THE HONG KONG POLYTECHNIC UNIVERSITY
香港理工大學

Annual Report on Activities and Advancement of Knowledge Transfer

2020-21

30 July 2021

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1. Executive Summary

This report summarises key knowledge transfer (KT) and entrepreneurship activities and developments of The Hong Kong Polytechnic University (PolyU, the University) for the fiscal year ended 30 June 2021.

PolyU aspires to be a world-class university with a strong emphasis on the societal impact of its educational, research and KT endeavours that are underpinned by research and innovation. Over the years, KT has always been one of PolyU's strategic focuses, with the overarching guiding principle that all PolyU intellectual properties (IPs) of practical value should leave campus to create industry and societal impact. The strategic focus of KT is also reflected in the establishment of a new President's Award in KT and the formalisation of KT performance indicators for academic units. Guided by the above principle, the University has been refining its policy and guidelines to motivate and further support inventors to translate their research outputs into applications and solutions for impact. In FY 2020/21, PolyU generated from KT an income of $795M (15% year-on-year increase), filed 235 patents (82% year-on-year increase), and formed 180+ partnerships in KT and entrepreneurship. The licence income of $7.4M represented an increase of 184% compared to that in FY2019/20.

While the COVID-19 pandemic is still posing serious threats to public health across continents, PolyU's researchers have been devoting themselves to finding ways to combat the pandemic. One of the most outstanding achievements was the setting up of The Hong Kong Polytechnic University – Molecular Diagnostic Laboratory in October 2020, the first university-based COVID-19 nucleic acid testing institution recognised by the HKSAR government. So far, the lab has conducted more than 36,000 virus tests for PolyU staff and students with a view to providing a safe environment for the community. They have also made use of genomics sequencing to analyse and track the virus' sources and transmission chains, and advanced AI technology to analyse medical images and clinical data of COVID-19 patients for more accurate diagnosis and effective treatment and management of patients. More details can be found in section 2.

As the only local institution involved in China's astronautical projects, PolyU has been extremely proud of its contributions to the nation's various space exploration missions. These started with the Chang'e-3, Chang'e-4 and Chang'e-5 lunar exploration missions in 2013, 2019 and 2020 respectively, and continued with the Tianwen-1 Mars exploration project in 2020. For this, the University developed the camera pointing system, the planetary remote sensing technology and the surface sampling and packing system. In a series of public lectures delivered by distinguished Chinese astronautical scientists in June 2021, PolyU's contributions to the nation's lunar and Mars explorations were highly appreciated. An exhibition organised in Hong Kong in June 2021 of lunar soil collected by PolyU's samplers inspired young people's interest in space exploration and education. The establishment of the University Research Centre for Deep Space Explorations, aiming to pool together experts in such fields as Geology, Architecture, Machinery, Physics, and Remote Sensing, is a clear demonstration of PolyU's strengths and its commitment to advancing the aerospace technology of the nation.

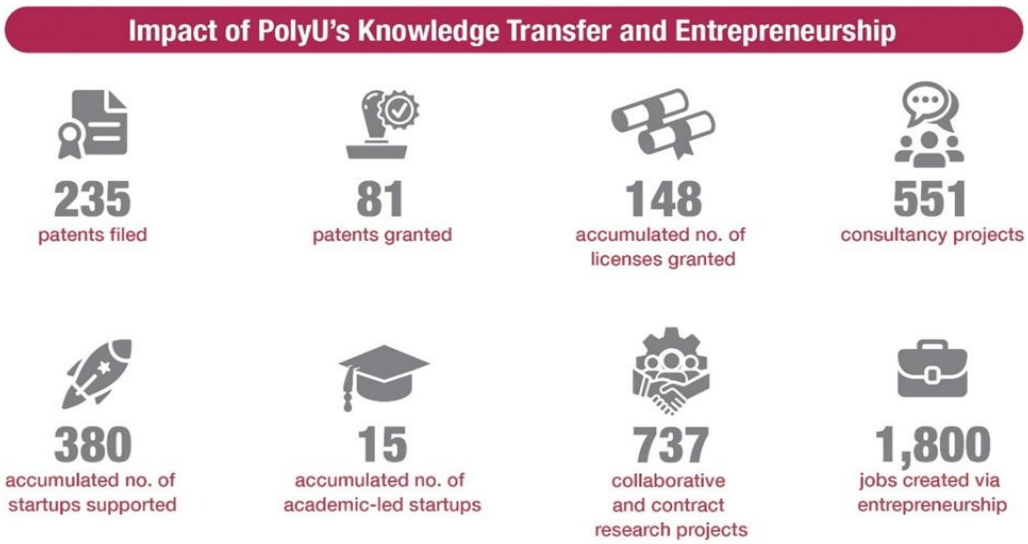
Furthermore, the Defocus Incorporated Multiple Segment (DIMS) spectacle lens jointly developed with HOYA Corporation prevents children from permanent blindness caused by high myopia. After winning the Grand Prize of the International Exhibition of Inventions of Geneva, the DIMS lens was introduced to Chinese Mainland and European markets to maximise its impact on society. PolyU's Smart Tree Monitoring System is an innovative technology for smart cities which detects tree instability to enhance urban resilience. Smart sensors have been installed on 8,000 urban trees to prevent hazards arising from falling trees. Additionally, the University has continued to strengthen its capacity in research, and established a number of research institutes and university research centres to encourage mission-driven interdisciplinary research. The University's strengths and achievements in research were also reflected in the high ratings attained in the Research Assessment Exercise (RAE) 2020. Details of the high impact cases are provided in section 2.

To continue to nurture innovation and technology talents and startup companies in Hong Kong and the GBA, the University revamped its funding programmes to further advance technological and social innovations through entrepreneurship. A pioneer GBA startup postdoc programme was successfully launched, while other programmes including the proof-of-concept programme (POC) and the 10-week technology-market validation programmes were enhanced. Cumulatively, the University has nurtured a total of 210 social/design/business innovation startups and 170 technology startups, 15 of which are academic-led startups as of June 2021 under a

more flexible and holistic PolyU framework. The details of the University's entrepreneurial pursuits are reported in section 3.

PolyU strives to advance societal impact through a community partnership model. The model of integrating education, research and KT is practised in its Optometry Clinic, Rehabilitation Clinic, Institute of Active Ageing, Jockey Club Design Institute for Social Innovation and Jockey Club Smart Ageing Hub, to name just a few. The social innovation programme, Good Seed, has trained more than 2,000 social innovators since 2015. Further details of PolyU's achievements in social innovations are provided in section 4.

With recurrent funding support from the UGC and the concerted efforts of members of the University community, PolyU's achievements in KT and entrepreneurship are summarised as follows:



2. Driving Research Excellence to Technological and Social Innovations for Impact

Embracing the overarching philosophy that all IPs of practical value should leave campus to create societal impact, PolyU is committed to transforming research excellence into impactful technological and social innovations through mission-driven, interdisciplinary and cross-institutional collaborations. The University has been strengthening KT across disciplines, and bringing together its various areas of strength in research to generate new technologies and knowledge to address social challenges.

Determined and augmented efforts to combat COVID-19

The COVID-19 pandemic has posed unprecedented challenges to every aspect of our lives. The University has been working towards an effective solution to the consequences of the pandemic for public health and sustainable global development.

In recognition of its efforts, PolyU secured $18.2M from the Health and Medical Research Fund of the Food and Health Bureau in August 2020 to conduct eight studies on COVID-19. These projects covered a wide range of disciplines including health technology, biomedical sciences, healthcare, rehabilitation, and social sciences. The University anticipates that research teams from different fields can contribute their expertise to supporting the local community in the fight against COVID-19 and facilitating the formulation of pandemic control measures, thereby protecting public health.

Recognised COVID-19 nucleic acid testing institution at PolyU

In response to the pressing need to restore a safe environment during the COVID-19 pandemic, PolyU initiated the project 'Surveillance of Asymptomatic Population for COVID-19 and Evaluation of Automatic Multiplex

(The Project Coordinator Dr Amber CHIOU (left); CEO of HKSTP Mr Albert WONG (middle); and Director of The Hong Kong Polytechnic University – Molecular Diagnostic Laboratory Dr Cesar WONG (right))

Diagnostic Platform in Hong Kong', and set up the Hong Kong Polytechnic University – Molecular Diagnostic Laboratory to conduct virus tests for COVID-19 within the University community. From October 2020 until June 2021, around 36,000 samples were tested from PolyU staff and students, and students undertaking internships at Hotel ICON and practicums in public hospitals.

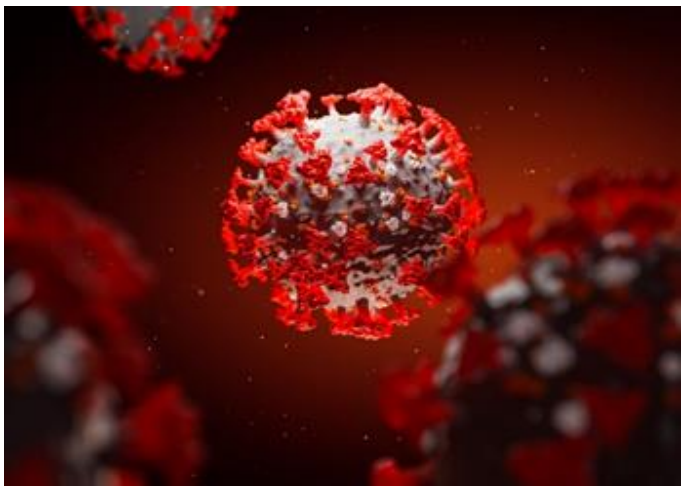
Eight months after its inception, the lab received the ISO15189 Certificate of Accreditation under The Hong Kong Laboratory Accreditation Scheme in late May 2021. Subsequently, the lab became the first university-based COVID-19 nucleic acid testing institution recognised by the HKSAR government in late July 2021.

AI-empowered chest X-ray and CT quantitative analysis for COVID-19 patient management

Led by Professor CAI Jing of the PolyU's Department of Health Technology and Informatics (HTI), this cross-sectoral project aims to develop multiple AI-empowered techniques for enhancing and quantitatively analysing chest X-ray and CT images for more effective COVID-19 diagnosis and patient management. Medical imaging and clinical data of COVID-19 patients are collected and split into training, validation, and testing cohorts. The training and validation cohorts are used to develop multiple AI techniques for further analysis, while the testing cohort is used to evaluate the techniques developed in multiple COVID-19 clinical applications. Through this multi-dimensional analysis, more informed clinical decisions will be made.

Use of genomics to find sources and transmission chains of COVID-19

Since the first wave of COVID-19 in early 2020, Dr Gilman SIU and his team from HTI have been using whole-genome sequencing to analyse the strains or variants of SARS-CoV-2 of locally acquired cases to determine their genomic and phylogenomic characteristics (or the evolutionary characteristics of the genomes). A phylogenomic database connected to a geographic information system (GIS) reveals the transmission linkage of the cases, and characterises the clinical and functional impact of genetic variants of SARS-Co-V-2 through structure-based mechanistic studies. By comparing their genomic analyses with clinical and epidemiological case data, the likely sources and transmission chains of the strains will be located. Further details of this impact case are provided in Appendix 3.



(Dr. Gilman SIU Kit Hang and his research team members)

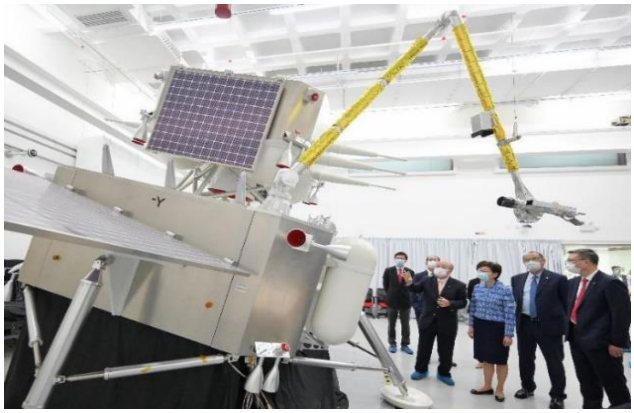
Deep space research contributing to national space missions

PolyU takes pride in improving the world through knowledge and technology transfer. The University's researchers eagerly transform innovations and research breakthroughs into authentic industry solutions and social innovations. Leveraging on its academic strength, research expertise and global network, PolyU takes its ideas and inventions from laboratory to life.

As the only local tertiary institution that possesses national space qualification experience, PolyU has been deeply involved in China's lunar and Mars missions. The University's researchers helped identify safe landing sites with high scientific value through innovative topographic mapping and geomorphological analysis. They also designed and manufactured space instruments that could withstand harsh conditions in space, underscoring PolyU's strength in cutting-edge precision engineering technology.

> *"PolyU is the only Hong Kong institution involved in China's astronautical projects with wide ranging and in-depth collaboration, and has made significant contributions to our country's lunar and Mars explorations."*
>
> **QI Faren**
> Chinese Academy of Engineering academician and the first chief designer of the Shenzhou spacecrafts

In addition, the University developed and manufactured the 'Surface Sampling and Packing System', specifically designed for Chang'e 5, the Nation's first lunar sample return mission. Chang'e 5, the third phase of the Nation's lunar exploration project, is China's first space mission to collect and return two-kilogram samples of lunar regolith. Transported on the Chang'e 5 lander, the PolyU-developed Surface Sampling and Packing System includes two samplers that can withstand 200°C for collecting samples of lunar regolith in loose and sticky form, two heat-resistant nearfield cameras for vision guidance during sample acquisition, and a packaging and sealing system for sealing the samples in a container.



(The Chief Executive of HKSAR, Mrs Carrie LAM visited the PolyU's Research Centre for Deep Space Explorations on 23 July 2021.)

(Mrs Carrie LAM (second left), holding the container developed by PolyU that sealed and stored the lunar samples from the moon in the nation's lunar exploration

Camera pointing system for lunar and Mars exploration

PolyU's research on systems engineering technology assisted the China National Space Administration with its Chang'e-3 mission in 2013 and Chang'e-4 mission in 2019, through the design and construction of a camera pointing system (CPS) installed atop the lunar landers. The CPS assisted in the tracking of the rovers and the capturing of panoramic views, which were required for building a model to plan the rovers' progression. PolyU's contributions have been acknowledged by Chinese national space agencies, leading to further collaboration with the China Academy of Space Technology in its Tianwen-1 mission, the nation's first Mars exploration project in 2020. More details are presented in Appendix 3.

Planetary remote sensing to support space exploration missions

An integrated 3D mapping model has been developed by Professor WU Bo of the Department of Land Surveying and Geo-Informatics for high-precision and high-resolution topographic mapping of the Moon and Mars, surpassing all existing technology such as photogrammetry or laser altimetry. Novel artificial intelligence (AI) approaches have also been developed for more automated and robust analysis of geomorphological features on planetary surfaces.

This helps optimise landing site evaluation, change descent orbit design, and improve surface operation of the national various space exploration missions. Further details can be found in Appendix 3.

In June 2021, a delegation of distinguished Chinese astronautical scientists who spearhead China's key space programmes from manned missions to lunar and Mars explorations visited PolyU, and delivered three public lectures on their extraordinary experience of the various space missions. During the visit, PolyU's significant contributions to the lunar and Mars explorations were acclaimed. PolyU's academics and researchers were also encouraged to participate even more in China's space projects and contribute to the nation's endeavours to become a space power.

(Ms ZHANG He, executive director of the Chang'e-4 lunar probe project, talked about China's lunar exploration programme.)

