RGC Ref. No.:
UGC/FDS13/E02/16
(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

Digitalized Assessment of Developmental Coordination Disorder with Integrated Eye-Motion Tracking Technology: System and Algorithms

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

Research Team	Name / Post	Unit / Department / Institution
Principal Investigator	Prof/FU/Hong Professor	Department of Computer Science/ Chu Hai College of Higher Education
Co-Investigator(s)	Professor/LO/Wai-Lun Professor	Department of Computer Science/ Chu Hai College of Higher Education
	Dr/CHI/Zheru Associate Professor	Department of Electronic and Information Engineering/ The Hong Kong Polytechnic University
	Prof/ SIT/ Hui-Ping Associate Professor	Department of Sports Science and Physical Education / Chinese University of Hong Kong
	Dr/YEUNG/ Kee-Sin Clinician / Chief Physician	Health Center/Matilda International Hospital
Others		

3. Project Duration

	Original	Revised	Date of RGC / Institution Approval *(must be quoted)*
Project Start Date	January 1, 2017	--	--
Project Completion Date	December 31, 2019	June 30, 2020	July 22, 2019
Duration *(in month)*	36	42	
Deadline for Submission of Completion Report	December 31,2020	June 30, 2021	

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 assessment of Developmental Coordination Disorder (DCD) with the following specific objectives:

(1) to develop an integrated system, including two subsystems for gross and fine movement evaluation, with a head-mounted eye tracker and multiple Kinect sensors to capture eye movement and body movement data;

(2) to develop body detection and major joint detection algorithms for gross movement subsystem, and finger joint detection algorithms for fine movement subsystem;

(3) to develop matching algorithm for fusing eye tracking data and motion tracking data, to obtain final eye-motion tracking data.

(4) to collect eye-motion tracking data both from DCD and normal subjects using the designed digital system and to construct a database for further analysis;

(5) to carry out data analysis on the above database for identifying the patterns of DCD and normal subjects and to study the mechanism of visual motion integration of DCD;

(6) to develop algorithms for training an intelligent classifier to perform automatic DCD assessment and to evaluate the specificity and sensitivity of the system for clinical purpose.

5.2 Revised objectives

Date of approval from the RGC: --

Reasons for the change: --

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1.
2.

3. ....

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:

An integrated and markerless eye motion system was developed to detect children's behavior in DCD assessment. In this system, a multi-Kinect system was developed to monitor body motion and extract the skeletal joints, including body joints and hand joints. The gaze point was detected by a head-mounted eye tracker and was integrated into the system of body motion using image processing method. With the proposed system, the skeletal joints and gaze points can be obtained simultaneously for further digital DCD assessment. Subjects are required to wear an eye-tracker and perform predefined fine motor tasks (e.g. placing pegs) and gross motor tasks (e.g. throwing beanbag onto a mat). A dataset with the data of both DCD subjects and normal subjects was established with the help of our collaborators.

Eye-motion data fusion and pattern analysis:

After collecting eye gaze and body movement of the subject, the eye gaze position after distortion correction was matched into the colour image from Kinect by using a fusion algorithm. Then the key points of the skeleton were detected in the fused images, and thus the eye gaze point and the key points of skeleton were integrated into an identical coordinate system for further analysis. To study the eye-motion pattern, the correlation coefficients of eye gaze position and joints position were calculated and compared. It was found that the visual movement speed of the children with DCD or at risk is a bit slower than that of the typical developing children when aiming at the target of interest, while their hand movement speeds are similar, which gives us a new hint for further study of DCD mechanism.

Intelligent algorithm for automatic DCD assessment:

A motor evaluation system was implemented with the proposed system to record children's performance, when they carry out predefined motor tasks. Automated algorithms were developed to perform automated scoring of motor skills. The automated algorithms included task localization and individual task evaluation. The purpose of task localization was to detect each task and extract segments belonging to each task from the original video that includes multiple segments of different tasks. A convolutional neural network with temporal filtering was used to do frame-wise classification, and a boundary localization algorithm was proposed to localize each task segment. Then the score of each task was computed according to the time spent or the resulting performance. The experimental results suggested that the evaluation result from our proposed algorithm are highly compatible with those from human experts (the ground truth).

