RGC Ref. No.:
UGC/FDS16/M02/14
(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

Development of an Exergaming System with Haptic Feedback for the Investigation of Energy Expenditure and Muscle Activities during Sports Training

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

Research Team	Name / Post	Unit / Department / Institution
Principal Investigator	Dr HUNG King Fai Kevin / Assistant Professor	Electronic & Computer Engineering / School of Science & Technology / The Open University of Hong Kong
Co-Investigator(s)	Dr CHOY Sheung On / Associate Professor	
	Dr NG Kei Shing Douglas / Assistant Professor	Mathematics & Statistics / School of Science & Technology / The Open University of Hong Kong
	Dr CHU Chun Fai Carlin / Assistant Professor	
	Prof CHOW Hung Kay Daniel / Chair Professor	Department of Health & Physical Education / The Education University of Hong Kong

3. Project Duration

	Original	Revised	Date of RGC / Institution Approval *(must be quoted)*
Project Start Date	1 January 2016	*N/A*	*N/A*
Project Completion Date	31 December 2017	30 April 2018	3 October 2017
Duration *(in month)*	24	28	3 October 2017
Deadline for Submission of Completion Report	31 December 2018	30 April 2019	3 October 2017

Part B: The Final Report

5. Project Objectives

5.1 Objectives as per original application

1. Design and develop an exergaming system with tactile and force haptic feedback;

2. Use the developed exergaming system to investigate the effects of tactile and force haptic feedback on energy expenditure and muscle activities during exergaming;

3. Use the developed exergaming system to investigate the relationship between body movements, energy expenditure and muscle activities during upper-extremity-focused exergames and lower-extremity-focused exergames.

5.2 Revised objectives

Date of approval from the RGC:	N/A
Reasons for the change:	N/A

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)*

The project was carried out in three phases. The first phase spanned 18 months, corresponding to the first project objective. The project team focused on the design and development of the hardware and software components of the proposed exergaming system. The hardware components included the wearable fixture (upper-limb and lower-limb orthoses), electromagnetic (EM) brakes as force haptic devices on the orthoses, Atmel-based microcontroller units (MCUs) as interfacing hubs, data acquisition (DAQ) unit, movement sensors, computer, and gaming unit. The software components included firmwares in the MCUs, haptic control in the computer, and DAQ software package for capturing electromyogram (EMG), energy expenditure, and movement data. During preliminary tests with human subjects, mechanical design problems were identified in the first version of the upper limb haptic subsystem. It was redesigned, leading to the second version to include i.) freely-rotating and freely-extending parts to allow improved range of motion and reduced slippage, ii.) heavy-duty rotation sensors which were more durable compared to common potentiometers, and iii.) aluminum fixtures (instead of 3D-printed ABS plastic parts) to withstand the force exerted by the player during exergaming sessions. The same design concept was then employed in the lower limb haptic subsystem. Due to this redevelopment time and lab renovation, the project end date was extended for four months. An alternative approach was used to realize the motion capture function of the exergaming system. Initially, the project team proposed video-capturing the players' movements with Microsoft Kinect ONE by interfacing it with a virtual instrument (LabVIEW) in a computer. However, the available LabVIEW-Kinect application programming interface (API) was still at beta (debugging) stage and could not meet our project's accuracy and speed requirements. Alternatively, the team turned to using gyroscopes and rotation sensors in the system. After testing, rotational sensors were chosen considering its accuracy, low cost, and no need for calibration. In torque meter tests and human tests with the three models of EM brakes (MBGS09AA, MBG02AA, and MBGS04AA) installed on the orthoses, our team found that only MBGS04AA could provide adequate resistive torque (up to 11.32N with driving duty cycle of up to 55%) to achieve noticeable force haptic. Tactile haptic function was built with miniature vibration motors. However, they were not included in the system eventually because we found that they had negligible effects on muscle activation and energy expenditure. The subsequent studies focused on the system with force haptic feedback. The second project phase involved human subject tests with the exergaming system. The player's upper- and lower-limb rotational movements about the elbow and knees, EMGs from three sets of related muscles (biceps, triceps, and rectus fermoris), and energy expenditure were recorded during predefined actions which simulated exergaming sessions. 23 and 21 subjects were recruited for the upper-limb and lower-limb focused experiments, respectively. Level of muscle activation and energy expenditure increased with the resistive force (haptic function) provided by the EM brakes. Using our system, activations of the bicep muscles over 20% of maximum isometric voluntary contraction (MVIC) in 18 subjects, and over 40% of MVIC in 15 subjects were achieved. Activation of triceps was over 20% in all subjects, and over 40% in 17 subjects. As for the rectus fermoris of lower limb, it was activated from 22% to 83% MVIC, 26% to 89% MVIC and 31% to 92% MVIC while the EM brakes were enabled at three increasing settings. With the haptic function enabled, energy expenditure of 1.5 to 1.7 MET was achieved. The above showed that our system's programmable haptic function was able to provide the player with moderate intensity of exercise. The third project phase involved 10 human subjects engaged in 8-minute exergaming sessions. An 8-bit game console was modified to interface with our system via an MCU, so that the player could play a car-racing game by moving their limbs, and thus the rotation sensors, in the orthoses. Due to different subjects' conditions and random nature of the exergames, no direct relationship between movement, muscle activity, and energy expenditure was identified. However, it was found that in general i.) energy expenditure increased with the level of muscle activity, and ii.) compared with haptic disabled, energy expenditure increased by 1 to 2 MET when haptic was enabled during the exergaming sessions, thus providing moderate level of energy expenditure equivalent to that of walking at a slow pace.

