1.6 Research contribution

This research provides a framework of image processing approach in creating a semi-automated strabismus detection system that will provide misalignment measurement of the iris. Several methods are used in the pre-processing stage in reducing the noise and enhancing the eye's image consist of Viola Jones algorithm, red channel extraction, contrast adjustment and median filtering methods. Then, a segmentation algorithm is proposed to identify the position of the iris through coordinates and the misalignment measurement by measuring the distance of the iris where binarization, morphological operations, regional descriptor and line ROI methods were implemented. Last but not least, the strabismus is classified by using CNN with a pretrained network of GoogleNet. In the end, a GUI is developed to provide the end-user with an interactive way to detect the strabismus. This system can act as pre-screening tool for strabismus and can aid in recording the data during the treatment of the strabismus.

1.7 Outline of the thesis

In this thesis, there are five important chapters to explain the significance and details of this research. Chapter 1 consists of a brief explanation of the background of the study and why this research is being conducted. The objectives, scopes, and research contributions are stated in this chapter.

Chapter 2 is the summary of the literature review. The explanation of each element in this research is explained in detailed in this chapter. The chapter consists the information on eye disease, strabismus, online image sources, and some of the previous research works.

Chapter 3 contain the research methodology. This chapter describes each method used to produce the correct system for detecting strabismus and the information on the misalignment measurement. The method consists of 4 important processes: pre-processing, feature extraction, classification, and the calculation of the performance measures.

While, Chapter 4 describes the simulation results and analysis. This chapter shows the result of each process and the result of the system produced. There is also data on the misalignment measurement for the iris.

Finally, Chapter 5 will conclude the result of the research. This chapter will revise the objectives achieved in Chapter 1 and consist of the ideas of future work that can be done to improve the research.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

This chapter comprises information on the proposed system. In brief, this chapter focuses on the introduction to eye structure, eye diseases, and previous research on image acquisition, pre-processing, feature extraction, and classification of strabismus.

2.2 Eye Diseases

Numerous eye disorders can affect children, adults, and newborns. Strabismus and amblyopia are one example of eye disorder in all three generations. Strabismus (squint,cross-eyed) is a misalignment of the eyes that can occur horizontally or vertically (Costakos, 2017). The strabismus occurs in 1.3-5.7% of all children. According to Jolene Rudell, an assistant professor of ophthalmology at the University of Washington School of medicine, said that "we still don't understand why or how some children develop strabismus" (2019). With the goal of advancing treatment, Rudell is working to detect what causes the strabismus. Research that she has been doing shows that sometimes problems in the brain can lead to strabismus, as it is common for a patient with brain injuries and strokes to develop eye disease (University of Washington, 2019).

The ability to see a single image with two eyes involves a complex system of muscles, nerves, and other eye parts. When two eyes correctly and accurately point and focus simultaneously, we will see only one image. When two eyes point and focus differently from each other, double vision may happen, as can be seen in

Figure 2.1. Having two eyes looking in different directions will confuse the brain. Somehow, double vision happens when your brain allows it because each eye is sending two different images at the same time. Usually, the brain will adapt to the situation by shutting down or ignoring the information from one eye. This will lead to another eye disorder called amblyopia, known as lazy eye.

Amblyopia is a visual impairment without apparent structural pathology developing in a consistently deviating eye. The cortical suppressed the image from the deviating eye to prevent diplopia and visual confusion. All children with strabismus are at risk of developing amblyopia in the deviated eye. Children who have not developed visual maturity are at risk of developing amblyopia, and it most commonly occurs in children less than 7 years of age. Untreated Strabismus also can cause reduced stereo acuity, an abnormal head posture, reduced eye contact, which affects the ability of pre-verbal children to communicate effectively, psychological and social issues due to the stigma of strabismus and reduced self-esteem and may also have an impact on certain career prospects (Taylor & Elliott, 2014).

Figure 2.1: The view of the person with strabismus (All About Vision, 2019)

2.3 Strabismus

The majority of people with strabismus have a better vision in one eye than the other, this is referred to as the deviating or non-fixating eye. Experienced clinicians agree that strabismus is a heterogenous disease and clusters in families. Population studies support a hereditary component with a prevalence in siblings of an affected individual ranging from 11% to 70%. Exotropia tends to have a lower incidence in siblings compared to esotropia (Bateman & Isenberg, 2013). While in children with strabismus, convergent squints, esotropia occur in 60.1% are more common than divergent squints exotropia, occur in 32.7%, with fully accommodative esotropias occurring the most frequently.

