RGC Ref. No.: UGC/FDS24/E02/20
(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

A Low Cost Autopilot System for Built Environment Applications

(一套在建構環境中能應用的廉價 的自動駕駛系統)

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

Research Team	Name / Post	Unit / Department / Institution
Principal Investigator	Dr CHAU Chun-pong / Principal Lecturer	Division of Science, Engineering and Health Studies / PolyU SPEED
Co-Investigator(s)	Prof SIU Wan-chi / Emeritus Professor	Department of Electronic and Information Engineering / PolyU
Others	Dr WOO Kin-sang / Former Principal Lecturer	PolyU SPEED (Retired)

3. Project Duration

	Original	Revised	Date of RGC / Institution Approval *(must be quoted)*
Project Start Date	01/01/2021	N/A	N/A
Project Completion Date	31/12/2022	30/6/2023	20/10/2022
Duration *(in month)*	24 months	30 months	20/10/2022
Deadline for Submission of Completion Report	31/12/2023	30/6/2024	20/10/2022

4.3 Please attach photo(s) of acknowledgement of RGC-funded facilities / equipment.

1. DJI Robomaster EP x 2

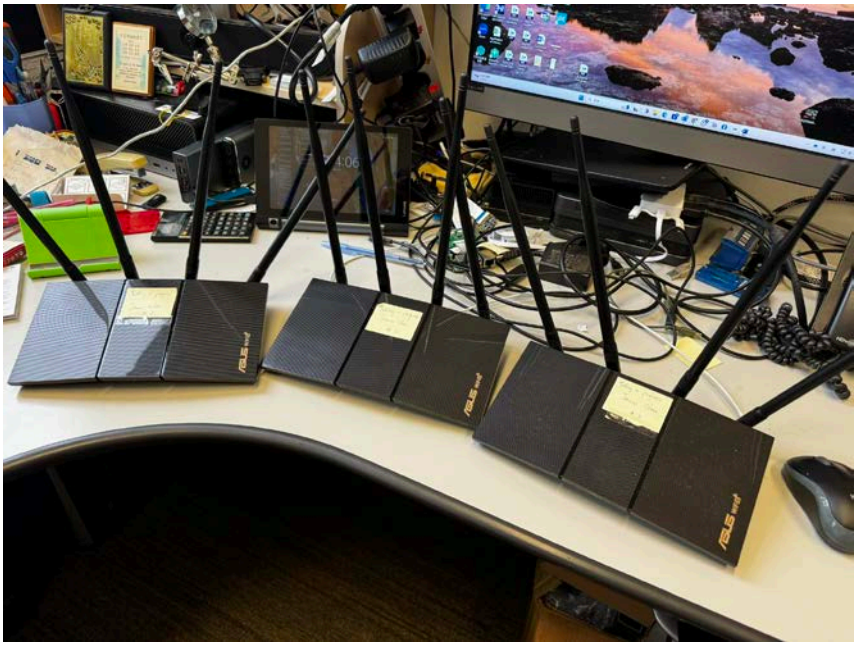
2. Nvidia Jetson Xavier AGP x 2

3. EAI D1 robot

4. ANTSDR E310V2 FPGA

5. Morefine M6S N5105 PC

6. ASUS Routers x 4



7. Peripherals and accessories

Part B: The Final Report

5. Project Objectives

5.1 Objectives as per original application

1. To study the integration of different types of sensors, RF receivers and cameras required for the indoor autopilot system in an embedded system and select the appropriate devices.

2. To study the preciseness and low latency indoor positioning algorithms without the installation of positioning hardware to the infrastructure in order to reduce the cost and time of development and implementation.

3. To study the methods for the reduction of computational power in the indoor autopilot system in order to release the requirement of huge data transmission in cloud computing.

4. To develop the control software for the indoor autopilot system for testing the system in different scenarios and conditions.

5. To produce the indoor digital maps for the testing scenes with proper alignments between the indoor and outdoor maps to deal with the transitions of the indoor and outdoor environments.

6. To tackle the discrimination of different storeys in buildings and its transition problems.

7. To define a new set of schema and pathways in the indoor environments for facilitating the indoor positioning and navigation applications.

8. To develop the object detection algorithms for preventing the system from collisions to other stationery or moving objects during its navigation movements.

9. To generate the navigation paths in the indoor digital maps using some path finding algorithms.

10. To design the functions and behaviors of a generic robot in which the indoor autopilot system is equipped.

11. To build an indoor positioning platform for developing applications and further research.

12. To identify some simple tasks in the project for the undergraduate students to train up their research capabilities and arouse their interests towards the Science, Technology, Engineering and Mathematics(STEM) industries and applications.