Following the visit of first class Chinese astronautical scientists and the exhibition of lunar soil in Hong Kong, which aroused many youngsters' interest in space exploration, PolyU plans to launch the 'Science World: Exploring Space to Benefit Mankind' education programme in the 2021-2022 academic year to introduce space sciences and technologies to local secondary school students. The programme aims to cultivate the interest of local youth in space science and unleash their enthusiasm to participate in the development of space technology.

Ground-breaking spectacle lens slows myopia progression in children

By 2050, half of the world's population will be myopic, while about one billion people will suffer from high myopia[1], which is the second eye condition causing permanent blindness and visual impairment in Asia. In collaboration with HOYA Corporation, a research team of the PolyU School of Optometry has invented the Defocus Incorporated Multiple Segments (DIMS) Spectacle Lens to slow down myopic progression in children. This invention is particularly meaningful for those children who would otherwise develop high myopia, who have an additional risk of developing complications such as retinal detachment and glaucoma.

(Award-winning DIMS Spectacle Lens to control myopia progression)

The DIMS Spectacle Lens comprises a central optical zone for correcting refractive error and multi-segments of constant myopic defocus surrounding the central zone and extending to mid-periphery of the lens. It provides clear vision and myopic defocus for vision correction simultaneously for the wearer at all viewing distances. This invention may be a viable option as the first line treatment for myopia control, preventing over 90% of the population from developing high myopia. The technology and patent rights of DIMS are co-owned by PolyU and HOYA Corporation.

Smart city tree monitoring system for enhancing urban resilience

Professor Charles WONG of the Department of Land Surveying and Geo-Informatics has developed the Smart Tree Monitoring System, the first of its kind to conduct large-scale monitoring of urban trees to prevent hazards arising from the tilting of trees, which can pose a danger to the public. The system was designed and structured with AI, smart sensing technology and GIS to monitor tree tilt. With tailor-made remote sensors installed on the lower trunk of urban trees, their tilt angles and sway trajectories can be monitored. The locations

(Smart tree monitoring device installed on urban trees)

[1] Holden BA, Fricke TR, Wilson DA, et al. Global prevalence of myopia and high myopia and temporal trends from 2000 through 2050. *Ophthalmology* 2016;123:1036–42.

of trees and data about their surrounding environment can also be identified for quantifiable analysis of tree root plate movement.

With funding support of $32.28M from the Hong Kong Jockey Club Charities Trust, the first stage of the Smart City Tree Management Project commenced in February 2018, with tailor-made sensors installed on the lower trunk of approximately 400 trees in Kowloon East, Wan Chai and Yuen Long Tai Tong. In the second stage of the project, the smart sensors were installed on 8,000 urban trees in Hong Kong, allowing timely and appropriate mitigation measures to be taken, and enhancing urban resilience and the living environment for the community in the long run. The Smart Tree Monitoring System will also be extended to the GBA. Further details of this impact case are provided in Appendix 3.

(Kick-off ceremony of the Jockey Club Smart City Tree Management Project)

Upholding HK's leading position in aviation services and technologies

The Aviation Services Research Centre (ASRC), jointly established by PolyU and Boeing in 2012 and joined by local aviation companies, has been consolidating Hong Kong's leading position as a world-class service provider of aircraft maintenance repair and overhaul (MRO), and steering the development of aviation-related industries in Hong Kong and Southern China. One of its key projects completed in FY2020/21 was 'Non-destructive Inspection of Fuel Tank Fasteners', with funding support from the Innovation and Technology Commission. This project involved the development of a series of technologies to improve the task of inspecting the inside of aircraft fuel tanks to detect nearly invisible cracks. With the advent of state-of-the-art technologies in the manufacturing of aircraft and engines, ASRC, the first of its kind in Hong Kong, has been expanding the capabilities of the industry, and providing the younger generation with exceptional training in aircraft engineering and maintenance.

(ASRC and team)

Strategic establishment of Research Institutes and University Research Centres

Harnessing the University's research capability and world-class scholars, the PolyU Academy for Interdisciplinary Research (PAIR) was established as a hub and catalyst for both basic and translational research. PAIR hosts a significant number of mission-driven interdisciplinary research institutes focusing on high-impact areas to address key societal challenges. As of June 2021, ten Research Institutes and one University Research Centre have been set up under PAIR:

- Smart Cities Research Institute
- Research Institute for Sustainable Urban Development
- Research Institute for Artificial Intelligence of Things
- Research Institute for Land and Space
- Research Institute for Smart Ageing
- Photonics Research Institute
- Research Institute for Smart Energy
- Research Institute for Advanced Manufacturing
- Research Institute for Future Food
- Research Institute for Intelligent Wearable Systems
- Research Centre for Deep Space Explorations

PolyU's research excellence as reflected in high ratings in Research Assessment Exercise 2020

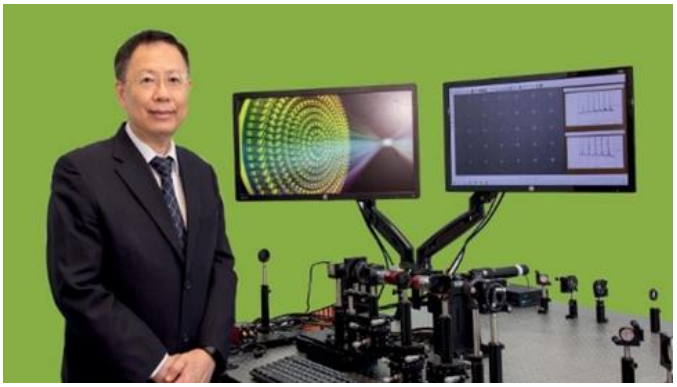
In recognition of its dedicated efforts in pursuing research excellence over the years, the University received high ratings in various areas of assessment in the Research Assessment Exercise (RAE) 2020. Of the eleven panels in which PolyU was rated as 'world-leading' (4-star) and 'internationally excellent' (3-star), the University's performance in **Physical Sciences** was the best among all UGC-funded institutions. Additionally, all of PolyU's

research impact case studies and research environment submissions in **Creative Arts, Performing Arts & Design** received 4-star ratings, which was the best performance in this area among the eight UGC-funded institutions.

Among the 20 units of assessment as defined in RAE, PolyU received outstanding ratings with the highest percentage of 4-star and 3-star ratings for **Materials Science and Materials Technology**, **Computer Studies/Science**, and **Hotel Management and Tourism**. PolyU also performed well in the units of assessment for Mechanical Engineering, Production Engineering (including Manufacturing & Industrial Engineering), Textile Technology and Aerospace Engineering, as well as Civil Engineering (including Construction Engineering & Management) and Building Technology. For Optometry, Rehabilitation Sciences and other health care professions, PolyU also showed marked improvements in research performance.

$65.6M to develop meta-optics, meta-acoustics and meta-devices

Professor TSAI Din-ping, Chair Professor of Nanophotonics and Head of Department of Electronic and Information Engineering[2], was awarded $65.6M from the Areas of Excellence Scheme 2020/21 (Ninth Round) of Research Grant Council (RGC) for his project '*Meta-optics, meta-acoustics and meta-devices*', which aims to develop novel meta-materials and meta-devices that can control and manipulate electromagnetic and acoustic waves for improving the quality of human daily life. These meta-devices are to be designed and manufactured for novel applications in such areas as imaging, sensing, energy, communications, biomedicine, industrial manufacturing, AI technology, and quantum technology.



(Professor TSAI showing the set-up of his AoE-funded project 'Meta-optics, meta-acoustics and meta-devices')

RGC's Research Impact Fund and Theme-based Research Scheme

Since FY2018/19, $107M has been awarded to 16 projects led by PolyU's researchers under the RGC's Research Impact Fund (RIF). The University's latest RIF project was 'wearable closed-loop neural control "remind-to-move" treatment for hemiparetic upper extremity in people with hemiplegia after stroke' led by Professor Kenneth FONG of the Department of Rehabilitation Sciences.

(Paired with an app, the second-generation wristwatch enables patients to follow videos selected by therapists to exercise their hemiparetic arms. The third-generation is in progress under the RIF project.)

In addition, three teams of eminent PolyU researchers joined forces with other local universities and secured $114M to conduct research projects funded by the RGC's Theme-based Research Scheme 2020/21, which aims to support collaborative research projects of strategic importance to HK's long-term development. The themes of the three awarded projects were 'promoting good health', 'developing a sustainable environment' and 'advancing emerging research and innovations important to Hong Kong' respectively.

3. Advancing Technological and Social Innovations through Entrepreneurship

PolyU has been enhancing funding, education and incubation programmes in partnership with industry and community stakeholders to support research- and student-led entrepreneurship.

Translating research into impact through research-led startups

Over the years, PolyU has embraced a culture of forging collaboration with industry and community partners to advance technologies and innovations for real-world impact, reflecting the spirit of its motto: To learn and to apply, for the benefit of mankind.

[2] Professor TSAI has left PolyU since Aug 2021.

GBA Startup Postdoc: transforming PhD into technopreneurs

The University piloted the GBA Startup Postdoc Programme in 2019 by leveraging support from both Shenzhen and Hong Kong. This specially designed programme supports recent PhD graduates in conducting translational research while pursuing technology entrepreneurship to turn their technologies into products/services, under both academic supervision and industry mentorship.

The six postdocs admitted under the pilot scheme in 2019 have established four startups in Shenzhen, won seven awards, and secured impressive funding/incubation support. The University has decided to scale up the programme since 2021 to support more postdocs in the coming years.

Technology and market validation of lab technology

Since 2018, PolyU pioneered a 10-week technology and market validation programme modelled after iCorps of US National Science Foundation and Lean LaunchPad Singapore, to guide research teams in searching for commercialisation pathways with one-on-one industry mentorship and intensive customer discovery exercises.

22 startups/licenses have been successfully created out of the 41 teams admitted to the programme, representing a 54% commercialisation rate. The reputation of the programme also attracted Southern University of Science & Technology in Shenzhen and National Cheng Kung University in Taiwan to the first-ever online market validation programme across the Greater China region in 2020.

PolyU Maker Fund: re-industrialising HK in GBA

With support from the Youth Development Fund of the Home Affairs Bureau, PolyU launched the first all-in-one hardware incubation programme, leveraging the University's strengths in engineering, design, and Industrial Centre infrastructures, and harnessing the unrivalled manufacturing capabilities of GBA.

Partnering with Hong Kong Science and Technology Parks (HKSTP), MIT Hong Kong Innovation Node, Federation of Hong Kong Industries (FHKI) and Shenzhen University, PolyU offered a two-year 'idea-to-product' incubation, including funding support and practical industry guidance and mentoring. The programme attracted over 400 young applicants as of early July 2021.

PolyU Entrepreneurship Investment Fund: nurturing winners

Early-stage investment for research-led startups is in short supply, with most private investors preferring quick wins. Given this scarcity of patient investors, the University established the Entrepreneurship Investment Fund (EIF) in FY2020/21 to complement other funding schemes. As part of the PolyU entrepreneurial ecosystem, EIF will leverage the resources and expertise of co-investors, partners and stakeholders to scale-up startups with great potential and transform PolyU's research and technological innovations into significant impact.

Nurturing future entrepreneurial leaders for HK, the nation and the globe

PolyU strives to advance social impact by creating a vibrant entrepreneurship ecosystem within and beyond the campus, nurturing entrepreneurial talents and supporting student-led startups to bring positive impact to the broader community. Since the launch of the first seed grant for entrepreneurship in 2012, PolyU has been enhancing its funding, education and incubation programmes in partnership with industry and community stakeholders to support academic- and student-led entrepreneurship, and nurture student mindsets on innovation and entrepreneurship.

Proof-of-Concept (POC) Fund: compete from strength to strength

In 2020/21, PolyU revamped the innovation project grant and turned it into a subsidy support scheme to prepare them to participate in local and overseas innovation and entrepreneurship competitions. 554 students in 106 teams benefited from the POC, and have won twelve awards as of June 2021. An online talent-matching platform, PolyU Innovator Exchange, was also established to facilitate competition/start-up team formation.

Entrepreneurship Society (ES): student innovators united

With about 600 current members, ES has organised a series of activities to stimulate students' interest in innovation and entrepreneurship since its establishment in 2015.

Despite the class suspension due to COVID-19, ES attracted 100+ new members in FY2020/21 through webinars and online competitions, such as the 'Student Start-up Award Secrets' webinar with the Alibaba Entrepreneurs Fund (AEF) and Cloud Career Pathways Competition 2020 in partnership with Amazon Web Service Educate. Around 170 students competed in the latter.

PolyU InnoHub: upscale and upgrade

The University completed the expansion of PolyU InnoHub, in both Hong Kong and Shenzhen, doubling the floor space at each site. PolyU InnoHub serves a co-creation and collaborative hub for PolyU community to promote communal innovation and entrepreneurship in the ecosystem.

More information about the PolyU InnoHub and entrepreneurship activities is provided in Appendix 4.

Outstanding PolyU entrepreneurs

Mr Richie CHEN, Founder of Hai Robotics, graduate of the Department of Electronic and Information Engineering, **'40 under 40' Fortune China in 2021**

Starting from his undergraduate research project at PolyU, Richie embarked on entrepreneurship in 2014 with PolyU seed fund and founded Hai Robotics in 2016. Hai Rotobics is now a leader in Autonomous Case-handling Robotic System ('ACR System') for logistics and industrial automation.

Mr Edwin WONG and Mr Leo SIU, Co-founders of CloudBreakr, graduates of the Faculty of Business, **'30 under 30 (Media, Marketing and Advertising)' Forbes 2021**

Edwin and Leo, both PolyU graduates, co-founded the AI-aid Key Opinion Leader (KOL) marketing platform with the PolyU seed grant in 2015. The platform has grown into a regional leader in the new media advertising platforms.

Professor LI Pei, Co-Founder of Grand Rise Technology, Professor of the Department of Applied Biology and Chemical Technology, **Recipient of Gold Medal in International Exhibition of Inventions of Geneva 2021**

Prof. LI co-founded Grand Rise with a PolyU DBA student Mr Tenny LAM to commercialise her life-long research on core-shell particles to develop CareCoatex™: a biocompatible, non-toxic and eco-friendly antibacterial and antiviral coating in 2019, with PolyU referred angel investment and matching grant.

Mr Nick ZENG, Founder of People Strong Technology, graduate of the School of Design, **'Under 30s To Watch 2020' list by Hurun China**

After graduating from the School of Design, Nick established his smart healthcare device startup back in 2014 in China with PolyU seed funding to productise a 'smart pillbox' design in his class project. The startup is currently carrying a wide range of IoT devices for elderly care communities all over the country.

Some examples of startups with good progress

PolyU students and researchers have been actively participating in different innovation and entrepreneurship related competitions locally and overseas with the University's funding and support.

In FY2020/21, Occupational Therapy students from PolyU grabbed five design awards in the **2020 Global Student Innovation Challenge** at the 14th International Convention on Rehabilitation Engineering and Assistive Technology (i-CREATe 2020). The design awards won by PolyU students include the prestigious Silver and Bronze awards.

The PolyU students and researchers also scooped eleven prizes, including a First Prize and a Second Prize in the Innovation Stream, and a Second Prize and three Third Prizes in the Entrepreneurship Stream, in the 7th Hong Kong University Students Innovation and Entrepreneurship Competition. A list of the awards won by the PolyU startups is shown in Appendix 5.