Heterophoria or latent strabismus is the deviation of the eyes without stimulus for fusion. The deviation may be inwards (esophoria) or outwards (exophoria). This condition is usually physiologically, with the eyes remaining aligned in normal conditions with both eyes open. However, when the fusional reflex becomes insufficient to overcome this latent deviation, the individual may develop symptoms like diplopia or asthenopia.

Heterotropia or manifest strabismus occurs when both eyes' visual axes are misaligned (or do not intersect at the fixation point). Simply put, it is the inability of the eyes to fixate simultaneously at the object of regard.

The deviation may be present at all times (constant) or be controlled by fusion under certain conditions (intermittent).

2.3.1 Screening test conducted by ophthalmologists

Strabismus can be diagnosed when the patient attends an eye examination at the hospitals or eye clinics. There are four practical tests that will be conducted: the light reflex test, the red reflex test, the cover test, and the uncover test. The pediatric doctor will conduct the tests if the parent senses something is not right about their child's vision.

2.3.1.1 The light reflex tests

The light reflex test is also known as the Hirschberg test. It is usually conducted on children as it is a quick and simple way to check ocular alignment. The child will be placed on the parent’s lap. The doctor will stand around 1m away from the child and hold a small torchlight. The position of the light’s reflection in each of the child's eyes will be checked thoroughly and noted. The illustration of the light reflex test is

REFERENCES

Alake, R. (2020). Deep Learning: GoogLeNet Explained. Retrieved February 1, 2022, from https://towardsdatascience.com/deep-learning-googlenet-explained-de8861c82765#

All About Vision. (2019). Diplopia: Double vision causes and treatment. Retrieved June 20, 2020, from https://www.allaboutvision.com/en-in/conditions/double-vision/

American Academy of opthalmology. (2018). Tear Duct. Retrieved November 26, 2021, from https://www.aao.org/eye-health/anatomy/tear-duct.

Association, A. O. (2021). Strabismus (Crossed Eyes). Retrieved October 12, 2019, from https://www.aoa.org/patients-and-public/eye-and-vision-problems/glossary-of-eye-and-vision-conditions/strabismus#1

Bateman, J. B., & Isenberg, S. J. (2013). Strabismus. In *Emery and Rimoin's Principles and Practice of Medical Genetics* (pp. 1–19). Elsevier Ltd. https://doi.org/10.1016/B978-0-12-383834-6.00148-8

Chauhan, N. S. (2020). Introduction to Convolutional Neural Networks. Retrieved February 15, 2021, from https://www.kdnuggets.com/2020/06/introduction-convolutional-neural-networks.html

Chen, Z., Fu, H., Lo, W. L., & Chi, Z. (2018). Strabismus Recognition Using Eye-Tracking Data and Convolutional Neural Networks. *Journal of Healthcare Engineering*, *2018*. https://doi.org/10.1155/2018/7692198

Chen, Z. H., Fu, H., Lo, W. L., Chi, Z., & Xu, B. (2018). Eye-tracking-aided digital system for strabismus diagnosis. *Healthcare Technology Letters*, *5*(1), 1–6. https://doi.org/10.1049/htl.2016.0081

Costakos, D. M. (2017). Eye Disorders. In *Nelson Pediatric Symptom-Based Diagnosis*. https://doi.org/10.1016/B978-0-323-39956-2.00032-7

Dixit, A., Pathak, S., Raj, R., Naveen, C., & Satpute, V. R. (2018). An Efficient Fuzzy Based Edge Estimation for Iris Localization and Pupil Detection in

Human Eye for Automated Cataract Detection System. In *2018 9th International Conference on Computing, Communication and Networking Technologies (ICCCNT)*. https://doi.org/10.1109/ICCCNT.2018.8493740

Gary Heiting, O. (2017). Sclera: The White of The Eye. Retrieved January 2, 2020, from https://www.allaboutvision.com/resources/sclera.htm.

