RGC Ref. No.:
UGC/FDS13/E04/14
(please insert ref. above)

RESEARCH GRANTS COUNCIL
COMPETITIVE RESEARCH FUNDING SCHEMES FOR THE LOCAL SELF-FINANCING DEGREE SECTOR

FACULTY DEVELOPMENT SCHEME (FDS)

Completion Report
(for completed projects only)

Submission Deadlines: *1. Auditor's report with unspent balance, if any: within **six** months of the approved project completion date.*
*2. Completion report: within **12** months of the approved project completion date.*

Part A: The Project and Investigator(s)

1. Project Title

Eye-tracking Aided Digital System for Intelligent Strabismus Diagnosis and Therapy Training: Principle and Prototype

2. Investigator(s) And Academic Department(s) / Unit(s) Involved

Research Team	Name / Post	Unit / Department / Institution
Principal Investigator	Dr. FU HONG Associate Professor	Department of Computer Science, Chu Hai College of Higher Education
Co-Investigator(s)	Dr. Zheru CHI Associate Professor	Department of Electronic and Information Engineering, Hong Kong Polytechnic University
Co-Investigator(s)	Dr. YAM Cheuk Sing Assistant Professor	Department of Ophthalmology and Visual Sciences, Chinese University of Hong Kong
Co-Investigator(s)	Prof. W.L.LO Professor	Dept. of Computer Science, Chu Hai College of Higher Education
Co-Investigator(s)	Professor FENG Dagan Professor	School of Information Technologies/The University of Sydney
Others	NA	NA

3. Project Duration

	Original	**Revised**	**Date of RGC / Institution Approval** *(must be quoted)*
Project Start Date	17 Nov 2014	NA	NA
Project Completion Date	16 Nov 2017	16 May 2018	12 May 2017
Duration *(in month)*	36 months	42 Month	12 May 2017
Deadline for Submission of Completion Report	16 Nov 2018	16 May 2019	12 May 2017

Part B: The Final Report

5. Project Objectives

5.1 Objectives as per original application

This proposed work aims to develop a digital system for intelligent strabismus diagnosis and therapy training with the following specific objectives:

1) to develop new gaze estimation and calibration algorithms for strabismic eyes and then build up an eye-tracking system for digital acquisition of eye moving data;
2) to collect eye tracking data both from strabismic and normal subjects, based on the above digital system, to construct a database for storage and further analysis;
3) to carry out a data mining on the above database for figuring out the featured eye movement patterns for strabismus;
4) to establish the relationship between extraocular muscles and eye movements, based on theoretical analysis, computational algorithms and the above strabismic pattern mining;
5) to develop a prototype of the proposed system for preliminary strabismic diagnosis and then evaluate the validity and efficiency of the prototype by comparing the results with the existing benchmarks; and
6) to further develop the above prototype for therapy training and to assess the response to the training for system refinement and application.

5.2 Revised objectives

Date of approval from the RGC: NA

Reasons for the change: NA

5.3 Realisation of the objectives
(Maximum 1 page; please state how and to what extent the project objectives have been achieved; give reasons for under-achievements and outline attempts to overcome problems, if any)

System setup and data collection:
We developed an objective, digital and automatic system based on eye-tracking technique for collecting eye gaze data from the subject. In this system, a commercial eye tracker, Tobii X2-60, is adhered below the monitor. In the test process, the subject sits at a fixed distance from the laptop, and looks at the objects shown on the monitor. We designed the calibration data collection procedure based on the need of strabismic people. By using this system, we established a dataset containing eye-tracking data of both strabismic subjects and normal subjects with the help of our collaborators.

Strabismus pattern mining and diagnosis:
We studied the eye movement patterns and proposed to recognize strabismus using both statistical methods and machine learning algorithms. A group of statistical features was proposed to characterize the gaze data. We also proposed to recognize strabismus using convolutional neural networks. A gaze deviation (GaDe) image was proposed to characterize the subject's eye-tracking data according to the accuracies of gaze points. The GaDe image is fed to a convolutional neural network (CNN) that has been trained on a large image database called ImageNet. The outputs of the full connection layers of the CNN are used as the GaDe image's features for strabismus recognition. Experimental results demonstrate that strabismus can be effectively recognized by our prototype system, compared with the ground truth from human experts.

Extraocular muscles and eye movements:
The research team has developed an extraocular muscle model for eye movements with eye tracking aided strabismus diagnosis data using finite element method. A parametric finite element model of binocular motion was proposed to establish and analyze the relationship between the extraocular muscles and horizontal eye movement. In this model, the eyeball is modeled with shell element and the tendon and muscle are simplified into beam element. More importantly, the mechanical parameter of extraocular muscles in the proposed theoretical model can be evaluated and modified by gaze data from eye-tracking aided system for the individual model. The result shows the theoretical result is very close to the measurement data and the model is workable.