4. Social Innovations for the Benefit of the Community and the Globe

Sowing good seeds to groom social innovators

Jointly launched by the Jockey Club Design Institute for Social Innovation (JCDISI) and the Institute for Entrepreneurship (now renamed as Knowledge Transfer and Entrepreneurship Office, KTEO) in 2015, Good Seed is the first ever open-to-public social innovation training and funding programme supported by the Social Innovation and Entrepreneurship Development Fund (SIE Fund) of the HKSAR Government. Leveraging strong partnership support from NGOs and the entrepreneurial community, the programme has created 82 high quality social innovation projects from various sectors, and gained a good reputation in the community. It has also trained more than 2,000 social innovators, and provided innovative yet practical solutions to poverty among the underprivileged.

JCDISI: Strategic Public Policy Research Funding Scheme for the "Study on Effective Transitional Housing Delivery in Hong Kong"

Increasing transitional social housing provision by MiC technology

Since 2018, JCDISI has been actively supporting the transitional social housing provision in Hong Kong. One of its action projects, 'The Ma Wan Old Village Scheme', received the 2020 Silver Award from the Hong Kong Institute of Planners.

From 2019 to 2021, with funding from the Chinese National Engineering Research Centre (Hong Kong Branch), JCDISI led and completed an applied research project on 'Relocatable Housing by Modular Integrated Construction'. In May 2021, JCDISI received $3.15M under the RGC's Strategic Public Policy Research Funding Scheme for its study on effective transitional housing delivery in Hong Kong. It aims to make pragmatic recommendations to the government and NGOs for enhancing the city's capacity to deliver transitional housing using Modular Integrated Construction (MiC) technology.

Furniture prototypes for children residing in subdivided units

Residing in cramped housing may expose children to a complex chain of socio-environmental risks to which they are highly susceptible during their golden years of childhood. Another action project undertaken by JCDISI was 'Adaptive Design in Subdivided Unit: Co-designing Child-friendly Furniture' to mitigate the negative health impact on children living in subdivided units by developing furniture prototypes. With optometrists and chiropractors who evaluated the refractive error development and the change of position, the co-design process translated discipline-specific knowledge into implementable prototypes that were affordable, ergonomically fitting and adjustable to different types of cramped housing.

Service-learning projects for societal impact

PolyU was honoured to receive the 2020 International Research Award from the International Association for Research on Service-Learning and Community Engagement (IARSLCE) for its Service-Learning (SL) programme, which was recognised as 'one of the world's most impressive and impactful service-learning initiatives in higher education'. The award recognizes both "the impact of these programs on the lives and livelihoods of community partners" as well as the "scholarly contributions about multicultural and cross-cultural engagement [which] showcase the contributions of PolyU to the enhancement of international efforts in service-learning and community engagement."

SL has been a core part of PolyU's educational strategy since 2012. The objective is to develop students' social responsibility through serving the community using their classroom knowledge. Since then, PolyU has created a positive impact on the lives of many through SL subjects, ranging from installing solar electricity and water filtration systems, to performing eye examinations and teaching STEM for hundreds of children. The University has built up long-term SL collaboration with partners in more than ten countries and regions, including Cambodia, Hong Kong, Indonesia, Kazakhstan, Kyrgyzstan, Mainland China, Myanmar, Rwanda and Vietnam. As of June 2021, PolyU students have contributed more than 1,000,000 person-hours of service to underserved communities.

Fostering university social responsibilities and tackling global issues

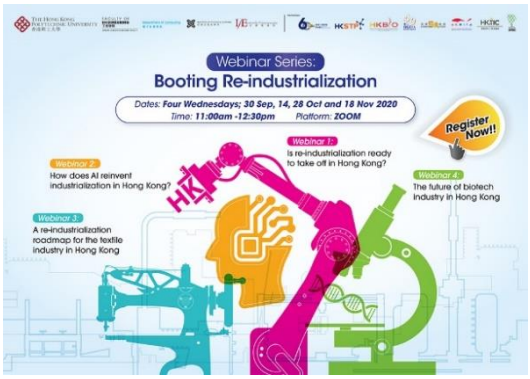
PolyU also championed the establishment of the University Social Responsibility Network (USRN) in 2015 with 15 other universities around the world, including Peking University, the University of Manchester and Washington University in St. Louis. As the secretariat of USRN, PolyU and the member universities advocate the increasingly important and broader role of universities in educating youth and delivering knowledge, as well as contributing to the betterment of society through the integration of social responsibility into institutional management, teaching, research, services and public activities.

Led by PolyU, USRN has become a vibrant platform for collaborations among and beyond member universities to promote global awareness of USR through different activities. Its flagship event, the International USR Summit, has been held biannually since 2012, the last summit being co-hosted virtually with the University of Pretoria in February 2021.

5. Engaging Industry and Community Partners in GBA and Local Community for KT and Impact

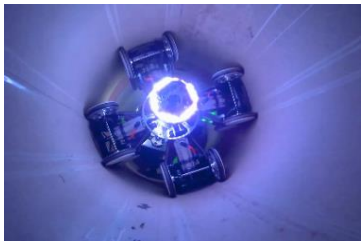
PolyU proactively reaches out to different communities and seeks to form an extensive network with industry partners to drive KT and entrepreneurship development, with a specific focus on forging synergy among different stakeholders for integrated communication.

Booting Re-industrialisation



PolyU partnered with eight industry associations including the Federation of Hong Kong Industries (FHKI), The Hong Kong Research Institute of Textiles and Apparel (HKRITA), Hong Kong General Chamber of Textiles, Hong Kong Young Industrialists Council, Hong Kong Electronic Industries Association to organise the 'Booting Re-industrialisation' webinar series from September to November 2020. It explored the development of high-end manufacturing based on new techniques and smart production and the role of government-industry-academia collaboration in re-industrialising Hong Kong. It also showcased the University's research excellence in the areas of AI, Big Data analytics, textile technology and biotechnology.

Strategic partnership with government departments



(Water pipe repair robot)

PolyU has partnered with various government departments, such as the Electrical and Mechanical Services Department, Transport Department and Lands Department. One example is a research team from PolyU's Department of Industrial and Systems Engineering, which has been engaged by the Water Supplies Department to study the viability of robotic in-line section of water mains. The in-line inspection robot will detect the presence of surface cracks and the general conditions of pipes and their linings using advanced technologies, including robotics, sensors, scanning and imaging as well as artificial intelligence. The use of robots to assess the condition of pipes will minimize labour intensive works in the working environment of confined spaces, reduce road opening works and thus reduce disturbances to traffic and the public, enhance site safety, as well as improve the quality and efficiency of in-line inspection works.

Introducing PolyU's expertise to GBA, the nation and the globe

PolyU has proactively engaged its partners in the GBA and overseas, such as Southern University of Science and Technology, Shenzhen University, and The Catalan Efficient Energy Cluster, to attract collaborators, institutions and investors to support research, KT and entrepreneurship of the University. More marketing, networking and engagement activities are presented in Appendix 6.

6. Closing and Forward Looking

Achieving world-class excellence for societal impact is central to PolyU's vision and mission. The future of the University's KT endeavours should not be limited to Hong Kong, but lie very much beyond Hong Kong's borders in the GBA, the entire nation, and around the globe. The University will further i) advance mission-driven interdisciplinary research, ii) engage industry and community partners to undertake strategic important research projects to address grand challenges of society, and iii) drive KT under the guiding principle that all PolyU's IPs of practical value should leave campus to create substantial societal impact. The University will also constantly review and enhance its policies on KT and entrepreneurship to seed and scale up technology- and research-based startups, in response to the innovation-driven development of the GBA and the nation.

To strengthen the undergraduate education to develop innovation and technology talents for Hong Kong, the GBA and the nation, the University will launch an enriched curriculum which embeds AI and Data Analytics as well as innovation and entrepreneurship as part of the curriculum to equip students with knowledge of the emerging technologies of the Fourth Industrial Revolution.

With a holistic and entrepreneurial support framework, the PolyU GBA Postdoc Programmes, the Maker Fund, and the enhanced Micro Fund 2.0 will continue to be important components in generating needed innovations to address industry and market needs in the year ahead. Riding on the success of the existing funding programmes and infrastructure, PolyU will adopt a proactive approach to develop long-term strategic and collaborative partnerships with industries and institutions to advance KT and entrepreneurship for societal impact.

PolyU is celebrating its 85th anniversary in 2022. While the University is planning a series of celebratory events to showcase PolyU's long and proud history of success in teaching, research, KT, industry partnership and community engagement, its past achievements also serve as propellant to members of the University to continuously dedicate their efforts to teaching and research excellence, and contribute to society and the nation at large, under the University Motto: 'To learn and to apply, for the benefit of mankind'.

Dr Miranda LOU
Executive Vice President

Appendix 1: Performance Measure – KPIs & Additional Measures

(a) Key KT Performance Indicators

A summary of the key performance indicators for various KT areas are presented in the table below, with figures expressed in HK$'000:

Performance Indicators	2019/20 Actual	2020/21 Actual
Patenting & Licensing		
No. of patents filed [Note 1]	129	235
No. of patents granted [Note 1]	79	81
Accumulative no. of licenses granted	134	148
Income generated from IPR [Note 2]	$2,641	$7,380
Expenditure involved in generating income from IPR	$7,934	$7,690
Consultancy, Collaborative / Contract Research & Spin-off / Joint Ventures		
No. of collaborative research, income generated and total contract value [Note 3]	420 $234,620 $761,121	439 $250,022 $880,145
No. of contract research, income generated and total contract value [Note 4]	326 $118,656 $461,440	298 $82,822 $441,569
No. of consultancy projects and income generated [Note 5]	705 $75,033	551 $63,298
No. of economically active spin-off companies [Notes 6]	236	277
Net income generated (or net loss arising) from spin-off companies [Notes 7]	$657	$1,160
Other Knowledge Transfer / Dissemination Activities		
No. of equipment and facility service agreements and income	178 $3,535	62 $1,596
No. of student contact hours for business or CPD needs [Notes 8,9]	1,373,767	1,395,790
Income received from CPD courses [Note 9]	$254,646	$389,340
No. of public lectures / symposiums / exhibitions and speeches to community	303	554
No. of performances and exhibitions of creative work by staff or students	33	35
No. of staff engaged as members of external advisory bodies	389	393

(b) Additional Performance Measurements

Performance Indicators	2019/20 Actual	2020/21 Actual
Innovation and Entrepreneurial Activities Enabling KT		
Accumulative no. of startups supported [Note 10]	332	380
Accumulative no. of academic involving startups [Note 11]	11	15
Accumulative no. of PolyU innovations / technologies / knowledge transferred through startups by students / alumni / staff [Note 12]	60	71
• No. of Entrepreneurship Fund applications [Note 13] • No. of students, alumni and staff involved [Note 14] • No. of new startups / entrepreneurial projects funded [Note 15]	231 554 44	326 1,001 56

Notes:

1. The reported figures include patent or patent applications co-owned by PolyU and external parties as well as patent or patent applications owned or co-owned by PolyU's subsidiaries. A detailed list of patents granted is presented in Appendix 2.
2. The reported figure includes license income generated from PolyU supported startups which licensed PolyU's IPs. This license income was also included in the "Net income generated (or net loss arising) from spin-off companies" (refer to Note 7 below).
3. Collaborative research income reported is on cash-receipt basis from on-going projects in the reporting period, with an aggregate project value of $880.1 million. As some of the internally funded projects also involved third parties as collaborators for KT purpose, the number of those projects was counted here but not the income nor project value.
4. Contract research projects are those involving third parties from public, private and NGO sectors. The income reported is on cash-receipt basis from on-going projects in the reporting period, with an aggregate value of $441.6 million.
5. The reported figure for FY2020/21 includes $9.5 million income from corporate and executive development training related consultancies and $53.8 million income from consultancy and advisory services, such as investigation, advisory on business, management, social, technical or policy related issue(s), as well as product, technology, materials or process enhancements.
6. The reported figure includes the number of all active startups that were either funded by PolyU funding programmes (including PolyU Micro Fund, China Entrepreneurship Fund, Tech Incubation Fund (TIF), Tech Launchpad Fund (TLF), Good Seed Programme), or obtained license from PolyU to commercialise the University's IPs. Subsidiaries set up as operating vehicles for specific functional purposes, e.g. PTeC, Hotel ICON and PolyU Base in Shenzhen are not included.
7. The reported figures represent the license income generated from PolyU supported startups which licensed PolyU's IPs. This license income was also included in the "Income generated from IPR" (refer to Note 2 above).
8. The student contact hours are defined to be the number of enrolments multiplied by the number of contact/course hours.
9. The CPD courses include award-bearing and credit-bearing programmes (both in and outside Hong Kong) for learners already in work who are undertaking the course for purposes of professional development / upskilling / workforce development, in addition to short term non-credit-bearing training programmes.
10. The reported figure includes all funded startups from Micro Fund, China Entrepreneurship Fund (CEF) Schemes, TIF, TLF and Good Seed programmes.
11. The reported figure includes all academic-led startups with licenses from PolyU for commercializing the University's IPs.
12. The reported figure includes all PolyU supported startups founded by students, alumni or academic staff licensed PolyU's IPs and/or commercializing PolyU's innovations (e.g. students' final year projects).
13. The reported figure includes all applications under Micro Fund, China Entrepreneurship Fund (CEF) Schemes, TIF, TLF and Good Seed schemes.
14. It also includes non-PolyU participants from the Good Seed Programme.
15. The reported figure includes all new startups under Micro Fund, China Entrepreneurship Fund (CEF) Schemes, TIF, TLF and Good Seed schemes. The actual number of funded startups in FY2020/21 was 61. Among them 5 were existing startups seeking for further funding from PolyU's other funding schemes. As such, the total number of new startups supported was 56.