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 an integrated system, including two subsystems for gross and fine movement evaluation, with a head-mounted eye tracker and multiple Kinect sensors to capture eye movement and body movement data;	√	100%
2. to develop body detection and major joint detection algorithms for gross movement subsystem, and finger joint detection algorithms for fine movement subsystem;	√	100%
3. to develop matching algorithm for fusing eye tracking data and motion tracking data, to obtain final eye-motion tracking data.	√	100%
4. to collect eye-motion tracking data both from DCD and normal subjects using the designed digital system and to construct a database for further analysis;	√	100%
5. to carry out data analysis on the above database for identifying the patterns of DCD and normal subjects and to study the mechanism of visual motion integration of DCD;	√	100%
6. to develop algorithms for training an intelligent classifier to perform automatic DCD assessment and to evaluate the specificity and sensitivity of the system for clinical purpose.	√	100%

6. 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 (a) an integrated eye-motion detection system; (b) eye-motion pattern analysis; (c) automated DCD assessment algorithms; and (d) action recognition algorithms.

(a) Integrated eye-motion detection system

A markerless visual-motor tracking system was implemented to monitor the gross and fine motor skills in the tasks of DCD assessment [4]. The system consists of a binocular eye-tracker for eye tracking and multiple Kinects for motion capture. The eye gaze position after distortion correction was matched into the videos from Kinect using a fusion algorithm. Then the key points of the body skeleton were detected in the fusion images and thus the eye gaze point and the key points of the body were integrated into an identical coordinate system for further analysis [3].

(b) Eye-motion pattern analysis

Based on the gaze and body movement data collected by our system, the pattern of eye-motion were studied. In motor task, the correlation coefficient of eye gaze position and thumb tip position was investigated to explore the pattern of visual-motor coordination [3]. Compared with typical developing peers, the eye movement of children with DCD or at risk seem less flexible. It was observed that the visual movement speed of the children with DCD or at risk is a bit slower than that of the typical developing children to focus on the target of interest, while their hand movement speeds are almost the same, which gives us a new viewpoint to understand DCD mechanism.

(c) Automated DCD assessment algorithms [1]

The purpose of the automated DCD assessment algorithms is to locate and score the actions from the captured videos and data. Two main algorithms, *i.e.* task localization and individual task evaluation, were proposed and implemented. The purpose of task localization was to detect and recognize each motor task and extract segments belonging to each task from the original video that includes multiple segments of different tasks. In this algorithm, a convolutional neural network with temporal filtering was used to do frame-wise classification, and then a boundary localization algorithm was proposed to localize each task segment. For individual task evaluation, the extracted video segments were evaluated based on the proposed object extraction and tracking, time positioning and other image processing methods. The results demonstrated high consistency between our automated algorithms and the human examiner, and that the proposed methods were effective for automated motor evaluation.

(d) Action recognition algorithms [2]

As a fundamental step in action evaluation, skeleton based action recognition algorithms were also developed in this project. A key-segment descriptor and a temporal step matrix model were proposed to semantically present the temporal-spatial skeleton data. After proper normalization and clustering, each skeleton sequence was coded as a meaningful and characteristic key segment sequence based on the key segment dictionary formed by the segments from all the training samples. The temporal structure of the key segment sequence was coded into a step matrix by the proposed temporal step matrix model. Experimental results on public datasets demonstrate that the proposed method outperforms all the hand-crafted methods and comparable to recent deep learning-based methods.

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

To further facilitate the usage of the evaluation system, a home version of the system can be developed by using cloud computing and mobile devices. An APP can be developed to facilitate the parents to collect data which records the activities of their kids while performing certain tasks, and then to direct the parents to upload the data to a cloud server. The server analyses the data and get back the results to the parents. This home version can be used for screening and preliminary evaluation of the intervention.