Golden, A. (2019). Eye doctor specializes in children's needs. Retrieved October 13, 2019, from https://www.freeweekly.com/2019/09/20/new-vision/

He, K., Zhang, X., Ren, S., & Sun, J. (2016). Deep residual learning for image recognition. *2016 IEEE Conference on Computer Vision and Pattern Recognition (CVPR)*, 770–778. https://doi.org/10.1109/CVPR.2016.90

Ibarra, J. B., Paglinawan, A., Sejera, M., Dema-Ala, F. A., Enriquez, M., Glodo, J. R., & Marty, F. P. (2018). Measurement of Overall Decentration, Angle Deviation, and Prism Diopters in categorized strabismus cases using Mathematical Morphology Algorithm. In *9th Int. Conference on Humanoid, Nanotechnology, Information Technology, Communication and Control, Environment and Management* (Vol. 2018, pp. 1–4). https://doi.org/10.1109/HNICEM.2017.8269435

Kaudki, O., & Bhurchandi, K. (2018). A Robust Iris Recognition Approach Using Fuzzy Edge Processing Technique. In *2018 9th International Conference on Computing, Communication and Networking Technologies (ICCCNT)* (pp. 1–6). IEEE. https://doi.org/10.1109/ICCCNT.2018.8493855

Kawaguchi, T., & Rizon, M. (2003). Iris detection using intensity and edge information. *Pattern Recognition*, *36*(2), 549–562. https://doi.org/10.1016/S0031-3203(02)00066-3

Khumdat, N., Phukpattaranont, P., & Tengtrisorn, S. (2013). Development of a computer system for strabismus screening. In *6th Biomedical Engineering International Conference* (pp. 1–5). IEEE. https://doi.org/10.1109/BMEiCon.2013.6687635

Kondwani. (2019). Eye Disease Dataset. Retrieved January 1, 2020, from https://www.kaggle.com/kondwani/eye-disease-dataset

Krafka, K., Khosla, A., Kellnhofer, P., Kannan, H., Bhandarkar, S., Matusik, W., & Torralba, A. (2016). Eye Tracking for Everyone. *Proceedings of the IEEE Computer Society Conference on Computer Vision and Pattern Recognition, 2016*. https://doi.org/10.1109/CVPR.2016.239

Lameski, J., Jovanov, A., Zdravevski, E., Lameski, P., & Gievska, S. (2019). Skin lesion segmentation with deep learning. *EUROCON 2019 - 18th International Conference on Smart Technologies*, 1–5. https://doi.org/10.1109/EUROCON.2019.8861636

Li, Z. (2017). An Iris Recognition Algorithm Based on Coarse and Fine Location. In *2017 IEEE International Conference on Big Data Analysis* (pp. 744–747). https://doi.org/10.1117/12.780158

Lu, J., Fan, Z., Zheng, C., Feng, J., Huang, L., Li, W., & Goodman, E. D. (2018). *Automated Strabismus Detection for Telemedicine Applications*. Retrieved from http://arxiv.org/abs/1809.02940

Model, D., & Eizenman, M. (2011). An automated Hirschberg test for infants. *IEEE Transactions on Biomedical Engineering*, *58*(1), 103–109. https://doi.org/10.1109/TBME.2010.2085000

Monaheng, M. S., & Kuruba, P. (2013). Iris Recognition using Circular Hough Transform. *International Journal of Innovative Research in Science, Engineering and Technology*, *2*(8), 3546–3553.

Muhammad, U., Wang, W., & Ali, S. (2018). Pre-trained VGGNet Architecture for Remote-Sensing Image Scene Classification. *2018 24th International Conference on Pattern Recognition (ICPR)*, 1622–1627.

Naguru, I., & Rao, B. N. K. (2017). Feature matching in Iris recognition system using Matlab. *International Journal on Advanced Science, Engineering and Information Technology*, *7*(5), 1748–1757. https://doi.org/10.18517/ijaseit.7.5.2765

Nazari, A., Mustafa, M. M., & Zulkifley, M. A. (2015). Analyzing the effect of multi-channel multi-scale segmentation of retinal blood vessels. *ARPN Journal of Engineering and Applied Sciences*.

O'Dowd, C. (2013). Evaluating squints in children. *Australian Family Physician*, *42*(12), 872–874.

Okokpujie, K., Noma-Osaghae, E., John, S., & Ajulibe, A. (2017). An Improved Iris Segmentation Technique Using Circular Hough Transform. *Springer Nature Singapore Pte Ltd.*, 203–211. https://doi.org/10.1007/978-981-10-6454-8

Paglinawan, A. C., Sejera, M. M., Paglinawan, C. C., Ancheta, R. E. H., Guatato, N. J. D., Nava, R. J. H., & Sison, K. P. (2018). Detection of three visual impairments: Strabismus, blind spots, and blurry vision in rural areas using

Raspberry PI by implementing hirschberg, visual field, and visual acuity tests. *9th International Conference on Humanoid, Nanotechnology, Information Technology, Communication and Control, Environment and Management*, *2018*, 1–9. https://doi.org/10.1109/HNICEM.2017.8269550

Piyush Mishra. (2021). Convolutional Neural Network (CNN). Retrieved December 4, 2021, from https://iq.opengenus.org/convolutional-neural-networks/

Podder, P., A.H.M Shahariar Parvez, Yeasmin, M. N., & Khalil, M. I. (2018). Relative Performance Analysis of Edge Detection Techniques in Iris Recognition System. In *2018 International Conference on Current Trends towards Converging Technologies (ICCTCT)* (pp. 1–6).