Appendix 2: List of Patents Granted in FY2020/21

No.	Patent Title	Filing Country
1.	使用羧基修蝕的金納米顆粒的超靈敏閉管式比色環介導等溫擴增法	China
2.	實時檢測物體的多處結構變形或位移的方法與裝置	China
3.	一種水泥混凝土廢棄物的資源化回收再利用工藝	China
4.	可調節的漂浮裝置	China
5.	用於信號處理的方法及裝置	China
6.	A 型肉毒神經毒素底物型多肽抑制劑及其篩選方法	China
7.	紡織面料中水分吸收及傳輸的檢測方法和裝置	China
8.	有抗腫瘤活性的納米硒水溶膠及製備、保存方法和應用	China
9.	鞋內底組合件、底部部件、鞋類物品、組裝方法和套件	China
10.	用於產生負剛度的電磁設備和振動控制的方法	China
11.	光致發光納米粒子及其合成和應用	China
12.	用於拋光的多射流工具及包括該工具的拋光系統	China
13.	一種基於超彈性形狀記憶合金的自復位連梁	China
14.	一種原位合成雙相磷酸鈣納米複合材料塗層的方法	China
15.	一種光纖布拉格光柵角度感測器	China
16.	納微結構件快速成型裝置及快速成型方法	China
17.	自由曲面型二元光學元件及其設計、製作方法及自由曲面型二元光學投影系統	China
18.	一種基於光纖超聲導波技術的鐵軌裂紋監測系統	China
19.	一種多尺度混合視力障礙分析儀及其分析方法	China
20.	發電布的製造方法	China
21.	利用聲學黑洞特徵的寬頻帶振動抑制裝置	China
22.	可飽和吸收體製備方法、可飽和吸收體及光纖激光器	China
23.	一種光學玻璃模壓溫度在線檢測方法以及裝置	China
24.	一種光場顯微圖像的自動校正和重新聚焦方法	China
25.	極化碼的編解碼方法及其裝置	China
26.	一種供改善青少年特發性脊柱側凸的矯形墊	China
27.	嵌入式金屬網柔性透明電極及其製備方法	China
28.	一種蛋白質纖維非水介質的染色方法	China
29.	自復位黏滯複合阻尼器	China
30.	一種智慧三維動態織物拉伸-壓力測試裝置及測試方法	China
31.	一種適用於軌道檢測的影像分析系統和裝置	China
32.	磁懸浮控制系統	China
33.	一種低頻且頻率可調的浮子式波浪發電裝置	China
34.	一種負泊松比經編針織物的製作方法	China
35.	物聯網設備的委託授權方法、伺服器、終端機物聯網設備	China
36.	一種移動機械臂系統及圍捕控制方法	China
37.	一種單連杆柔性機械臂在線自我適應近優控制方法	China
38.	冗餘度機械臂的可操作度優化的運動規劃方法和裝置	China
39.	多固定基座冗餘度機械臂的任務動態追蹤方法和裝置	China
40.	一種短時交通流量預測方法及裝置	China
41.	仿生蜘蛛絲聚氨基酸生物彈性體材料及其製備方法	China
42.	針對待加工表面結構的變角度切削方法	China

No.	Patent Title	Filing Country
43.	一種提高閃存固態盤壽命的方法及高壽命閃存體固態盤	China
44.	C 類 β-內醯胺酶抑制劑及其製備方法和應用	China
45.	喹啉類二聚體製備方法及用途	China
46.	一種網路狀態的測試方法、測試裝置及終端設備	China
47.	一種集成灰度值、空間資訊和類別知識的變化檢測方法	China
48.	非均勻鋰離子電池負極片及鋰離子電池	China
49.	用於檢測丁醯膽鹼酯酶的螢光探針及其應用	China
50.	一種點雲濾波方法及設備	China
51.	一種區域吸引力評估方法及設備	China
52.	一種地物變化的檢測方法、檢測系統及終端	China
53.	一種超精密加工技術製備梯度納米結構金屬材料的方法	China
54.	一種室內建模方法、裝置及終端設備	China
55.	高清深度資訊獲取系統、系統製備方法及系統測距方法	China
56.	一種基於深度學習的單類目標檢測方法、設備及存儲介質	China
57.	一種人體建模方法、裝置及電子設備	China
58.	A METHOD AND/OR SYSTEM FOR RECONSTRUCTING FROM IMAGES A PERSONALIZED 3D HUMAN BODY MODEL AND THEREOF	United States of America
59.	改進的被動減振設備	China
60.	IMPROVED PASSIVE VIBRATION REDUCING APPARATUS	Hong Kong
61.	鋼平臺和豎井孔壁固定式挖掘設備	China
62.	SHAFT-MOUNTED ROBOTIC-DUG EXCAVATOR	Hong Kong
63.	REUSABLE FACE MASK	Hong Kong
64.	REUSABLE FACE MASK	Hong Kong
65.	HUMAN-COMPUTER INTERACTIVE LEARNING SYSTEM FOR TRAINING DATABASE DEVELOPMENT AND VISION-BASED CONSTRUCTION MONITORING	Hong Kong
66.	METHOD FOR DEVELOPING SYNTHETIC IMAGE DATASETS FOR VISIONBASED CONSTRUCTION SITE MONITORING	Hong Kong
67.	METHODS AND CATALYSTS FOR GREEN BIODIESEL PRODUCTION FROM UNREFINED LOW GRADE FEEDSTOCK	Malaysia
68.	METHODS AND VIEWING SYSTEMS FOR INHIBITING OCULAR REFRACTIVE DISORDERS FROM PROGRESSING	United States of America
69.	PRODRUG OF GREEN TEA EPIGALLOCATECHIN-3-GALLATE (PRO-EGCG) FOR USE IN THE TREATMENT OF ENDOMETRIOSIS	United States of America
70.	IONIC TAGS FOR SYNTHESIS OF OLIGORIBONUCLEOTIDES	United States of America
71.	SPECTACLE LENS	United States of America
72.	MULTI-LEVEL-ARCHITECTURE MULTIFIBER COMPOSITE YARN	United States of America
73.	APPARATUS AND METHOD FOR IMPARTING FALSE TWIST TO A YARN	United States of America
74.	RESONATOR FOR FORCE DETECTION	United States of America
75.	SEGMENTING ULTRASOUND IMAGES	United States of America

No.	Patent Title	Filing Country
76.	CESIUM TUNGSTEN BRONZE-BASED SELF-CLEANING NANO HEAT-INSULATION COATING MATERIAL AND PREPARATION METHOD THEREOF	United States of America
77.	A NOVEL HIGH-FIDELITY AND REAL-TIME 3D FETAL ULTRASOUND VISUALIZATION SYSTEM	United States of America
78.	METALLIC SODIUM AND SODIUM-TIN BINARY ALLOY ELECTRODE	United States of America
79.	食用油分析方法、識別系統、產生庫的方法及數據載體	Taiwan
80.	IMPROVED OIL ANALYSIS SYSTEM AND METHOD	United States of America
81.	SYSTEM FOR RETARDING PROGRESSION OF MYOPIA	European Procedure (Patents)

Appendix 3: Details of Selected Impact Cases

Case 1: Whole-genome sequencing of COVID-19 cases in Hong Kong

1. Summary of the Impact

The Coronavirus Disease 2019 (COVID-19) pandemic caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) is the most devastating emerging infectious disease in the 21st century. The rapid sequencing technique developed by Dr. Gilman SIU Kit Hang, Associate Professor of PolyU's Department of Health Technology and Informatics has played an important role in identifying and stopping transmission chains of COVID-19 in Hong Kong. His work has provided scientific support for the Government's anti-pandemic measures [Fig. 1].

Identifying transmission chains

During the first wave of COVID-19, Dr SIU used whole viral genome sequencing to identify the source patient of the Buddha worship hall super-spreader event. His work, which was published in the journal ***Emerging Infectious Diseases***, demonstrated for the first time that an asymptomatic carrier of SARS-CoV-2 could be the source of a community outbreak. It highlighted the importance of testing all close contacts of a COVID-19 case, regardless of whether they had symptoms.

In April 2021, Dr SIU used phylogenomic analysis to identify the transmission link between Filipino domestic helpers and an Indian businessman who had travelled from Dubai and tested positive for a variant of concern. His work enabled the Centre for Health Protection (CHP), under the Department of Health, HKSAR Government, to trace the entire transmission chain and their close contacts, preventing the further spread of this variant in the community. The study has been accepted by the Journal ***Lancet Regional Health – Western Pacific***.

Later in June 2021, Dr SIU's research team uncovered the first local case of the Delta variant and showed the case was likely infected by inbound travellers from Indonesia. The team reported its sequencing analysis to CHP, enabling it to identify the source of infection.

Closing loopholes

In the summer of 2020, Dr SIU identified a new SARS-CoV-2 lineage in multiple local cases with a viral genome identical to that found in aircrew and sailors, who were exempt from compulsory quarantine. The Government subsequently suspended the practice of allowing unrestricted crew changes in Hong Kong.

During Hong Kong's fourth wave of COVID-19, Dr SIU's research showed that locally acquired cases were phylogenetically more closely related to cases imported from Nepal in September and October 2020. His findings, which were published in ***Emerging Microbes & Infections***, highlighted flaws in hotel quarantine arrangements, under which travellers could still receive visitors. The Government later adopted the policy that inbound travellers should be quarantined at designated hotels and not be allowed visitors.

Investigating hospital outbreaks

In December 2020, the United Christian Hospital experienced a large outbreak of SARS-CoV-2 in a palliative care and medicine ward. Later in January 2021, two healthcare workers from North District Hospital tested positive after taking care of COVID-19 patients. In both cases, Dr SIU conducted genome analysis, enabling the hospitals to trace the transmission chain and prevent further cases. The findings of the two studies were published in ***Clinical Infectious Diseases*** and the ***Journal of Hospital Infection*** respectively.

2. Underpinning Research

During the outbreak of COVID-19, Dr Gilman SIU Kit Hang in Department of Health Technology and Informatics of PolyU developed a new nanopore sequencing-based platform for rapid and accurate monitoring of COVID-19 transmission in Hong Kong. Using this new method, the whole genome of SARS-CoV-2 can be accurately detected ***within 8 hours*** which is much shorter than when using the conventional sequencing methods (72 hours). The genetic relatedness among the COVID-19 cases was determined by phylogenomic analysis. Under the first wave of community outbreak in January – February 2020, it was the first time for Dr. SIU's team to validate that their study was able to unveil the hidden transmission linkages among the cases even in the absence of apparent epidemiological linkage [Fig.2].

Furthermore, Dr. SIU integrated the viral genomic data with the patients' epidemiological and geospatial information to conduct phylogeographic analysis [Fig.3]. The new analysis method provided simultaneous access to phylogenetic data of COVID-19 cases with time stamps and dynamic displays of their closeness in the Hong Kong map view, which helped to visualize the transmission chain of the virus in our community. The method successful identified the transmission chain of a new variant of SARS-CoV-2 with S-T470N mutation circulating in East Kowloon District in December 2020, which eventually led to nosocomial outbreak in United Christian Hospital [Fig.4]. The method also helped to identify the transmission link between Filipino domestic helpers and an Indian businessman who had travelled from Dubai and tested positive for SARS-CoV-2 VOC Beta [Fig.5].

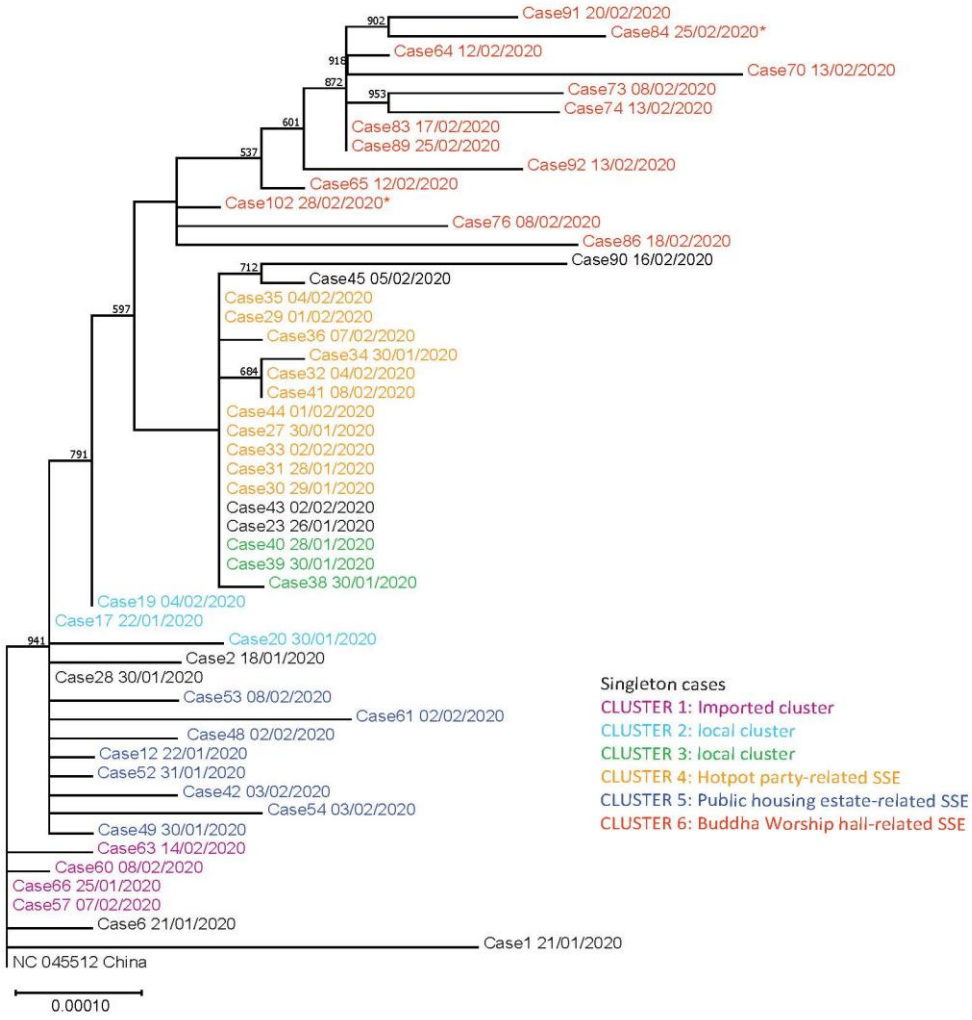


Fig.2: Phylogenetic analysis to unveil the genetic relatedness of COVID-19 cases reported during the first wave of COVID-19 outbreak in Hong Kong

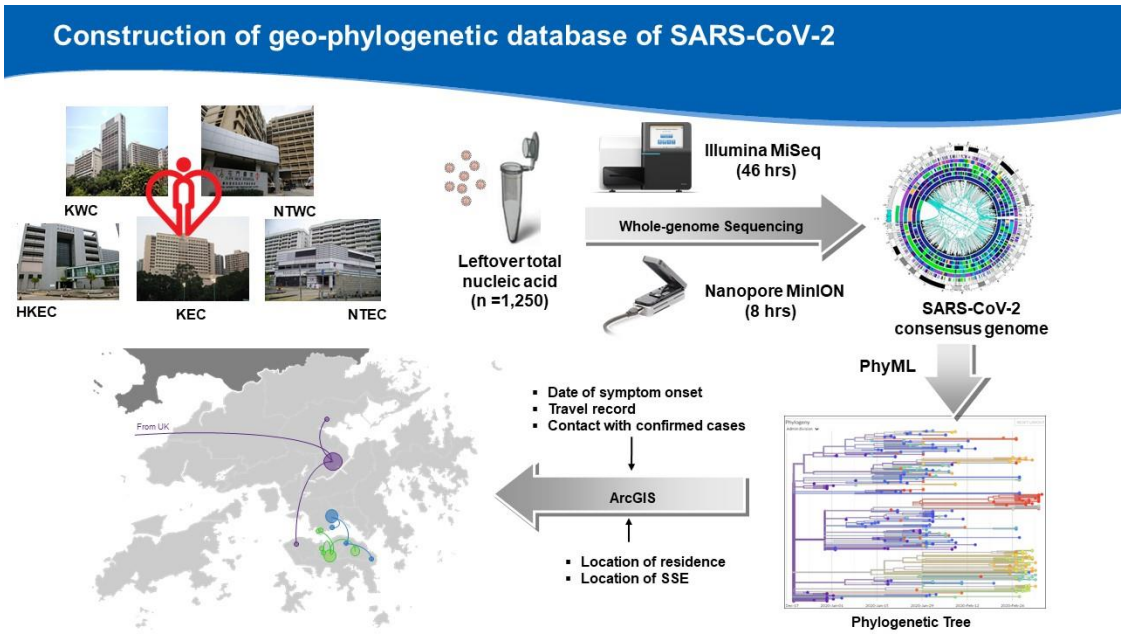


Fig.3: The study design of Dr. SIU's phylogeographic analysis of SARS-CoV-2.