Therapy training:
We designed training programs to help strabismus people train eye muscle movements with eye trackers. The disparities of the two eye gazes of strabismus sufferers are displayed on the screen immediately, providing real time and interactive feedback. Two groups of subjects with strabismus and with normal eyes were invited to participate in the training with the proposed system. We achieved promising results that demonstrated the effectiveness of the proposed training system and the possibilities of using this system in the real life applications. We refined the training program according to the comments from the subjects.

5.4 Summary of objectives addressed to date

Objectives *(as per 5.1/5.2 above)*	**Addressed** *(please tick)*	**Percentage Achieved** *(please estimate)*
1. to develop new gaze estimation and calibration algorithms for strabismic eyes and then build up an eye-tracking system for digital acquisition of eye moving data;	✓	100%
2. to collect eye tracking data both from strabismic and normal subjects, based on the above digital system, to construct a database for storage and further analysis	✓	100%
3. to carry out a data mining on the above database for figuring out the featured eye movement patterns for strabismus;	✓	100%
4. to establish the relationship between extraocular muscles and eye movements, based on theoretical analysis, computational algorithms and the above strabismic pattern mining;	✓	100%
5. to develop a prototype of the proposed system for preliminary strabismic diagnosis and then evaluate the validity and efficiency of the prototype by comparing the results with the existing benchmarks; and	✓	100%
6. to further develop the above prototype for therapy training and to assess the response to the training for system refinement and application	✓	100%

7. Research Outcome

6.1 Major findings and research outcome
(Maximum 1 page; please make reference to Part C where necessary)

The major findings and research outcome include four major aspects: strabismus pattern mining and diagnosis, therapy training, extraocular muscles and eye movements, as well as eye image processing algorithms.

Strabismus pattern mining and diagnosis:
We developed an objective, digital and automatic system based on eye-tracking technique for diagnosing strabismus [7]. We established a dataset containing eye-tracking data of both strabismic subjects and normal subjects. Then we studied the eye movement patterns and proposed to recognize strabismus using both statistical methods and machine learning algorithms. In [4], a group of statistical features is proposed to characterize the gaze data. The person's strabismus condition can be diagnosed according to the features. Experimental results on the dataset demonstrate the effectiveness of the proposed system for strabismus diagnosis. In [1], we proposed to recognize strabismus using eye-tracking data and convolutional neural networks. A gaze deviation (GaDe) image is proposed to characterize the subject's eye-tracking data according to the accuracies of gaze points. The GaDe image is fed to a convolutional neural network (CNN) that has been trained on a large image database called ImageNet. The outputs of the full connection layers of the CNN are used as the GaDe image's features for strabismus recognition. Experimental results demonstrate that the natural image features can be well transferred to represent eye-tracking data, and strabismus can be effectively recognized by our proposed method.

Therapy training:
In [6], we propose an eye-tracking aided training system for strabismus therapy. We aim at helping strabismus people train eye muscle movements with a real-time training system. The disparities of the two eye gazes of strabismus sufferers are displayed on the screen immediately, providing real time and interactive feedback. Two groups of subjects with strabismus and three subjects with normal eyes were invited to participate in the training with the proposed system. In this study, we achieved very promising results that demonstrated the effectiveness of the proposed training system and the possibilities of using this system in the real life applications.

Extraocular muscles and eye movements:
In order to investigate the eye movement behaviour of persons with strabismus, the research team has developed an extraocular muscle model for eye movements with eye tracking aided strabismus diagnosis data using finite element method [5]. A parametric finite element model of binocular motion was proposed to establish and analyze the relationship between the extraocular muscles and horizontal eye movement. In this model, the eyeball is modeled with shell element and the tendon and muscle are simplified into beam element. More importantly, the mechanical parameter of extraocular muscles in the proposed theoretical model can be evaluated and modified by gaze data from eye-tracking aided system for the individual model. The result of the case of normal eye shows the theoretical result is very close to the measurement data and the model is workable. Furthermore, the model is extended for a strabismus patient and the simulation result shows the theoretical model can reasonably explain the status of EOMs for the misalignment of eye motion. This may provide some indications for the operation and individual training schedule of strabismus therapy.

Eye image processing algorithms:

We have also developed some fundamental eye image processing algorithms which are beneficial to enhance the eye tracking and strabismus detection accuracy, including a real time eye detector with cascaded Convolutional Neural Networks [3] and a retinal vessel extraction algorithm using dynamic multi-scale matched filtering and dynamic threshold processing based on histogram fitting [2].