5.4 Summary of objectives addressed to date

Objectives *(as per 5.1/5.2 above)*	**Addressed** *(please tick)*	**Percentage Achieved** *(please estimate)*
1. Design and develop an exergaming system with tactile and force haptic feedback;	✓	100%
2. Use the developed exergaming system to investigate the effects of tactile and force haptic feedback on energy expenditure and muscle activities during exergaming;	✓	100%
3. Use the developed exergaming system to investigate the relationship between body movements, energy expenditure and muscle activities during upper-extremity-focused exergames and lower-extremity-focused exergames.	✓	100%

6. Research Outcome

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

An exergaming system with force haptic feedback was designed and developed. Its hardware components included wearable aluminum fixtures (upper-limb and lower-limb orthoses), electromagnetic (EM) brakes as force haptic devices on the orthoses, Atmel-based microcontroller units (MCUs) as interfacing hubs, data acquisition (DAQ) unit, rotational sensors, computer, and 8-bit gaming unit with car-racing game. The software components included firmwares in the MCUs, haptic control in the computer, and DAQ software package for capturing electromyogram (EMG), energy expenditure, and movement data. The system allows the subject under test to play a car-racing game by moving their limbs in the orthoses, while electromyogram, movement and energy expenditure signals are acquired.

In torque meter tests and human tests, it was found that the model MBGS04AA EM brake could provide adequate resistive torque (up to 11.32N with driving duty cycle of up to 55%) to achieve noticeable force haptic for training. Tactile haptic function was built with miniature vibration motors, but they were found to have negligible effects on muscle activation and energy expenditure.

In the testing of the haptic-enabled exergaming system with human subjects, there were activations of the bicep muscles over 20% of maximum isometric voluntary contraction (MVIC) in 18 subjects, and over 40% of MVIC in 15 subjects. Activation of triceps was over 20% in all subjects, and over 40% in 17 subjects. The rectus fermoris muscle in the lower limb was activated from 22% to 83% MVIC, 26% to 89% MVIC and 31% to 92% MVIC while the EM brakes were enabled at three increasing resistance settings. With the haptic function enabled, energy expenditure of 1.5 to 1.7 MET was achieved. It was concluded that the system's programmable haptic function was able to provide the player with moderate intensity of exercise.

In test with 10 human subjects engaged in 8-minute exergaming sessions. Due to different subjects' conditions and random nature of the exergames, no direct relationship between movement, muscle activity, and energy expenditure was identified. However, it was found that in general i.) energy expenditure increased with the level of muscle activity, and ii.) compared with haptic disabled, energy expenditure increased by 1 to 2 MET when haptic was enabled during the exergaming sessions, thus providing moderate level of energy expenditure equivalent to that of walking at a slow pace.