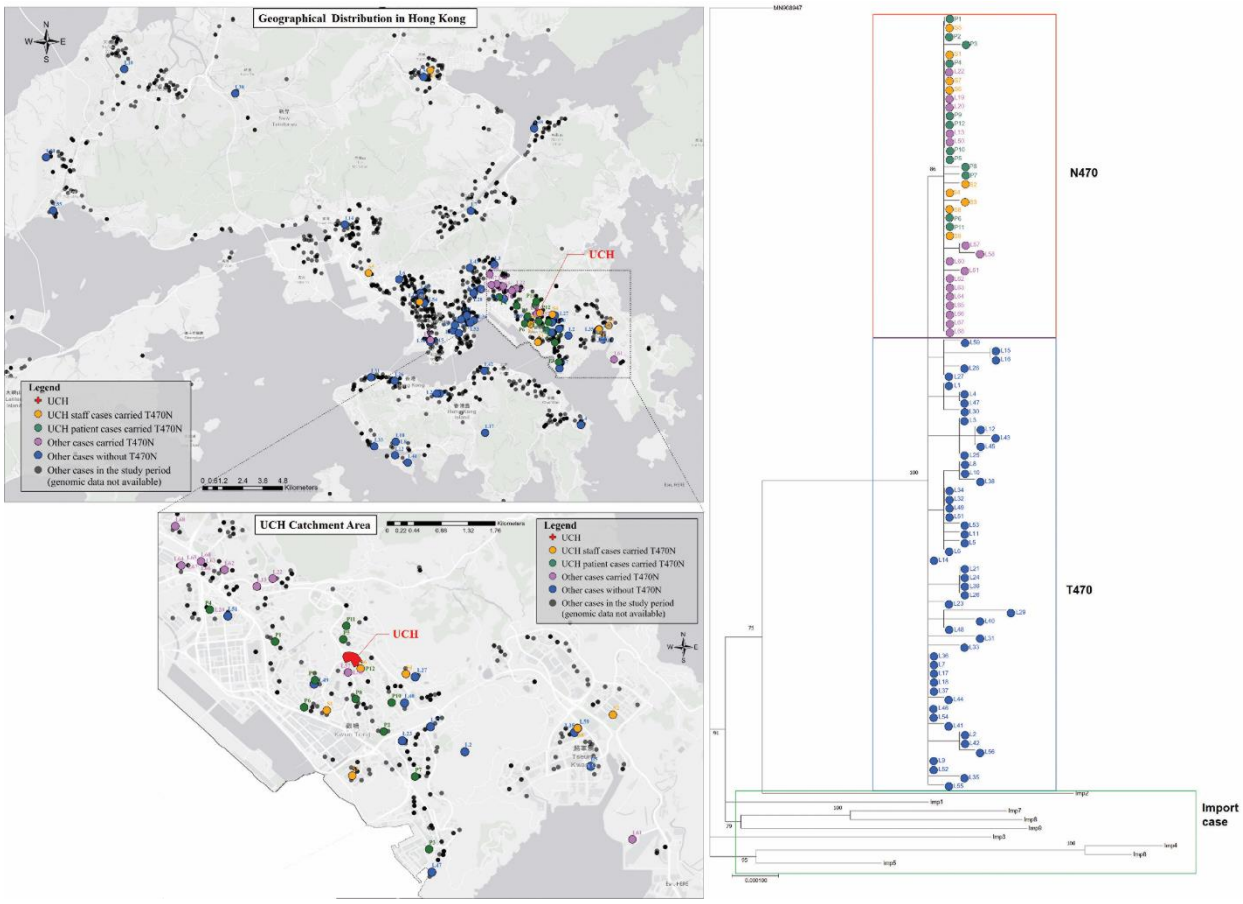


Fig.4: Identification of the transmission chain of a new SARS-CoV-2 variant with S-T470N mutation in Kowloon East District by phylogeographic analysis.

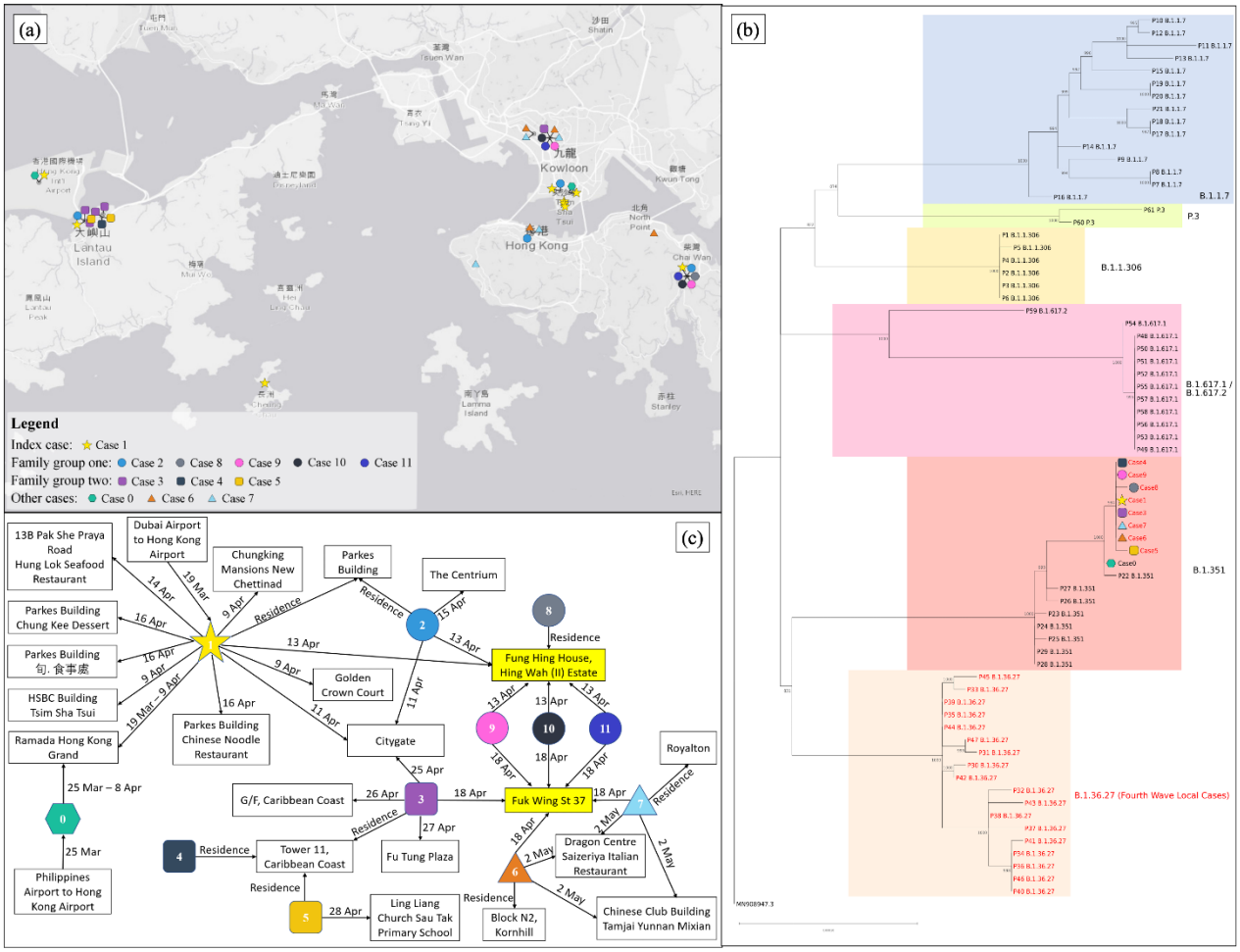


Fig.5: Phylogeographic analysis of the genomic and spatial relationship among the patients with SARS-CoV-2 VOC B.1.351 in Hong Kong.

3. References to Research

Related Research Grant:

2020 **HMRF Commissioned Research on the COVID-19 HK$2,998,100**
Genome sequencing of COVID-19 cases in Hong Kong: Development of a geo-phylogenetic database and characterisation of SARS-CoV-2 variants circulating in the community

2020 **ITF- Public Sector Trial Scheme HK$1,800,000**
Development of nanopore sequencing-based platform for rapid monitoring of COVID-19 transmission in Hong Kong

Research Output:

1. Cheng VCC, **Siu GKH (Co-first author)**, Wong SC, Au AKW, Ng CSF, Chen H, Xin L, Lee LK, Leung JSL, Lu KK, Lo HWH, Wong EYK, Luk S, Lam BHS, To WK, Lee RA, Lung DC, Kwan MYW, Tse H, Chuang SK, To KKW, Yuen KY. Complementation of contact tracing by mass testing for successful containment of beta COVID-19 variant (SARS-CoV-2 VOC B.1.351) epidemic in Hong Kong. ***Lancet Reg Health West Pac***. 2021 (in press)

2. Wong RCW, Lee MK, **Siu GK**, Lee LK, Leung JSL, Leung ECM, Ho YLL, Lai RWM. Healthcare workers acquired COVID-19 disease from patients? An investigation by phylogenomics. ***J Hosp Infect***. 2021;S0195-6701(21) (IF 2020: 3.271)

3. Cheng VCC, Fung KSC, **Siu GKH (Co-first author)**, Wong SC, Cheng LSK, Wong MS, Lee LK, Chan WM, Chau KY, Leung JSL, Chu AWH, Chan WS, Lu KK, Tam KKG, Ip JD, Leung KSS, Lung DC, Tse H, To KKW, Yuen KY. Nosocomial outbreak of COVID-19 by possible airborne transmission leading to a superspreading event. ***Clin Infect Dis.*** 2021 (In press) (IF 2020= 8.31)

4. **Siu GK (First and corresponding author)**, Lee LK, Leung KS, Leung JS, Ng TT, Chan CT, Tam KK, Lao HY, Wu AK, Yau MC, Lai YW, Fung KS, Chau SK, Wong BK, To WK, Luk K, Ho AY, Que TL, Yip KT, Yam WC, Shum DH, Yip SP. Will a new clade of SARS-CoV-2 imported into the community spark a fourth wave of the COVID-19 outbreak in Hong Kong? ***Emerg Microbes Infect.*** 2020;9(1):2497-2500. (IF 2020= 5.828)

5. Leung KSS, Ng TTL, Wu AKL, Yau MCY, Lao HY, Choi MP, Tam KKG, Lee LK, Wong BKC, Ho AYM, Yip KT, Lung KC, Liu RWT, Tso EYK, Leung WS, Chan MC, Ng YY, Sin KM, Fung KSC, Chau SKY, To WK, Que TL, Shum DHK, Yip SP, Yam WC, **Siu GK (Corresponding author)**. A Territorywide Study of Early Coronavirus Disease Outbreak, Hong Kong, China. ***Emerg Infect Dis.*** 2021;27(1):196-204. (IF 2020= 6.883)

4. Impact and Benefits

Over the last 18 months, Dr SIU's team has clearly demonstrated that his new technology can rapidly identify the transmission links among COVID-19 cases and ***provide a scientific basis for the government to implement precise healthcare policies to interrupt the spread of COVID-19 in Hong Kong community*** (see below for details).

During the **first wave of COVID-19 outbreak in Hong Kong**, based on the viral sequencing result, Dr SIU revealed a hidden transmission chain in Eastern district. He was also able to identify the source patient of the Buddha worship hall cluster, which was the first super-spread event of COVID-19 in Hong Kong.

(1) *This is the first time Hong Kong scientists have been able to demonstrate that an asymptomatic carrier of SARS-CoV-2 could be a source of a large-scale community outbreak,* and

(2) *for the first time this highlighted the importance of SARS-CoV-2 nucleic acid testing for all close contacts regardless the presence of fever and other symptoms associated with respiratory infection*.

His finding was published in Emerging Infectious Diseases with him as the corresponding author [3], a peer reviewed journal published monthly by the Centers for Disease Control and Prevention of the US government.

The summer of 2020 witnessed the **third wave of COVID-19 outbreak**. Dr SIU identified a new SARS-CoV-2 lineage (GR/B.1.1.63) in multiple local cases. Surprisingly, the viral genome was identical to those isolated from aircrew and sailors who were exempted from compulsory quarantine, suggesting that they were the source of local outbreak. ***With the support of Dr. SIU's genomic sequencing finding, the government suspended unrestricted crew changes in order to avoid further introduction of import cases to the community***. The achievement of Dr SIU's work were widely covered by many TV and paper media in press releases and interviews arranged by PolyU's Communications and Public Affairs Office (CPA).

In October 2020 (the beginning of the **fourth wave of COVID-19 outbreak**), Dr SIU's research discovered that locally acquired cases were phylogenetically more closely related to recently imported cases from Nepal in September and October than to the strains causing the 1st, 2nd and 3rd waves. This finding led his team to raise the possibility that a next wave could be set off if loopholes were not closed. His research clearly indicated that although electronic wristbands were arranged to monitor travellers' location during the 14-day quarantine, they could still be visited by their families or friends at their homes or hotel rooms. This could be a possible transmission route for the imported infections to the community [4]. ***Dr SIU was among the first health experts in Hong Kong to raise publicly the alarm about loopholes in the city's home and hotel quarantine arrangements*** and the unexpectedly high rate of false negative COVID-19 test results at the city's airport. In a private meeting with the Secretary of Food and Health (Professor Sophie CHAN) in the presence of the HTI Head, Dr SIU proposed that

(1) inbound travellers undergoing the 14-day compulsory quarantine should do so only in designated hotels for quarantine with visitors barred, and

(2) travellers should be transferred from the airport to their designated quarantine hotel or quarantine centre via a designated shuttle bus service instead of using public transport.

The Government took Dr SIU's advice and established designated quarantine hotels and hotel transportation in December 2020.

In April 2021, a SARS-CoV-2 variant of concern (B.1.351, a.k.a South Africa variant) was detected in various local cases associated with Filipino domestic helpers without apparent epidemiological relationship. Based on whole-genome sequencing, Dr SIU identified the transmission links between these cases and an Indian businessman who returned from Dubai in March. He timely reported this finding to the Food and Health Bureau, Centre of Heath Protection (CHP) and Hospital Authority Head Office. With the support of his genomic sequencing result, CHP re-conducted the epidemiological investigation and eventually traced out the entire transmission chain and their close contacts among these cases. This avoided the further dissemination of SARS-CoV-2 variant of concern in the community.

Dr. SIU's research innovation has significant impact to the community during the outbreak of COVID-19 by 1.) providing rapid and accurate detection of the virus, 2.) identifying the transmission links, and 3.) giving recommendations to the Hong Kong Government for setting healthcare and infection control policies. PolyU recently named Dr Siu as "Limin Endowed Young Scholar in Medical Laboratory Science" for his contribution to society through research excellence.