7. Layman's Summary

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

Developmental coordination disorder (DCD) is a type of motor learning difficulty that affects five to six percent of school-aged children, which may have a negative impact on the life of the sufferers. Timely and objective diagnosis of DCD are important for the success of the intervention. The present evaluation methods of DCD rely heavily on the observational analysis of occupational therapists and physiotherapists, which are expensive, subjective, and are not easy to expand to a larger population. In this project, we implemented an integrated system with an eye tracker and multiple Kinects to perform automated DCD assessment. The system was used to record subjects' performance, when they carry out predefined motor tasks. Automated algorithms were developed to perform automated scoring of motor skills which included task localization and individual task evaluation. The proposed methods are validated on a group of subjects with or without DCD. The experimental results suggested that the proposed methods can effectively achieve motor evaluation for DCD assessment. The system is a low-cost solution, and the evaluation methods developed are automated, objective, and can be suited for large population evaluation and analysis. The visual-motor coordination pattern was also studied in this project.

Part C: Research Output

8. 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 correspond-ing 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)*	Acknowl-edged 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]	2019				R. Li, H. Fu*, Y. Zheng, W. L. Lo, J. Yu, Cindy H. P. Sit, Z. Chi, Z. Song and D. Wen	"Automated Fine Motor Evaluation for Developmental Coordination Disorder", *IEEE Transactions on Neural Systems & Rehabilitation Engineering*, Vol. 27, Issue. 5, pp. 963 – 973, 2019. SCI Impact Factor = 3.972	No	Yes	Yes	No
[2]	2019				R. Li, H. Fu*, W. L. Lo, Z. Chi, Z. Song and D. Wen	"Skeleton-based Action Recognition with Key-segment Descriptor and Temporal Step Matrix Model", *IEEE Access*, 2019. vol. 7, pp. 169782-169795, 2019, doi: 10.1109/ACCESS.2019.2954744. SCI Impact Factor = 4.098	No	Yes	Yes	No
[3]	2018				R. Li, B. Li, S. Zhang, H. Fu*, W. L. Lo, J. Yu, Cindy H.P. Sit, D. Wen	"Evaluation of the Fine Motor Skills of Children with DCD using the Digitalized Visual-motor Tracking System" January 2018, *The Journal of Engineering*, 2018(2)	2018	Yes	Yes	**No**

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

(Please attach a copy of each conference abstract)

	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)*
[4]	12-15 Dec. 2017 Kuala Lumpur, Malaysia	A markerless visual-motor tracking system for behavior monitoring in DCD assessment	2017 Asia-Pacific Signal and Information Processing Association Annual Summit and Conference (APSIPA ASC)	2018	Yes	Yes	No

10. Whether Research Experience And New Knowledge Has Been Transferred / Has Contributed To Teaching And Learning

(Please elaborate)

Nil.

11. 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
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12. Other Impact

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

[5]. Bronze Award in 2018 CityU App Innovation Contest (3 out of 138 teams)
Organizer: *City University of Hong Kong*
Project title: Developmental Coordination Disorder Evaluation and Training Application
Students' name: Tang Y., Lau O. and Zhao H.
Institution: Chu Hai College of Higher Education
Supervisor: Hong Fu

[6]. "Developmental Coordination Disorder", Hong Fu and LO Wai-Lun were interviewed by the i-Cable TV Program "至fit男女", Oct. 2017

[7]. InnoTech Talk 2017: Analyze the Development Coordination Disorder (DCD) problems of children. Speaker: Professor LO Wai-Lun. Date: 27 Sep, 2017.

13. Statistics on Research Outputs

	Peer-reviewed Journal Publications	Conference Papers	Scholarly Books, Monographs and Chapters	Patents Awarded	Other Research Outputs (please specify)	
					Type	No.
No. of outputs arising directly from this research project	3	1	0	0	Student Award	1
					TV Interview	1
					Invited Talk	1

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
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