Having met the technical requirements, the developed exergaming system will serve as a useful platform for studies of different types of exergames on physiological conditions. The data can then be used for developing standards for the prescription of exergaming sessions with target health benefits. Three international conference papers and four undergraduate theses were produced in the project. All the data from these outputs are being aggregated for preparation of two journals, which will be submitted in May and July 2019.

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

The exergaming system can be further improved by i.) using smaller-size EM brakes or other comparable devices; ii.) miniaturizing the MCU subsystems; iii.) introducing wireless connectivity between all subsystems, iv.) developing more user-friendly interfaces for non-technical users; and v.) integrating all PC-based software components into a single one.

Further experiments can be carried out by introducing different haptic control algorithms, and investigating how different control approaches would affect the muscle activities and energy expenditure. This can be done by changing the transfer function in the software. Experimenting with different types of exergames, and subject groups (e.g. age, and medical condition) will give further and detailed insights in the impact of exergames.

The proposed course of action is to improve the existing exergaming system as mentioned above and to perform further tests on different subject groups. It is expected that in the next few years, more final year students will be invited to contribute to expansion of the project.

7. Layman's Summary

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

In the past, numerous parties have used traditional exercises as interventions for improving physical activity levels in individuals. Recent studies have shown that exergames can provide an alternative means of physical activity intervention. However, two challenges remain to be tackled before exergames can be effectively deployed for the above applications. First, there is no standard for the prescription of exergame-based physical activity intervention. Second, previous studies have revealed that due to the lack of haptic element, players' levels of energy expenditure in exergames are generally lower than in traditional exercises. Considering the above problems, this project aims to develop a haptic-enabled exergaming system which will serve as a useful research platform for getting quantitative physiologic data. The data will be useful reference for developing health-benefiting exergames and the corresponding prescription levels. The system was built and tested on human subjects. It was found that with the force haptic feature enabled, the system allowed the player to undergo moderate level of exercises of the upper and lower limbs, and the energy expenditure was comparable with that of walking at a slow pace. A novel feature of the system was the use of electromagnetic (EM) brakes to provide passive haptic functions.

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.)

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)*						
			✓ (To be submitted in May 2019)	Kevin Hung*, Ho-Yuen Cheung, Nathan Wan, Eva Lee, Chi-Nang Lai, Kun Pan, Rongle Liang, Carlin Chu, Sheung-On Choy, Douglas Ng, D.H.K. Chow	Upper and Lower Limb Orthoses with Haptic Feedback for the Investigation of Energy Expenditure and Muscle Activities / IET Science, Measurement & Technology	*No*	*No*	*Yes*	*Yes*
			✓ (To be submitted in July 2019)	Kevin Hung*, Ho-Yuen Cheung, Nathan Wan, Eva Lee, Chi-Nang Lai, Kun Pan, Rongle Liang, Carlin Chu, Sheung-On Choy, Douglas Ng, D.H.K. Chow	Design, Development and Evaluation of an Exergaming System with Haptic Feedback for the Study of Energy Expenditure and Muscle Activities / IEEE Access	*No*	*No*	*Yes*	*Yes*

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)*	**Acknowl-edged the Support of RGC** *(Yes or No)*	**Accessible from the institutional repository** *(Yes or No)*
July / 2016 / Poitiers, France	Design of an Exergaming System with Haptic Feedback for the Investigation of Energy Expenditure and Muscle Activities	INDIN 2016 (IEEE 14th International Conference on Industrial Informatics)	Yes	Yes [Attachment 2]	Yes	Yes
July / 2017 / Shenzhen, China	Development of an Upper-limb Orthosis with Force Haptic Feedback for Rehabilitation	IEEE-EMBS MDBS 2017 (The 11th IEEE Engineering in Medicine & Biology Society International Summer School & Symposium on Medical Devices & Biosensors)	No	Yes [Attachment 3]	Yes	Yes
November 2017 / Bandung, Indonesia	Development and Evaluation of a Haptic-based Upper-limb Orthosis for Rehabilitation	ICICI-BME 2017 (5th International Conference on Instrumentation, Communication, Information Technology & Biomedical Engineering)	No	Yes [Attachment 4]	Yes	Yes