5. References to the Corroboration of Impact and Benefits

1. **TV show:**

- **NOW TV news 【經緯線】病毒追蹤 [25 April 2021]**
  https://news.now.com/home/local/player?newsId=432418

- **RTHK 【城市論壇】變種病毒入社區 檢測化驗問程序 [9 May 2021]**
  https://www.rthk.hk/radio/radio1/programme/City_Forum/episode/727812?lang=zh-hant

- **RTHK 【The Pulse】Covid-19 mutant variants & quarantine arrangement in HK [14 May 2021]**
  https://podcast.rthk.hk/podcast/item.php?pid=205&eid=179961&year=2021&lang=en-US

- **NOW TV news 【大鳴大放】新冠病毒變種**
  https://news.now.com/home/local/player?newsId=434901

Media & Time	Headline	Content (First paragraph)	Link
2. News (Broadcast)			
RTHK 香港電台	理大：近兩個月輸入個案最少 27%未在機場檢測被發現	理大分析本港新型冠狀病毒基因的變異與傳播情況，發現第三波疫情最常出現的 GR 型病毒株，在 9 月過後基本上已在香港消失，即是本港曾經戰勝病毒。而 10 月的本地個案則出現 GH 型病毒株，分析後相信是從外地傳入，病毒基因與印度及尼泊爾的輸入個案相似。	Link
RTHK 香港電台	本港增 8 宗輸入確診 理大稱輸入個案令病毒流入社區	本港新增 8 宗新型肺炎輸入個案，全屬輸入個案。	Link
RTHK 香港電台	'Airport Covid tests can miss a quarter of cases'	Polytechnic University researchers said on Monday that Covid-19 tests at the airport could miss at least a quarter of imported infections because of what could be "false negative" results.	Link
CRHK 商業電台	理大分析指第四波似乎即將爆發	理工大學分析本港新型冠狀病毒的基因及傳播率，指本港首三波新型冠狀病毒疫情，都是源於輸入個案，又指第四波疫情未開始，但似乎即將爆發。	Link
CRHK 商業電台	理大分析指本港第三波疫情 9 月本已完 惟輸入個案致上月再失守	理工大學分析本港新型冠狀病毒的基因及傳播率，發現第三波疫情最常見的 GH 型病毒株，在 9 月份已經在本港消失；上月份的本地病例，均驗出帶 GR 型病毒株，與印度及尼泊爾輸入個案相似，反映病毒已經變種，亦證明上月的本地個案，都是源於輸入病例。	N/A
Cable News 有線新聞	增 8 宗輸入個案 理大發現病毒株近兩月突變 與印度、尼泊爾相近 憂爆第四波疫情	【有線新聞】今日多 8 宗新型肺炎確診個案，全部是輸入病例，包括由印度、尼泊爾抵港。理工大學的基因排序研究發現，新型肺炎病毒株最近兩個月有突變，與印度、尼泊爾相近。	Link
TVB 無綫電視	理大研究指最近本地新冠肺炎源頭來自外地 促收緊入境檢疫	理工大學研究推斷，最近確診的新冠肺炎本地病例，源頭來自外地抵港的隱形患者，建議政府收緊入境人士檢疫措施。	Link
3. News (Newspaper)			
Apple Daily 蘋果日報	武漢肺炎｜理大研究稱已戰勝第三波疫情 惟港府防疫漏洞隨時引爆第四波	本港武肺疫情近日以輸入個案主導，情況與 6 月時第三波疫情爆發的前奏相似。理工大學醫療科技及資訊學系副教授蕭傑恒的團隊，最新病毒基因分析發現，9 月起本港出現全新的 GH 型武肺病毒株，首先來自尼泊爾及阿根廷的輸入個案，半個多月後蔓延至 China Secret 群組等多宗本地個案。分析證實，港人雖然捱過第三波疫情，但再因為政府阻截輸入個案有明顯漏洞，隨時重蹈覆轍。	Link

Oncc 東方日報	理大研究指本港曾打贏第三波疫情　輸入個案致再度失守	本地疫情仍然嚴峻，近日再爆出多宗源頭不明的本地個案，理工大學研究團隊今（16 日）發表研究內容，指分析本港病毒的基因變異情況及傳播率，本港第三波疫情的病毒主要是 GH 型病毒株，但該病毒株已於 9 月消失，反映本港一度「打贏」病毒。惟上月起的案例均帶有 GR 型病毒株，與尼泊爾及印度的輸入個案高度相似，估計是因酒店未有限制探訪隔離人士，導致社區再次失守。團隊建議港府應加強入境人士的隔離措施，包括考慮設立「檢疫酒店」等。	Link
Etnet 經濟通	【新冠肺炎】理大憂爆第四波：近三成輸入個案未在機場檢測時發現	《經濟通通訊社 16 日專訊》理工大學分析發現，上月的本地個案均源於輸入病例，而近三成輸入個案未能在機場即場檢測中發現，情況令人擔心，建議政府加強入境人士的隔離措施，包括在機場設立專用化驗室、避免讓入境人士乘坐公共交通工具前往酒店、立法禁止探訪檢疫人士、酒店業界亦要與政府商討，設立「檢疫酒店」的可行性。	Link
Headline Daily 頭條日報	理大指本港曾戰勝第三波疫情 輸入個案再致傳播	本港疫情反覆，理大分析本港新冠病毒基因的變異與傳播情況，發現第三波疫情時本港曾經一度戰勝病毒，第三波疫情最常出現的 GR 型病毒株，在 9 月過後基本上已消失。而 10 月的本地個案則出現 GH 型病毒株，病毒基因與印度及尼泊爾的輸入個案相似，相信是從外地傳入。	Link
Hong Kong China News Agency 香港新聞網	香港理大研究表明香港近三成輸入個案無法在機場被測出	香港新聞網 11 月 16 日電 香港中通社前方記者報道，香港理工大學 16 日發表研究報告表明，香港最少 27%的輸入個案無法在機場被檢測出來。	Link
HKEJ 信報	理大:第三波病毒株已消失 上月個案源於輸入病例	理大分析本港新型冠狀病毒基因的變異與傳播情況，指第三波疫情最常出現的 GR 型病毒株，9 月過後基本上已在香港消失，即是本港曾戰勝病毒。而 10 月的本地個案則出現 GH 型病毒株，與印度及尼泊爾輸入個案相似，反映病毒已變種，亦證明上月的本地個案源於輸入病例。	Link
Sing Tao 星島日報	理大指本港曾戰勝第三波疫情 輸入個案再致傳播	本港疫情反覆，理大分析本港新冠病毒基因的變異與傳播情況，發現第三波疫情時本港曾經一度戰勝病毒，第三波疫情最常出現的 GR 型病毒株，在 9 月過後基本上已消失。而 10 月的本地個案則出現 GH 型病毒株，病毒基因與印度及尼泊爾的輸入個案相似，相信是從外地傳入。	Link

Online			
Stand News 立場新聞	【武漢肺炎】理大指本港曾「打贏」第三波疫情　輸入個案致再失守　促加強入境隔離措施	香港理工大學分析本港導致武漢肺炎的 SARS-CoV-2 病毒基因及傳播率，發現第三波疫情最常見的 GR 型病毒株，在 9 月份已於本港消失，可代表「打贏」該波疫情。不過，上月份的本地病例均驗出帶 GH 型病毒株，與印度及尼泊爾輸入個案相似，除反映病毒變種外，亦證明上月錄得的本地個案，均源於輸入病例。	Link
HK01	理大揭 10 月起新冠病毒流行種類已變　酒店探訪檢疫者或散出社區	本港新冠肺炎疫情反覆，理工大學團隊分析本港新型冠狀病毒的基因及傳播率，發現第三波疫情最常見的 GR 型病毒株，在 9 月份已經在本港消失。10 月的本地病例，譬如 China Secret 酒吧群組、尖沙咀帝苑酒店群組、梅窩 Staycation 群組等，均驗出帶 GH 型病毒株，他們的病毒感染類型與印度及尼泊爾輸入個案相似。	Link
dotdotnews	理大團隊：本港第三波疫情源於輸入個案	香港理工大學早前研究本港新冠病毒的基因及傳播率，指本港首三波新冠病毒疫情都是源於輸入個案，又指第四波疫情雖未開始，但似乎即將爆發。理大研究團隊今日（16 日）表示，第三波疫情最常見的 GH 型病毒株，在 9 月份已經在本港消失；上月份的本地病例，均驗出帶 GR 型病毒株，與印度及尼泊爾輸入個案相似，反映病毒已經變種，亦證明上月的本地個案，都是源於輸入病例。	Link
Bastille Post 巴士的報	理大:第三波疫情曾一度消失 輸入個案再致傳播	本港疫情反復，理大分析本港新冠病毒基因的變異與傳播情況，發現第三波疫情時本港曾經一度戰勝病毒，第三波疫情最常出現的 GR 型病毒株，在 9 月過後基本上已消失。	Link
Bastille Post 巴士的報	理大：近兩個月輸入個案最少 27%未在機場檢測被發現	理大分析本港新型冠狀病毒基因的變異與傳播情況，發現第三波疫情最常出現的 GR 型病毒株，在 9 月過後基本上已在香港消失，即是本港曾經戰勝病毒。而 10 月的本地個案則出現 GH 型病毒株，分析後相信是從外地傳入，病毒基因與印度及尼泊爾的輸入個案相似。	Link
Bastille Post 巴士的報	本港增 8 宗輸入確診 理大稱輸入個案令病毒流入社區	本港新增 8 宗新型肺炎輸入個案，全屬輸入個案。	Link
Yahoo News Yahoo 新聞	理大：近兩個月輸入個案最少 27%未在機場檢測被發現	理大分析本港新型冠狀病毒基因的變異與傳播情況，發現第三波疫情最常出現的 GR 型病毒株，在 9 月過後基本上已在香港消失，即是本港曾經戰勝病毒。而 10 月的本地個案則出現 GH 型病毒株，分析後相信是從外地傳入，病毒基因與印度及尼泊爾的輸入個案相似。	Link

Case 2: Camera Pointing System (CPS) for China Lunar Exploration

1. Summary of the Impact

Research on systems engineering technology has assisted the China National Space Administration (CNSA) with its Chang'e-3 mission in 2013 and Chang'e-4 mission in 2019, as shown in Figures 1 and 2 respectively, through the design and construction of a camera pointing system (CPS), which was installed atop the lunar landers. The CPS assisted with the tracking of the rovers and the capturing of panoramic views for building a model to plan the rovers' progression. The CPSs can function on the front and far sides of the moon many months after landing, well beyond their life expectancies. The first lunar far side landing in human history was achieved by Chang'e-4; this lunar lander has discovered new minerals there. Our contributions have been acknowledged by high-level Chinese space agencies such as the CNSA and the China Academy of Space Technology (CAST), leading to further collaboration in space projects. The CPS has also attracted additional industrial research funding for several civil projects.

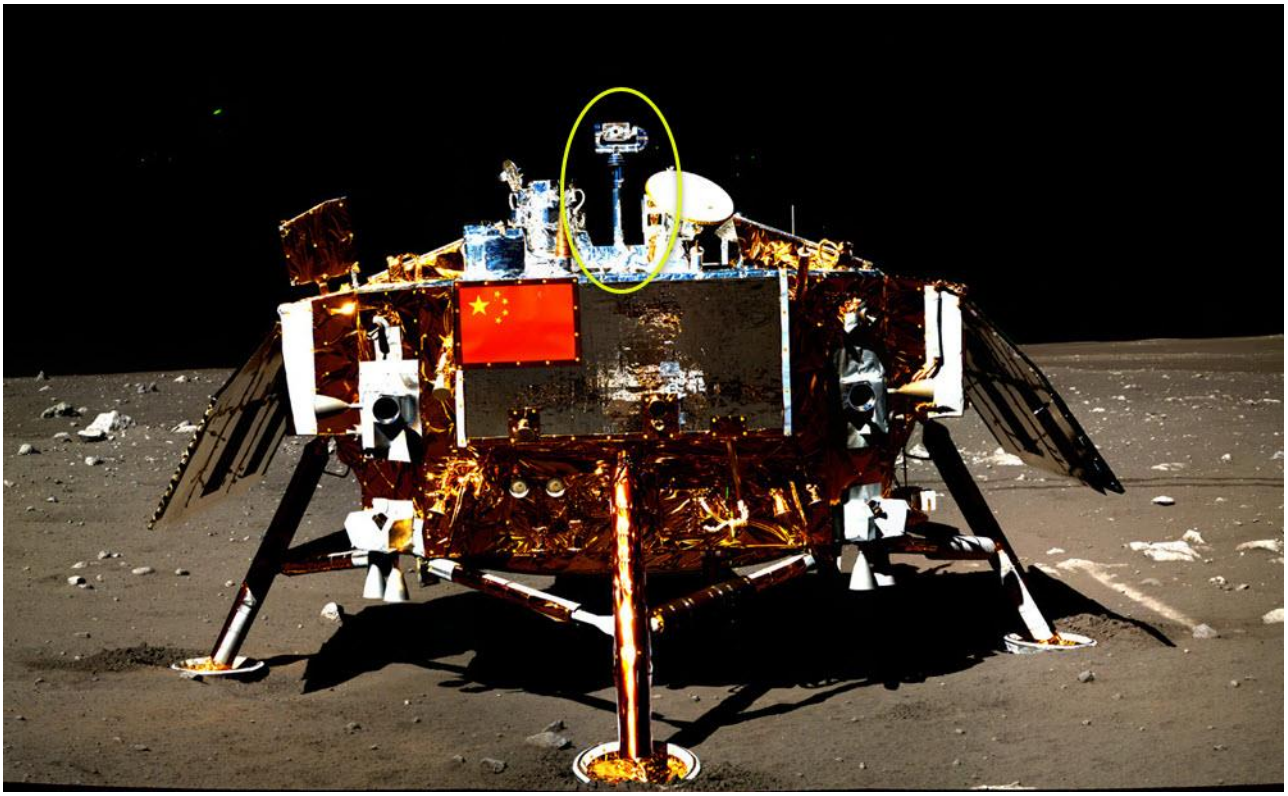


Figure 1. CPS deployed in Chang'e 3 mission (source: CNSA)

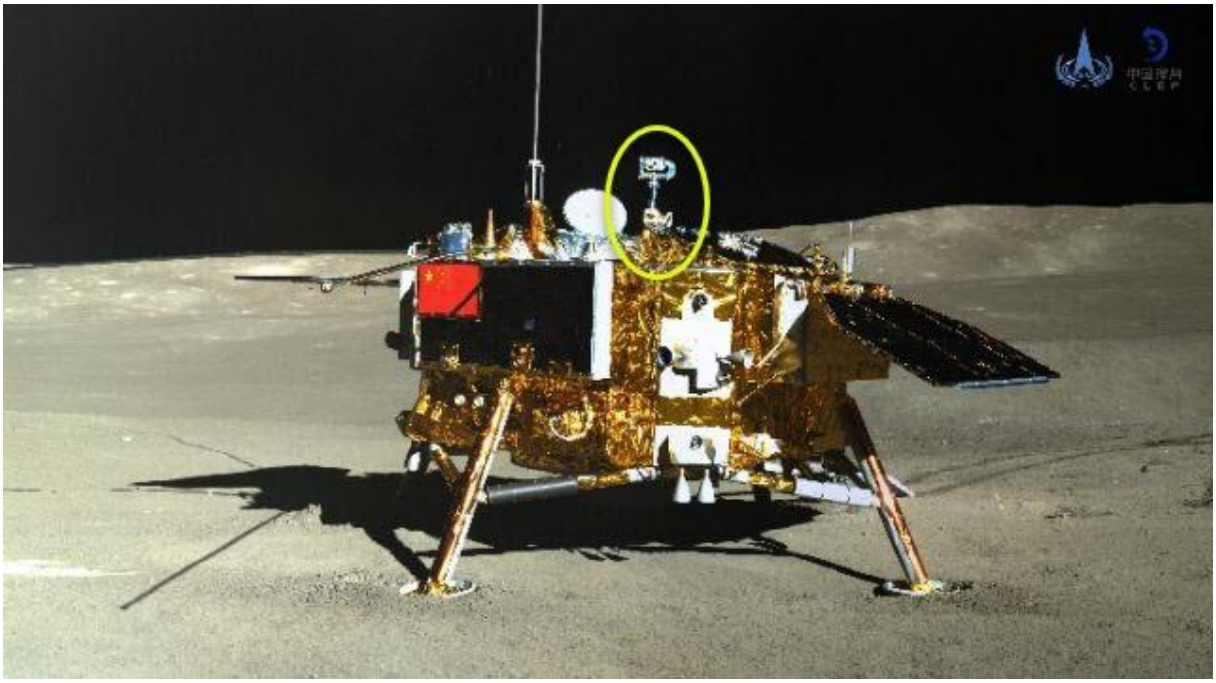


Figure 2. CPS deployed in Chang'e 4 mission (source: CNSA)

2. Underpinning Research

The Hong Kong Polytechnic University (PolyU) research underpinning the development of the camera pointing system (CPS) (Figure 3) addressed a major challenge in systems engineering, which is interdisciplinary and involves consideration of optimal thermo-characteristics, the strength to weight ratio, precision motion, reliability, and material compatibility in space, to aid the precision modelling of the lunar surface. The development of the CPS was underpinned by many years of research in several diverse areas, such as precision engineering, mechatronics, materials, design optimization, thermo-modelling, and micro/nano fabrication [R3], that integrated to create an optimal system. The development process included the concept formulation stage, prototype stage, engineering model (EM) stage, qualify model (QM) stage, and flight model (FM) stage; each stage produced distinctive research outputs drawing on previous underpinning research [R4][R6]. Each stage also involved panels of experts examining every details of the research.