6.2 Potential for further development of the research and the proposed course of action *(Maximum half a page)*

The system and algorithms can be further integrated and optimized. The cost of the device can be reduced. The therapy training can be extended to other groups who have attention problems. The viewing pattern of strabismic people can also be further investigated by using a head mounted eye tracker. With a head mounted eye tracker, the subject can move freely and the dynamic eye movement pattern can be investigated.

8. Layman's Summary

(Describe in layman's language the nature, significance and value of the research project, in no more than 200 words)

Strabismus affects about 4% of the population and it is one of the most common eye diseases in preschool children in Hong Kong and other counties. If not well treated, strabismus may cause "lazy eye", poor depth perception, and even permanent vision loss. Studies show that appropriate eye movement trainings can effectively treat most of the strabismus. Therefore, we developed an objective, digitalized and intelligent system based on eye-tracking technique for strabismus diagnosis and therapy training. With this system, people just need to sit in front of a computer and watch the objects on the screen, and then a strabismus diagnosis can be conducted by the program automatically. Experimental results demonstrate that strabismus can be effectively recognized by our proposed method. Therapy training can also be done by playing eye controlled games, with the aid of an eye tracker. We achieved promising results that demonstrated the effectiveness of the proposed training system and the possibilities of using this system in the real life applications. The relationship between extraocular muscle and eye tracking data were also studied in this project.

Part C: Research Output

9. Peer-Reviewed Journal Publication(s) Arising Directly From This Research Project

(Please attach a copy of the publication and/or the letter of acceptance if not yet submitted in the previous progress report(s). All listed publications must acknowledge RGC's funding support by quoting the specific grant reference.)

No.	The Latest Status of Publications				Author(s) *(denote the corresponding author with an asterisk*)*	Title and Journal / Book *(with the volume, pages and other necessary publishing details specified)*	Submitted to RGC *(indicate the year ending of the relevant progress report)*	Attached to this Report *(Yes or No)*	Acknowledged the Support of RGC *(Yes or No)*	Accessible from the institutional repository *(Yes or No)*
	Year of Publication	Year of Acceptance *(For paper accepted but not yet published)*	Under Review	Under Preparation *(optional)*						
[1]	2018	-	-	-	Z. Chen, **H. Fu***, W. L. Lo and Z. Chi	"Strabismus Recognition Using Eye-tracking Data and Convolutional Neural Networks", *Journal of Healthcare Engineering*, Volume 2018, Article ID 7692198, 9 pages, 2018. SCI Impact Factor = 1.261	-	YES	YES	YES
[2]	2018	-	-	-	D. Gou, Y. Wei*, **H. Fu** and N. Yan	"Retinal vessel extraction using dynamic multi-scale matched filtering and dynamic threshold processing based on histogram fitting", *Machine Vision and Applications*, Volume 29, Issue 4, pp 655–666, May 2018. SCI Impact Factor = 1.306	-	YES	YES	YES
[3]	2018	-	-	-	B. Li and **H. Fu***	"Real time eye detector with cascaded Convolutional Neural Networks", *Applied Computational Intelligence and Soft Computing*, Volume 2018, Article ID 1439312, 8 pages, 2018.	-	YES	YES	YES

[4]	2018	-	-	-	Z. Chen, **H. Fu***, W. L. Lo, Z. Chi and B. Xu	"Eye-tracking Aided Digital System for Strabismus Diagnosis", *Healthcare Technology Letters*, Volume 5, Issue 1, February 2018, p. 1 – 6.	-	YES	YES	YES

10. Recognized International Conference(s) In Which Paper(s) Related To This Research Project Was / Were Delivered

(Please attach a copy of each conference abstract)

No.	Month/ Year / Place	Title	Conference Name	Submitted to RGC *(indicate the year ending of the relevant progress report)*	Attached to this Report *(Yes or No)*	Acknowledged the Support of RGC *(Yes or No)*	Accessible from the institutional repository *(Yes or No)*
[5]	Aug/2016/ Xi'an, China	"Extraocular muscle modeling for eye movements with eye tracking aided strabismus diagnosis data using finite element method", S. Li, **H. Fu***, B.G. Xu, W.L. Lo and K. Kay, (*Corresponding Author)	The 12th International Conference on Intelligent Unmanned Systems (ICIUS 2016) and the Workshop of the Eye Tracking and Visual Intelligence 2016 (ETVI 2016), Xian, China, Aug 23-25, 2016.	-	YES	YES	YES
[6]	Aug/2016/ Hong Kong	"Eye-tracking Aided Digital Training System for Strabismus Therapy", Z. Liang, **H. Fu***, B. Xu and W. L. LO (*Corresponding Author)	2016 9th International Conference on Advanced Computer Theory and Engineering (ICACTE 2016), Hong Kong, August 19-21, 2016. (This paper was awarded to Excellent Paper in ICACTE 2016.) (This paper was recommended to publish in Journal of Advances in Information Technology. Vol.8, No.1, pp. 57-62, 2017.)	-	YES	YES	YES
[7]	Oct/2015/ Hong Kong	"Eye-tracking Aided Digital System for Strabismus Diagnosis", Z. Chen, **H. Fu***, W. L. Lo, and Z. Chi, (*Corresponding Author)	Proceedings of the 2015 IEEE International Conference on Systems, Man, and Cybernetics, pp. 2305-2309, Hong Kong, Oct., 2015	2016	YES	YES	YES