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

Research experience and new knowledge have contributed to the teaching and learning of four full-time undergraduate students, who assisted in the evaluation of part of the exergaming system. The students' contributions were counted towards their final year project. They have gained knowledge in embedded system design, experiment design, biosignal acquisition, biosignal processing, and physiology. The project was also used as a case study in teaching materials for two recently launched full-time courses: ELEC S420F (Biomedical Instrumentation and Sensors) and ELEC S421F (Biomedical Informatics).

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**
LIANG Rongle	B.Eng. (Hons) in Electronic & Computer Engineering	Sep 2013	May 2017 [Attachment 5]
PANG Kun	B.Eng. (Hons) in Computer Engineering	Sep 2016	May 2018 [Attachment 6]
LAI Chi Nang	B.Eng. (Hons) in Electronic & Computer Engineering	Sep 2014	May 2018 [Attachment 7]
LEE Yin Wa Eva	B.Eng. (Hons) in Computer Engineering	Sep 2017	May 2019 (*expected*)

Under the supervision of the PI, the four full-time undergraduate students listed above have been trained to assist in part of the exergaming system development and testing. Their contributions were considered as work for their final year project, and have been documented as their theses, as follows:

Name	Title of thesis
LIANG Rongle	Design and Development of a Haptic Orthosis for Upper Limb
PANG Kun	Design and Development of a Haptic Orthosis for Lower Limb Training
LAI Chi Nang	Investigation on the Effect of Haptic Orthosis on Muscle Activities and Energy Expenditure
LEE Yin Wa Eva	Investigation on the Effect of Haptic Orthoses on Muscle Activities and Energy Expenditure during Exergaming Sessions

12. Other Impact

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

Prizes

One of the students (LIANG Rongle) who were involved in the project submitted his thesis, entitled "Design and Development of a Haptic Orthosis for Upper Limb," to two open competitions and had the following achievements:

Competition: HKEIA Innovation & Technology Project Competition Award: for student of electronic engineering or related engineering fields (2017)
Achievement: Merit award and cash prize
Organizer: Hong Kong Electronic Industries Association (HKEIA)
Date of award: 17 Oct 2017

Competition: Hong Kong Electronics Project Competition (HKEPC) 2017
Achievement: Finalist
Organizer: Electronics (EN) Division, The Hong Kong Institution of Engineers (HKIE)
Date: Mar 2017

The same student co-authored a conference paper and presented his work at the 11th IEEE Engineering in Medicine & Biology Society International Summer School & Symposium on Medical Devices & Biosensors (IEEE-EMBS MDBS 2017), which was organized by IEEE EMBS in Shenzhen, China in July 2017.

Collaboration with other institutions

Some of the experiments in this project were carried out in a laboratory of The Education University of Hong Kong (EdUHK), which was a Co-I's (Prof. Daniel Chow) institution. System development and data processing were done at OUHK. This joint project has initiated discussion about possible mode of collaboration in the future. OUHK possesses expertise in electronic and computer engineering, while EdUHK has experience in sports science and human subject experiment design. A possible collaboration for future joint project is having OUHK focus on engineering design and signal processing, while EdUHK contributes in experiment design.

Teaching enhancement

The project had enhanced the teaching and learning for some of the full-time students in B.Eng. (Hons) in Electronic and Computer Engineering and B.Sc. (Hons) in Computer Engineering programmes. Four final year project students were trained while they took part in the system development and evaluation. The project deliverables have been included as case study in the teaching materials for two full-time courses.

13. 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
Nil	--

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/FDS16/M02/14

Principal Investigator: Dr HUNG King Fai Kevin

Project Title: Development of an Exergaming System with Haptic Feedback for the Investigation of Energy Expenditure and Muscle Activities during Sports Training

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]	2 *(to be submitted in May and July 2019)*	3			