In the prototype stage, the strength-to-weight ratio of devices similar to the CPS and their functions were comprehensively studied to determine the suboptimal initial topography of the CPS. A hardware thermo-model was built to study heat flow across the device and its thermal capacity and ascertain the thermo-effect at its various interfaces. The emissivity and absorptivity of materials such as Ti6 and AL7075 were investigated for thermal profile compatibility, drawing on previous surface treatment research. The compatibility of CPS components with each other and with actuators in the space environment was tested using previous research on sound and vibration [R5]. The results formed the basis for the Design Proposal (DP) and Detailed Design Report (DDR) [R5], which were assessed by a panel before CPS construction began. Finally, a Prototype Research and Development Conclusion Report (RDCR) was then drafted for assessment and passed validations.

The EM stage followed a similar workflow [R1]. Design optimization [R6] was achieved through new multi-domain-based design optimization strategies; this established the mechanisms by which integrated internal frameworks generated high (structural rigidity) resonance frequencies and aided precision motion. The design also included an ultra-thin skin structure for high strength-to-weight ratios while maintaining compatible thermal behaviour [R2]. Further empirical research on internal

cabling methodology enabled the determination of optimal bending radius required to protect the cable insulation in extreme space environment. The theories were verified through extensive experimentation (environmental tests and dynamic electrical and mechanical stress tests).

The QM stage involved reliability analysis, thermo-analysis, electro-compatibility analysis, kinematic analysis [R3], and dynamic stress/strain analysis along with extensive experimentation in a simulated space environment. The research was much more comprehensive at this stage than that at the EM stage. The results were summarized in the DP, DDR, and RDCR.

The FM stage followed a workflow similar to that of the QM stage, but included additional research on the active and passive thermo-controls of the CPS based on reflectivity and emissivity in a lunar environment with different materials, thermo-characteristics, surface treatments, and angles of incident radiation.

Figure 3. Camera Pointing System

3. References to Research

PolyU researchers are in bold.

[R1] **Yung, KL**; **Ko, SM**; **Kwan, FY**; **Foster, J**; "The Phobos-Grunt Microgravity Soil Preparation System", ACTA ASTRONAUTICA, Vol. 141, pp 22-29 (2017).
[R2] **Weiss, P**; **Yung, KL**; Komle, N; **Ko, SM**; Kaufmann, E; Kargl, G; "Thermal drill sampling system onboard high-velocity impactors for exploring the subsurface of Europa", ADVANCES IN SPACE RESEARCH, Vol. 48, pp 743-754 (2011).
[R3] **Tian, W**; **Yung, KL**; **Xu, Y**; **Huang, L**; Kong, J; **Xie, Y**; "Enhanced nanoflow behaviors of polymer melts using dispersed nanoparticles and ultrasonic vibration", NANOSCALE, Vol. 3, pp 4094-4100 (2011).
[R4] **Weiss, P**; **Shi, WZ**; **Yung, KL**; "Attribute uncertainty modelling in lunar spatial data", INTERNATIONAL JOURNAL OF REMOTE SENSING, Vol. 31, pp 197-211(2010).
[R5] **Lei YM**; **Yung KL**; **Xu Y**; "Chaos synchronization and parameter estimation of single-degree-of-freedom oscillators via adaptive control", JOURNAL OF SOUND AND VIBRATION, Vol. 329, pp 973-979 (2010).
[R6] **Weiss, P**; **Yung, KL**; "Mission architecture decision support system for robotic lunar exploration", PLANETARY AND SPACE SCIENCE, Vol. 57, pp 1434-1445 (2009).

The details of key research grants are listed below:

Project	Funding (HK$)	Period
Camera Pointing System (CPS)	HK$ 6 million from the China Academy of Space Technology (CAST) and The Hong Kong Polytechnic University	2009-2012

4. Impact and Benefits

The camera pointing system (CPS) is the first instrument developed in Hong Kong to have reached the surface of the moon, on the front and far sides. It is also the only instrument built in Hong Kong that continues to be active on both the front side and far side of the moon. The impact of this work is not only that Hong Kong has moved into the arena of instrumentation research for space technology but also that several other research and development initiatives have been taken based on it. The proven core technologies and solutions developed during the research were innovative and transferrable to solve many other engineering and industrial problems. These included optimisation of mechanics kinematics and strength to weight ratio, and a better understanding of chemical interactions between lubricants and tribological materials in high vacuum, under stress plus extreme temperatures (hot and cold) and surface roughness; lubricant migration in vacuum, under different pressure, speed of interaction; surface crack generation and propagation of cable coating installations such as Kapton and PTFE under extreme temperature (hot and cold) and in vacuum to determine the amount of bending radius sustainable by a particular cable and its life expectancy. The transfer of these technologies to industrial applications include the micro-moulding of transdermal hollow microneedles (a new domain of medical robotics), high reliability unmanned aerial vehicles (UAV), and new robots capable of repairing water supply pipelines (Figure 4).

The contribution of CPS to CAST was recognized in a letter from CAST and an honorary certificate from China Aerospace Science and Technology Corporation (CASC), which are enclosed [S4]. Further, Professor YUNG K.L., PI of the project, was appointed to the Expert Committee on Lunar Exploration Phase 3 in 2012, by the Lunar Exploration and Space Engineering Centre, China National Space Administration (CNSA-LESEC), for his work on the CPS system [S5]. He was also requested to participate in the Implementation Plan Development Committee for "Deep Space

Exploration of Significant National Importance" in the People's Republic of China in 2017 by the State Administration for Science and Technology for National Defence [S6]. In addition, CAST and CNSA are collaborating with our PolyU team in several other key space projects of high importance: Chang'e-5, Chang'e-6, and Mars 2020. The Chang'e-5 mission has since successfully returned sample from the moon with the aid of our developed Lunar Surface Sample Acquisition and Packaging System. Our developed Mars Surveillance Camera also successfully functioned on Mars earlier this year. Our team has also been invited to collaborate with the Swedish Institute of Space Physics to build instruments for the European Space Agency (ESA)'s Jupiter Mission in 2022.

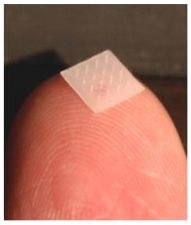
The successful soft landings of Chang'e 3 in 2013 and Chang'e 4 in January 2019 put the CPS on the near and far sides of the Moon respectively, as witnessed by billions on TV worldwide, with unprecedented coverage by hundreds of newspapers, media reports, and web links, both local and global [S1][S2]. Our team also directly engaged the Hong Kong public with the engineering required for space travel through talks and lectures, such as an event at the Hong Kong Science Museum with over 300 attendees.

Another significant impact of technologies developed for the CPS was the technology transfer to the research and development of a surgery robot, with funding from industries and grants from the Innovation and Technology Fund (ITF) [S7]. This research involved the development of a new single port internally motorized surgery robotic system for minimal/non-invasive surgery (Figure 5). The materials' properties, design and mechatronics research for the CPS was applied to create a reduced-size, light-weight and high-precision robotic system that is both smaller than the current system on the market and provides tactile feedback.

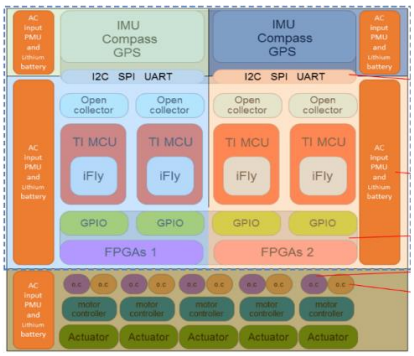
The surgical system was developed in partnership with a new startup, Bio-Medical Engineering (HK) Ltd, part of the NISI group, between 2012 and 2016. The start-up then raised investment for its further development, for the requisite product engineering, and for the FDA/CFDA approval applications

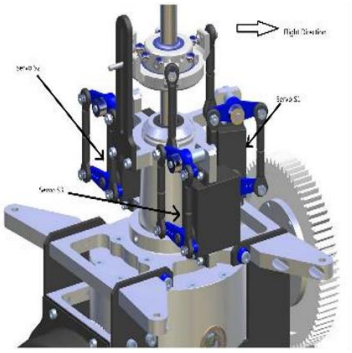
This system has gained significant interest among surgeons and the general public [S8]. The company has since successfully completed a number of world-first robotic natural orifice transluminal endoscopic surgeries in a live porcine model using the second generation of the Novel Surgical Robotic System [S3].

Water pipe repair robot



Microneedle





High Reliability Unmanned Aerial Vehicles

World 1st bottom-up vertical injection moulding machine

Figure 4. Industrial application examples inspired by CPS

Figure 5. Prof. Yung introducing the animal trial test with the Novel Surgical Robotic System to Hospital Chief Executive, University of Hong Kong-Shenzhen Hospital Chin Lan Hong Professor and Chair of Hepatobiliary and Pancreatic Surgery, Prof. LO Chung Mau

5. References to the Corroboration of Impact and Benefits

[S1] Example of media coverage of the soft landing of Chang'e 3 in 2013:
Xinhua News Report for 16 December 2013.

[S2] Example of media coverage of the soft landing of Chang'e 4 in 2019:
Xinhua News Report on 11 January 2019.

[S3] The team successfully developed the new single port internally motorized surgery robotic system for minimal/non-invasive surgery, which has been transferred to a start-up that then raised investments and now employs over 100 staff members. Enclosed is a letter of appreciation from Mr. WONG David T., Managing Director and CEO of NISI (HK) Limited.

[S4] A letter of appreciation was received from the China Academy of Space Technology for our contribution to Chang'e-3 and Chang-4 missions; the letter is enclosed.

[S5] Appointment Certificate of Expert Committee on Chinese Lunar Exploration Programme Phase 3; the certificate is enclosed.

[S6] Appointment Certificate of Implementation Plan Development Lead of China's Deep Space Exploration of Significant National Importance Committee; the certificate is enclosed.

[S7] K.L. Yung, Magnetic-anchored Robotic System (MRS), Innovation and Technology Support Programme, HKSAR, Project Reference ITS/149/13FX.

[S8] The Hong Kong Polytechnic University, "Robotic Surgery Transformed", South China Morning Post, 23 January 2017

Case 3: Planetary Remote Sensing Contributing to Space Exploration Missions

1. Summary of the Impact

PolyU's research on planetary remote sensing has been adopted by China's space exploration missions for landing site characterization and selection. A new integrated 3D mapping model has been developed for high-precision and high-resolution topographic mapping of the Moon and Mars, surpassing existing technology such as photogrammetry or laser altimetry. Novel artificial intelligence (AI) approaches have been developed for more automated and robust geomorphological analysis on planetary surfaces. These developments and results have been extensively used by the China Academy of Space Technology (CAST) to optimize landing site evaluation, design data collection strategies, change descent orbit design, and improve surface operation of the Chang'e-3, Chang'e-4, and Chang'e-5 missions to the Moon and the Tianwen-1 mission to Mars. The developments are also now being used for landing site mapping and supporting mission design for the forthcoming Chang'e-7 mission to the lunar south pole and China's asteroid exploration mission.

2. Underpinning Research

High-precision and high-resolution topographic information for surface hazard analysis and landing site evaluation are vital for the success of any landing mission to planetary bodies, such as missions to the Moon, Mars, or asteroids. They are also essential for planetary scientific research, for example, for studying surface geomorphology and geology. Remote sensing to obtain high-precision and high-resolution topographic information on planetary bodies is extremely difficult, unlike that on Earth, due to the lack of control information. Further, weak textures, shadow casts, and specular reflections on a planetary surface could render existing remote sensing techniques unusable. A PolyU research group, comprising Prof. WU Bo, Prof. CHEN Yongqi, Prof. Huseyin BAKI LZ, Prof. LI Zhilin, Prof. DING Xiaoli, Prof. CHEN Wu and Dr. Robert TENZER, has systematically researched planetary remote sensing over the past decades. They have advanced research and development in planetary mapping [**R1**, **R3, R5**], planetary reference systems [**R2**], and planetary remote sensing data analysis [**R4, R6**].

For high-precision and high-resolution topographic mapping of the Moon and Mars, a new 3D mapping model that integrates several types of planetary remote sensing data [**R1, R3, R4**] and multiple complementary methods [**R5**] was developed by our team. This model enables the combined adjustment of multiple-platform multiple-sensor remote sensing imagery and laser altimeter data [**R1, R3, R4**] to generate high-precision and consistent digital topographic models (DTMs). Nowadays large amounts of planetary remote sensing data have become available. The data sets have different characteristics such as sensor configuration, spatial-temporal attributes, and uncertainty. There are usually different levels of inconsistencies or even contradictions among each other. The integrated 3D mapping model is essential for the proper calibration, registration, and analysis of multiple-source planetary remote sensing datasets. In turn, it facilitates the full comparative and synergistic use of them. These developments led to a "*Gold Medal*" and a "*R. Alekseev Award*" for the PolyU team at the *44th International Exhibition of Inventions* in Geneva in April 2016. The research article [**R3**] about multiple-source data integration for precision lunar topographic mapping was cited by *Nature Index* as "*a landmark paper on lunar topographic models*" in an analysis of the research produced by universities in Hong Kong (https://www.nature.com/articles/516S64a).

The current technique of photogrammetry requires stereoscopic images for 3D mapping; however, high-resolution stereoscopic images of planetary surfaces are rare. Moreover, photogrammetry may fail to produce dense mapping results for planetary surfaces due to a lack of image texture. Shape-from-shading (SfS) is a complementary approach to photogrammetry that produces more accurate mapping results for untextured input images. SfS can generate topographic information with pixel-level resolution and can be used for a single image or multiple images. However, SfS alone has never

been practically used in planetary mapping due to problems such as uncertainties in the reflectance model and surface albedo. Therefore, a new shape-and-albedo-from-shading (SAfS) approach [**R5**] was developed by our team for generating high-resolution DTMs from a single image with the constraint of a low-resolution DTM generated from photogrammetry or laser altimetry. Further, an SfS-assisted image matching method was developed for the illumination-invariant matching of lunar surface images; with this method, reliable and dense matching results could be generated from images with illumination differences as large as 90°. This pioneering work extends the scope of applying photogrammetry to planetary mapping. The integrated 3D mapping model enables the synergistic integration of complementary datasets and methods to generate higher-quality DTMs of the lunar and Martian surfaces with improved spatial resolution and precision than are attainable using individual datasets or methods.

Moreover, novel AI approaches were developed for the analysis of planetary remote sensing data; these approaches improved surface hazard (e.g., rocks, craters) evaluation and landing site characterization. An innovative deep-learning method was developed to extract rocks from high-resolution lunar images. Based on that, we developed a new rock abundance model to study the rock distribution pattern on the lunar surface [**R4**]. A new active learning approach was also developed for more automated and robust crater detection using planetary remote sensing data [**R6**], which solves the cumbersome task of providing training samples of favourable quality and quantity that is required in conventional deep learning approaches. The developed approaches have been extensively used for landing site mapping and characterization for China's lunar and Mars landing missions [**R3, R4, R5, R6, G2-G4**].