Rodrigo, R. (2009). Morphological image processing (pp. 1–12). https://doi.org/10.1007/978-1-84996-169-1_19

Safitri, D. W., & Juniati, D. (2017). Classification of diabetic retinopathy using fractal dimension analysis of eye fundus image. *AIP Conference Proceedings*, *1867*(August). https://doi.org/10.1063/1.4994414

Salman, B. (2012). *Iris Recognition System*. Tennessee State University.

Seibel Vision Surgery. (2020). Normal Vision. Retrieved June 30, 2020, from https://www.vision-surgery.com/patient-education/normal-vision/

Singh, B., Rajiv, P., & Chandra, M. (2015). Lie detection using image processing. *2015 International Conference on Advanced Computing and Communication Systems*, 1–5. https://doi.org/10.1109/ICACCS.2015.7324092

Singh, V., Agrawal, S., Singh, N., & Yadav, A. (2019). *Strabismus*. (S. Agrawal, Ed.) (1st ed.). Springer Nature, Singapore. https://doi.org/https://doi.org/10.1007/978-981-13-1126-0

Smith, B. A., Yin, Q., Feiner, S. K., & Nayar, S. K. (2013). Gaze locking: Passive eye contact detection for human-object interaction. *Proceedings of the 26th Annual ACM Symposium on User Interface Software and Technology*, 271–280. https://doi.org/10.1145/2501988.2501994

Sousa de Almeida, J. D., Silva, A. C., Teixeira, J. A. M., Paiva, A. C., & Gattass, M. (2015). Computer-Aided Methodology for Syndromic Strabismus Diagnosis. *Journal of Digital Imaging*, *28*(4), 462–473. https://doi.org/10.1007/s10278-014-9758-0

Sridhar, S. (2015). *Digital Image Processing*. Oxford University Press.

Sun, Y., & Hua, Y. (2018). Image Preprocessing of Iris Recognition. In *2018 IEEE*

3rd International Conference on Integrated Circuits and Microsystems, ICICM (pp. 401–405). IEEE. https://doi.org/10.1109/ICAM.2018.8596533

Suriyal, S. S. (2018). *Quantitative Analysis Of Strabismus using Image Processing*. California State University, Long Beach.

Taylor, K., & Elliott, S. (2014). Interventions for strabismic amblyopia. *Cochrane Database of Systematic Reviews*. https://doi.org/10.1002/14651858.CD006461.pub4

Tengtrisorn, S., Teerawattananon, K., Wongkittirux, K., Phukpattaranont, P., & Khumdat, N. (2017). Applied computer systems for strabismus screening. *Journal of the Medical Association of Thailand*, *100*(10), 1104–1109.

The MathWorks. Inc. (2021). color Thresholder.

The MathWorks Inc. (2020). Regionprops. Retrieved November 7, 2020, from https://www.mathworks.com/help/images/ref/regionprops.html

University of Washington. (2019). Researcher wants to unlock the mysteries of strabismus. Retrieved January 7, 2020, from https://newsroom.uw.edu/postscript/researcher-wants-unlock-mysteries-strabismus

Vieira, T. F., Bottino, A., Laurentini, A., & De Simone, M. (2014). Detecting siblings in image pairs. *Visual Computer*, *30*(12), 1333–1345. https://doi.org/10.1007/s00371-013-0884-3

Vision Eye Institute. (2017). Is Laser Eye Surgery Safe? Retrieved June 30, 2020, from https://visioneyeinstitute.com.au/eyematters/laser-eye-surgery-safe/

Wagh, A. M., & Todmal, S. R. (2015). Eyelids, Eyelashes Detection Algorithm and Hough Transform Method for Noise Removal in Iris Recognition. *International Journal of Computer Applications*, *112*(3), 28–31.