5.2 Revised objectives

Date of approval from the RGC: N/A

Reasons for the change:

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)

This project is focused on the design and development of a low-cost autopilot system in indoor environments without using expensive equipment, e.g. LIDAR, and deploying the system quickly without installing the equipment to the infrastructure, e.g. Bluetooth Beacon. Instead, we employ the WiFi signals, which are abundant inside buildings and the fixed objects and their positions as the tools for positioning the system in the buildings. To achieve the aim of the project, it is divided into several stages. Firstly, the digital maps of all floors on PolyU SPEED Hung Hom Bay and West Kowloon campuses (objective 5) were generated and they served as the ground information of the system for locating the system inside the campuses. In addition, the barrier-free pathways were identified and generated in the digital maps as the target system was built for the mobile robots (objective 7). As a result, the navigation paths for the mobile robots which were travelled in the buildings were generated based on the barrier-free pathways (objective 9) Secondly, WiFi signals were collected in the form of WiFi fingerprints in the grid positions of the whole buildings and generated the database for positioning the system. The WiFi fingerprints also served as the dataset for training up a neural network to identify the storeys where the system is located in the buildings (objective 6). By using the WiFi fingerprint positioning algorithms, the location of the system can be roughly estimated, and the more precise location of the system can be determined using the object recognition algorithms, which they made use of the positions of the fixed assets and signages within the area near the estimated position of the system (objective 1). The positioning techniques were implemented in embedded systems with limited processing power, and therefore, to release the computational complexity of the object recognition algorithms required, only the small and fixed objects were detected in the images captured by the camera installed in the system (objective 3), and subsequently, the system positions are calculated based on the per-measured dimensions of the objects and their geographic information stored in the digital maps. Moreover, the images, together with the ultrasound sensors, were used in the navigation function by detecting the occlusions in front of the system when it travelled inside the buildings (objective 8). After all these stages were completed, a control platform was implemented (objective 4) in order to integrate all the functions of the system, control its behaviours during its navigation (objective 10) and evaluate its accuracy and performance (objective 2). Experiments of the system were carried out to show the effectiveness of the system, and it demonstrated that without the use of the expensive positioning equipment and installation of the positioning hardware to the infrastructure, mobile robots could still navigate in the indoor environments using the detection of the WiFi fingerprints and fixed objects and assets. In fact, this system has been deployed to some applications, such as autopilot wheelchairs, autopilot shopping carts, and so on, and some undergraduate students have been working on them as their capstone projects (objectives 11 and 12).

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 study the integration of different types of sensors, RF receivers and cameras required for the indoor autopilot system in an embedded system and select the appropriate devices.	✓	100%
2. To study the preciseness and low latency indoor positioning algorithms without the installation of positioning hardware to the infrastructure in order to reduce the cost and time of development and implementation.	✓	100%
3. To study the methods for the reduction of computational power in the indoor autopilot system in order to release the requirement of huge data transmission in cloud computing.	✓	100%
4. To develop the control software for the indoor autopilot system for testing the system in different scenarios and conditions.	✓	100%
5. To produce the indoor digital maps for the testing scenes with proper alignments between the indoor and outdoor maps to deal with the transitions of the indoor and outdoor environments.	✓	100%
6. To tackle the discrimination of different storeys in buildings and its transition problems.	✓	100%
7. To define a new set of schema and pathways in the indoor environments for facilitating the indoor positioning and navigation applications.	✓	100%
8. To develop the object detection algorithms for preventing the system from collisions to other stationery or moving objects during its navigation movements.	✓	100%
9. To generate the navigation paths in the indoor digital maps using some path finding algorithms.	✓	100%
10. To design the functions and behaviors of a generic robot in which the indoor autopilot system is equipped.	✓	100%
11. To build an indoor positioning platform for developing applications and further research.	✓	100%
12. To identify some simple tasks in the project for the undergraduate students to train up their research capabilities and arouse their interests towards the Science, Technology, Engineering and Mathematics(STEM) industries and applications.	✓	100%

6. Research Outcome

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

1. In the WiFi fingerprint process, we investigated different methods, including fixed point collection method and walk-survey collection method on collecting the WiFi signals and an innovative walk-survey method using Gaussian process regression was proposed which its performance was outperforming the other methods in terms of collection time and accuracy. This research finding will be published in a journal paper with the title "Effects of Wi-Fi Signals in Android on the Positioning and Navigation in indoor environment".

2. The collected WiFi fingerprint had served as datasets for training a convolutional neural network for determining the storeys of the system in the buildings. We proposed using the locations-based similarity as the feature vectors and achieved better accuracy than other floor classification methods. This research finding was published in an international conference 2023 24th International Conference on Digital Signal Processing (DSP) with the title "A convolutional neural network architecture for multi-floor indoor localisation based on Wi-Fi fingerprinting".

3. In the study of the site surveying of the indoor environment of the autopilot system, the collected WiFi fingerprint database and the object detection techniques were found capable of integration with the other construction information to build a construction progress management system which can remotely manage and monitor the progress of construction sites. This research finding was published in the Twelfth International Conference on Construction in the 21st Century (CITC-12) with the title "Offshore construction progress management by indoor GIS positioning: Post COVID-19 new normal".