11. Whether Research Experience And New Knowledge Has Been Transferred / Has Contributed To Teaching And Learning
(Please elaborate)

Under the supervision of the PI, a group of students in Chu Hai developed an eye controlled game called "Goddess Army". This game can be used as a therapy training program for strabismus people. It can also be used by physically handicapped people, who are not able to use a mouse, so that they can also share the joy of playing games.

12. Student(s) Trained
(Please attach a copy of the title page of the thesis)

Name	Degree Registered for	Date of Registration	Date of Thesis Submission / Graduation
CHOI Ka Man LAW Tsz Kwan CHEUNG Ka Wai	Bachelor of Science (Hons) in Computer Science	1 September 2012	2016

13. Other Impact
(e.g. award of patents or prizes, collaboration with other research institutions, technology transfer, teaching enhancement, etc.)

1. Excellent Paper Award
Winning paper: Eye-tracking Aided Digital Training System for Strabismus Therapy.
Authors: Z. Liang, H. Fu, B. Xu and W. L. Lo
9th International Conference on Advanced Computer Theory and Engineering (ICACTE 2016), Hong Kong, August 19-21, 2016.

2. This is an interdisciplinary project. We worked with colleagues from other research institutions to implement the project. They contribute based on their expertise, including Dr. Z. Chi (System implementation and data mining) and Dr. B. Xu (modeling) from the Hong Kong Polytechnic University, Dr. C. Yam from the Chinese University of Hong Kong (recommendations for data collection), Prof. D. Feng from University of Sydney (strategic advice for the project), and Prof. Y. Wei and her team from Shandong University (eye image algorithm). We have also established collaborations with the Hong Kong Strabismus Association and the Double Vision Patient Association and the Department of Optometry of the Shanghai Tenth People's Hospital. For publications [1] and [3~7], the PI (corresponding author) conceived of the presented idea. The PI and the research staff (first author) developed the theory and performed the computations, collected the data, verified the analytical methods. All authors discussed the results and contributed to the final manuscripts. For publication [2], the PI discussed the results and contributed to the final manuscript. Under the supervision of the PI, four research staffs, Drs. Z. Chen, Z. Liang, S. Li and B. Li received training and they gained research experience in this project.

3. As the lead guest editor, the PI organized a special issue titled "Advances in Eye Tracking Technology: Theory, Algorithms, and Applications," in *Computational Intelligence and Neuroscience*, 2016. This special issue aims to bring together theoretical and practical perspectives

in the area of eye tracking technology to present and discuss the latest technological developments and to inspire interaction and creation. The editorial of the special issue is

H. Fu*, Y. Wei, F. Camastra, P. Arico, and H. Sheng, "Advances in Eye Tracking Technology: Theory, Algorithms, and Applications," *Computational Intelligence and Neuroscience,* Vol. 2016, Article ID 7831469, 2 pages, 2016. doi:10.1155/2016/7831469, SCI Impact Factor = 1.649

4. A patent application supported by Chu Hai College of Higher Education

H. Fu, S. Y. Li, B. Li and W. L. Lo, A digital method, device and system for strabismus diagnosis, Chinese Patent Application, No.: 201710612349.4, 2017

14. Public Access Of Completion Report

(Please specify the information, if any, that cannot be provided for public access and give the reasons.)

Information that Cannot Be Provided for Public Access	**Reasons**

RESEARCH GRANTS COUNCIL
COMPETITIVE RESEARCH FUNDING SCHEMES FOR THE LOCAL SELF-FINANCING DEGREE SECTOR

FACULTY DEVELOPMENT SCHEME (FDS)

Completion Report - Attachment
(for completed projects only)

RGC Ref. No.:	UGC/FDS13/E04/14
Principal Investigator:	Hong Fu
Project Title:	Eye-tracking Aided Digital System for Intelligent Strabismus Diagnosis and Therapy Training: Principle and Prototype

Statistics on Research Outputs

	Peer-reviewed Journal Publications	Conference Papers	Scholarly Books, Monographs and Chapters	Patents Awarded	Other Research Outputs (Please specify)
No. of outputs arising directly from this research project [or conference]	4	3	0	0	3 (One excellent paper award, an editorship for a special issue in journal and a patent application)