Wang, Y. (2014). An Analysis of the Viola-Jones Face Detection Algorithm. *Image Processing On Line*, *4*, 128–148. https://doi.org/10.5201/ipol.2014.104

Yamin, A., Khan, S. A., & Yasin, U. U. (2013). Automated system of hess screen for diagnosis of paralytic strabismus using computer aided diagnosis. In *2013 IEEE International Conference on Imaging Systems and Techniques (IST)* (pp. 300–305). IEEE. https://doi.org/10.1109/IST.2013.6729710

Yumang, A. N., Marquez, D. P. C., Paglinawan, A. C., Yamson, K. C. N., & Cuevas, E. B. (2019). Strabismus classification using digital image processing and horizontal coordinate classification algorithm. *ACM International Conference*

Proceeding Series, 136–141. https://doi.org/10.1145/3326172.3326200

Zhang, W., Wang, C., & Xue, P. (2017). Application of convolution neural network in Iris recognition technology. In *2017 4th International Conference on Systems and Informatics, ICSAI 2017* (pp. 1169–1174). https://doi.org/10.1109/ICSAI.2017.8248462

Zheng, C., Yao, Q., Lu, J., Xie, X., Lin, S., Wang, Z., … Qiao, T. (2021). Detection of referable horizontal strabismus in children's primary gaze photographs using deep learning. *Translational Vision Science and Technology*, *10*(1), 1–9. https://doi.org/10.1167/tvst.10.1.33

Zhu, Y., & Huang, C. (2012). An Improved Median Filtering Algorithm for Image Noise Reduction. *Physics Procedia*, *25*, 609–616. https://doi.org/10.1016/j.phpro.2012.03.133

Zolkifli, N. S., & Nazari, A. (2020). Tracing of Strabismus Detection Using Hough Transform. In *2020 IEEE Student Conference on Research and Development, SCOReD 2020* (pp. 313–318). https://doi.org/10.1109/SCOReD50371.2020.9250949

Zolkifli, N. S., Nazari, A., Mat Akir, R., & Vajravelu, A. (2021). Range Detection of Strabismus based on the Distance and Coordinates of the Iris. *ACCESS Online Journal IJACSSEJournal-International Journal of Advanced Computer Systems and Software Engineering*, *2*(1), 23–29. Retrieved from https://journal.scientiaca.org/index.php/ijacsse/article/view/169

Zolkifli, N. S., Nazari, A., Mustafa, M. M., Wan Zakaria, W. N. S., Suriani, N. S., & Wan Kairuddin, W. N. H. (2019). Retina blood vessel extraction based on Kirsch's template method. *Indonesian Journal of Electrical Engineering and Computer Science*, *18*(1), 318–325. https://doi.org/10.11591/ijeecs.v18.i1.pp318-325

APPENDIX C

LIST OF PUBLICATIONS AND AWARDS

1. N. S. Zolkifli, A. Nazari, M. M. Mustafa, W. N. S. Wan Zakaria, N. S. Suriani, and W. N. H. Wan Kairuddin, “Retina blood vessel extraction based on Kirsch’s template method,” Indonesian. J. Electr. Eng. Comput. Sci., vol. 18, no. 1, pp. 318–325, 2019.
2. N. S. Zolkifli, A. Nazari, ‘Tracing of Strabismus Detection using Hough transform’ in 2020 IEEE Student Conference on Research and Development, Scored 2020, 2020, no. September,pp. 313-318.
3. N. S. Zolkifli, A. Nazari, R. M. Akir, and A. Vajravelu, “Range Detection of Strabismus based on the Distance and Coordinates of the Iris,” ACCESS Online J. IJACSSE Journal-International J. Adv. Comput. Syst. Softw. Eng., vol. 2, no. 1, pp. 23–29, 2021.
4. N. S. Zolkifli, A. Nazari, R. M. Akir, “ Strabismus Pre-Screening System with Coordinates and Distance of the Iris”, Submitted to Indonesian Journal of Electrical Engineering and Computer Science. Status: Accepted.
5. Gold medal in Virtual International Research and Innovation Symposium and Exposition (RISE 2020).
6. Gold medal in National Innovation and Invention Competition (NIICE 2022).

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APPENDIX D

VITA

The author was born in January 13, 1996, in Ipoh, Perak, Malaysia. She went to Sekolah Menengah Sains Raja Tun Azlan Shah (SERATAS) for her secondary school. In 2014, she enter College Matriculation Pahang to further her studies. Then, she pursued her degree at Universiti Tun Hussein Onn Malaysia and graduated with the B. Eng (Hons) In Electronic Engineering in 2019 with vice chancellor award. Now she is a candidate for the Master degree of Electrical Engineering in Universiti Tun Hussein Onn Malaysia.