4. For the study of the autopilot system for the indoor environment, an embedded system installed on mobile robots which can travel around the indoor environment was designed and developed. The positioning and navigation functions were mainly provided by digital maps, WiFi fingerprint positioning algorithms and point-of-interest positioning algorithms. The experiments of the system showed that its navigation performance is compatible to those general mobile robots used in the indoor environment but with a cheaper implementation and deployment cost. Part of the research findings was presented in the International Workshop on Advanced Image Technology 2022, and the whole research findings will be published in a journal paper with the title "An autopilot system for built environment using WiFi fingerprinting and point-of-interest detection techniques".

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

After completing this project, we would like to continue with the following development:

(1) The current accuracy in positioning of the system using the WiFi fingerprints is 3 to 5 meters, we would like to improve this accuracy by using the mixed signal fingerprints which the other radio signals, such as 5G mobile signal, geomagnetic signal, etc. are collected as the fingerprints and its positioning algorithms will be redesigned.

(2) The autopilot system used the semantic segmentation methods to identify some indoor objects in the captured images. However, these methods consume a lot of computational power, which makes it become unable to apply frequently. This has affected navigation performance, and therefore, we would suggest developing some lightweight semantic

segmentation methods tailored to the indoor positioning system using the captured visual data.

(3) We would like to implement this autopilot system to the smart glasses for blind people's barrier-free navigations.

7. Layman's Summary

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

The project develops an autopilot system implemented in mobile robots which can be used in the indoor environment. It employs digital maps, WiFi signals and point-of-interest objects in locating the system which can be an analogue to positioning oneself in a hike with the use of a compass and map. The digital maps can provide a visual representation of the area where the mobile robots are exploring, the WiFi signals can roughly locate the mobile robots' position and the point-of-interest object detection helps fine-tune the position of the mobile robots. Without the additional installation hardware to the infrastructure and expensive hardware, the system has achieved a compatible navigation performance to the conventional mobile robots, and this can greatly reduce the cost of developing the mobile robot as the expensive peripherals are not required. Hence, the applications of indoor mobile robots can be disseminated easily.

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 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)*						
2024 (Anticipated)	N/A	N/A	Yes	X Chen, SY Hu, WC Siu and JQ Wu & CP Chau	Effects of Wi-Fi Signals in Android on the Positioning and Navigation in Indoor Environment	No	Yes (Appendix 1)	Yes	No
2025 (Anticipated)	N/A	N/A	Yes	CP Chau, X Chen, CY Chan, WC Siu and WS Woo	An autopilot system for built environment using WiFi fingerprinting and point-of-interest detection techniques	No	Yes (Appendix 2)	Yes	No

9. Recognised 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)*
01/2022/ HK	An indoor visual positioning system using points of interest detection for mobile robot application	International Workshop on Advanced Image Technology 2022 (IWAIT 2022)	2021	Yes (Appendix 3)	Yes	Yes

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)*
05/2022/ Jordan	Offshore Construction Progress Management by Indoor GIS positioning: Post COVID-19 new normal	12th International Conference on Construction in the 21st Century (CITC-12)	N/A	Yes (Appendix 4)	Yes	Yes

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

Our developed autopilot system was investigated and further developed in the following capstone projects of the undergraduate students:

1. Indoor patrolling robot (2021/22)
2. A study of Point of Interests (POI) positioning for video analysis in indoor environment (2023/24)
3. Autopilot shopping cart (2023/24)
4. Autopilot wheelchair (2023/24)

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
[redacted]	BEng (Hons) in Electrical Engineering	1/9/2020	30/4/2022
[redacted]	BEng (Hons) in Electrical Engineering	1/9/2020	30/4/2022
[redacted]	BEng (Hons) in Electrical Engineering	1/9/2020	30/4/2022
[redacted]	BEng (Hons) in Electrical Engineering	1/9/2022	28/4/2024
[redacted]	BEng (Hons) in Electrical Engineering	1/9/2022	28/4/2024
[redacted]	BEng (Hons) in Electrical Engineering	1/9/2022	28/4/2024
[redacted]	BEng (Hons) in Electrical Engineering	1/9/2022	28/4/2024
[redacted]	BEng (Hons) in Electrical Engineering	1/9/2022	28/4/2024

Name	Degree Registered for	Date of Registration	Date of Thesis Submission / Graduation
[redacted]	BEng (Hons) in Electrical Engineering	1/9/2022	28/4/2024
[redacted]	BEng (Hons) in Electrical Engineering	1/9/2022	28/4/2024
[redacted]	BEng (Hons) in Electrical Engineering	1/9/2022	28/4/2024

12. Other Impact

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

Through this research work, four capstone projects were generated for arousing students' interests towards the indoor autopilot systems. The students took part of the development in the autopilot system, applied the developed system into their specific applications, gained the experience on data collections and dataset preprations, and learned how to train and use the machine learning models.

13. 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	2 (Planned)	3	0	0	Type	No.
					N/A	

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
N/A	