All of this underpinning research was funded by the Research Grants Council of Hong Kong [**G1, G5, G6**] and CAST [**G2-G4**]. The research has been published in over 50 top journals (in Quartile 1 of the Journal Citation Ranking of the Web of Science).

3. References to Research

Publications:

[R1] Bo Wu, Jian Guo, Yunsheng Zhang, Bruce King, Zhilin Li, Yongqi Chen, 2011. Integration of Chang'e-1 Imagery and Laser Altimeter Data for Precision Lunar Topographic Modeling, ***IEEE Transactions on Geoscience and Remote Sensing***, 49(12), 4889-4903.

[R2] Huseyin Baki Iz, Yongqi Chen, CK Shum, Xiaoli Ding, Bruce King, Wu Chen, M Berber, 2012. Assessing consistency of Chang′e-1 and SELENE reference frames using nearly-colocated laser altimetry footprint positions. ***Journal of Geodesy***, 86(2), 109-117.

[R3] Bo Wu, Fei Li, Lei Ye, Si Qiao, Jun Huang, Xueying Wu, He Zhang, 2014. Topographic Modeling and Analysis of the Landing Site of Chang'e-3 on the Moon. ***Earth and Planetary Science Letters***, 405, 257-273.

[R4] Bo Wu, Jun Huang, Yuan Li, Yiran Wang, Jing Peng, 2018. Rock Abundance and Crater Density in the Candidate Chang'e-5 Landing Region on the Moon, ***Journal of Geophysical Research - Planets***, 123(12), 3256-3272.

[R5] Bo Wu, Yuan Li, Wai Chung Liu, Yiran Wang, Fei Li, Yang Zhao, He Zhang, 2020. Centimeter-Resolution Topographic Modeling and Fine-Scale Analysis of Craters and Rocks at the Chang'e-4 Landing Site, ***Earth and Planetary Science Letters***, 553, 116666.

[R6] Bo Wu, Jie Dong, Yiran Wang, Zhaojin Li, Zheyu Chen, Wai Chung Liu, Jiaming Zhu, Long Chen, Yuan Li, Wei Rao, 2021. Characterization of the Candidate Landing Region for Tianwen-1 –

China's First Mission to Mars, ***Earth and Space Science***, 8, 6, e2021EA001670.

Grants:

[G1] Mapping and Characterization for Optimized Evaluation of Potential Landing Sites on the Moon and Mars to support Future Missions, Funded by The Research Grants Council of Hong Kong - Research Impact Fund (RIF), HK$6.38 million, 06/2020-06/2024.

[G2] Mars Landing Site – Topographic and Geomorphological Characterization and Analysis. Funded by China Academy of Space Technology, HK$1,318,440, 03/2017-12/2020.

[G3] Chang'e-5 Probe - Lunar Topographic Mapping and Analysis, Funded by China Academy of Space Technology, HK$ 1 million, 03/2015-03/2020.

[G4] Chang'e-4 Landing Site – Topographic Mapping and Analysis. Funded by China Academy of Space Technology, HK$1,318,440, 03/2017-02/2020.

[G5] High-Resolution and High-Precision 3D Modeling of Lunar Topography by Integrating Multi-Image Shape-from-Shading, Image Matching and Range Data, Funded by The Research Grants Council of Hong Kong (GRF), HK$695,788, 01/2016 - 12/2018.

[G6] Integration of Multi-Source Lunar Orbiter Camera Imagery and Laser Altimeter Data for Precision Lunar Topographic Mapping, Funded by The Research Grants Council of Hong Kong (GRF), HK$ 589,558, 01/2011 - 12/2013.

4. Impact and Benefits

1) Chang'e-3 landing site mapping and selection

In recognition of PolyU's research achievements in planetary remote sensing, the research team was invited by CAST to work on the topographic mapping and analysis of the landing site for the Chang'e-3 lunar landing mission. The integrated 3D mapping model and analysis methods were extensively used, contributing to the success of the mission in 2014. The Deputy Chief Designer of the Chang'e-3 Spacecraft said: "*The research and developments from Prof. WU Bo and his team are very helpful for us to understand the topographic and geomorphological information of the landing area*".

2) Chang'e-4 landing site characterization, selection, and mission operation

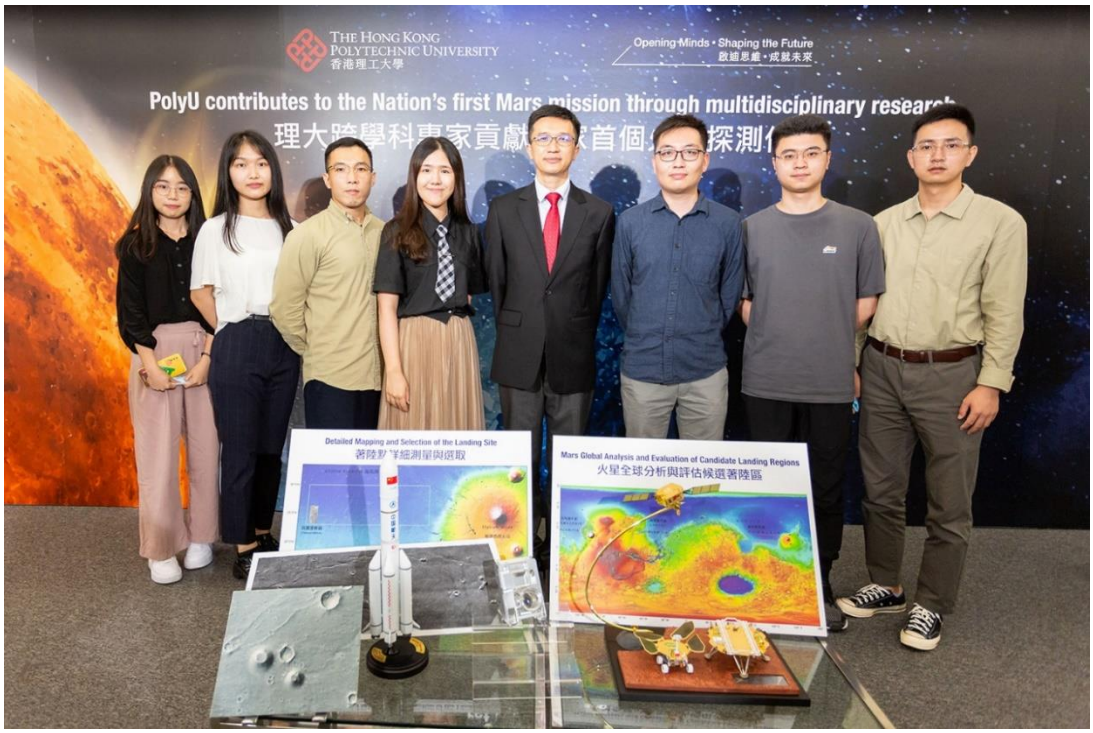
Another invitation from CAST in 2016 led to the nominee and his team working on topographic and geomorphological mapping and analysis for the characterization and selection of the Chang'e-4 landing site; this work ultimately contributed to the successful landing of Chang'e-4 on the far side of the Moon on 3 January 2019. Notably, the high-precision and high-resolution topographic mapping results revealed the very rough terrain of the landing surface. This enabled the decision to change the descent orbit design from the Chang'e-3's smooth descent orbit to the Chang'e-4's nearly 90º orbit maneuver during the descent phase, which proved critical for the successful landing. Based on the high-precision and high-resolution topographic models, the research team identified the exact location of the lander within an hour after the landing; this was faster than the mission requirement of three hours and added two hours to the time available for the deployment of scientific instruments to begin operations. Also, the research team generated a 1.5 m resolution DTM using the SAfS approach [**R5**] based on a single satellite image, which was the best quality DTM available immediately after landing. Knowledge of the exact lander position and the 1.5 m resolution DTM enabled detailed measurement and analysis of the topographic features (surface hazards, slopes, and occlusions) of the area surrounding the lander, which was critical for subsequently carrying out the surface operations of the mission.

The PolyU team contributed to the Chang'e-4 mission


Prof. WU at the Chang'e-4 launch site

3) Landing site characterisation and selection for the Chang'e-5 and Tianwen-1 Mars missions

With funding from CAST, the research team also worked on landing site characterization and selection for the Chang'e-5 mission and China's Tianwen-1 Mars mission. The developed topographic and geomorphological mapping methods were used for hazard analysis and evaluation of the Chang'e-5 landing site. Topographic and geomorphological analysis was also conducted to identify a suitable Mars landing site for China's Tianwen-1 Mars mission [**R6**]. In September 2016, Prof. WU Bo was appointed the Project Counsellor of the Mars exploration probe by CAST to advise on the mission design and landing site selection. He was further appointed by the China National Space Administration (CNSA) in February 2019 and has since become a member of the Science Team of China's first Mars mission. He has been invited by CNSA to join over 10 meetings and give talks on the developed techniques to the PIs of the main payloads, engineers, and scientists involved in the mission. The 3D integrated mapping model and the advanced AI-based geomorphological analysis techniques developed by PolyU have been extensively used for landing site mapping and selection for the Tianwen-1 mission, contributed to its successful landing on the Martian surface in May 2021.



The research team led by Prof. WU (middle) contributed to the Tianwen-1 Mars mission

The Chief Designer of the Tianwen-1 probe, Mr SUN Zezhou appreciated PolyU's contribution in a public seminar

4) Support the planning and design for the Chang'e-7 mission and China's asteroid mission

The research team has been more deeply involved in China's future space exploration missions, including the forthcoming Chang'e-7 mission and China's asteroid exploration mission to be launched around 2024. Chang'e-7 is planned to explore the south pole of the Moon, where the extreme illumination condition on the lunar south pole is a challenge. The developed 3D mapping model and AI-based geomorphological analysis techniques are critical for evaluating and selecting a suitable landing site for Chang'e-7. The nominee has also been closely working with CAST for the planning and design of the asteroid mission including suggestions for instrument design, orbit design, data collection strategy, and mapping and landing site selection.

5) Media coverage and outreach activities

The research achievements have also led to various public outreach activities. A video on the "Integrated 3D Mapping Model" is available on the YouTube Channel of the Hong Kong Research Grants Council [**E1**] and it garnered over 700 views as of July 2021. The achievements have received wide coverage by various media outlets, both locally and internationally. There were over 600 related news reports from 2014 to 2021, with an estimated readership number of millions [**E2**].

An exhibition at HKCEC in June 2021 about PolyU's participation in space missions well received by the general public

5. References to the Corroboration of Impact and Benefits

[E1] Online Video "Integrated 3D Mapping Model", YouTube Channel of the Hong Kong Research Grants Council: https://www.youtube.com/watch?v=ilDwPrvbz_Q

[E2] Examples of media coverage

Extensive media coverage on PolyU's participation in China's space programme

Case 4: Technology: Smart City Tree Monitoring System for Enhancing Urban Resilience

Description:

Every year before the onset of the wet season, tree management officers/ stakeholders in Hong Kong are required to complete tree risk assessments in areas with high pedestrian and traffic flow professionally and systematically and implement appropriate risk mitigation measures. Dangerous trees with untreatable problems need to be removed as soon as possible to safeguard public safety. Tree inspection personnel will have to perform a ground inspection to examine and assess various parts of a tree and may even need to climb up the tree to inspect the hidden parts from different angles. This takes a lot of manpower and time to cover all the trees (more than 1,700,000 trees[3]) in the whole of Hong Kong.

To combat these challenges, the research team has developed the Smart Tree Monitoring System ("the System") where it is the first-of-its-kind technology applying to urban forestry management on a city-wide scale. The Smart Sensing Technology sensors can capture the tilting angles and the direction of tree displacement, while the sensors given the baselines and trends of tree movement are known to be one of the vital clues for understanding uprooting failure. The System comprises of four major components: (a) dashboard visualization; and (b) a set of numerical algorithms; (c) Internet of Things (IoT) - Low Power Area Network (LPWAN); and (d) compatible design of sensors. The whole system architecture is invented by the research team, and it is widely adopted for urban tree management departments in Hong Kong (Please refer to Figure 1).

The tailor-made dashboard can visualize an array of tilting information captured by the compatible sensors (Please refer to Figure 2). A set of algorithms could identify the sharp variation of tilting angle and different patterns of increasing leaning trend of the tree, thereby indicating the tree risk index on the online dashboard platform by categorizing into four different levels, i.e. green, yellow, red and blue, based upon the System's underlying principle of "Alert, Alarm and Action". The green signal interprets as normal tilting of the tree, the yellow means a sign of attention on the tree stability and the red interprets as the concerned tree that requires immediate attention, while the blue one might have a high possibility to indicate the tree falling. If the data elicited that the tilting angle of the tree exceeds the thresholds of our developed tree risk index, the System would immediately send an alert to the designated tree management parties. Tree personnel can assess the risk urgency to commence the tree inspection and undertake timely and appropriate risk mitigation measures where necessary.

The compatible sensors installed at the lower trunks of the trees can collect trees' tilting angles and directions as well as the in-situ temperature (Please refer to Figure 3). The data would then be sent to the Hong Kong Polytechnic University's data centre via the state-of-the-art LPWAN wireless communication technology – LoRaWAN and NB-IoT, for spatial big data analytics alongside the essence of this invention is the first-ever tree monitoring system to transmit data to the endpoint server and GIS-based dashboard with the information pertaining and moving more in one data packet as compared to 3G/4G, Bluetooth and Wi-Fi networks.

Besides the competitive edge of the LPWAN network, the System is also capable to change the sampling frequency automatically according to the varying weather signals issued by the Hong Kong Observatory, whereby maximizing the data capture to visualize unusual tree moving pattern that may potentially lead to imminent tree risk hazard during the storms. The core competence of the "sleeping" mode of the wireless network modules could help on reducing the power consumption of each sensor which can sustain for at least 2 to 3 years, subject to the frequency of the weather events.

The System is influential as it utilizes a combination of novel technology that goes beyond simply identifying which trees require a safety inspection. The triggering functions of alert and alarm can timely inform the tree personnel to take action by responding and minimizing risk and it is vital. Currently, ground inspection on the highly concerned trees is conducted once or twice a year, while through the newly developed System, the research team can assess and monitor trees' swaying or tilting condition every day and manage the territory-wide of urban trees in Hong Kong

[3] As at March 31, 2017, the Legco LCQ8: Tree management, in response to the number of trees to be maintained in Hong Kong, where it had around 1,700,000 trees was maintained by nine core tree management departments. https://www.info.gov.hk/gia/general/201801/17/P2018011700827.htm

amidst of the developed tree risk index which is closely associated with uprooting failure. The System is commissioned by the research team for more than three years since 2018, and there were over 20 urban trees including Stonewall Trees and Old Valuable Trees that are being detected with unusual tree movement under the normal weather and in the storms; it also played an important role in detecting falling urban trees in a short period during extreme weather events, such as Typhoon Higo – one of the strongest typhoons in years - hit Hong Kong on 19 August 2020. With the unprecedented tree fell that occurred in the typhoon, relevant parties could be informed of such tree hazard location given faster emergency and remedial response can be made to the falling tree event. While for other monitoring trees that tended to tree lean, its displacement trend can bring early attention to tree personnel so that they can react to moderate the potential tree risk through the proper tree preservation mechanism with timely and appropriate mitigation measures to be taken in advance.

The System is the first worldwide project piloting at a hustle and bustle urban city to monitor extensive coverage of urban trees over the whole territory of Hong Kong. The project has gained interest from many cities and industries, that are facing challenges in tree management under increasing extreme weather conditions worldwide.

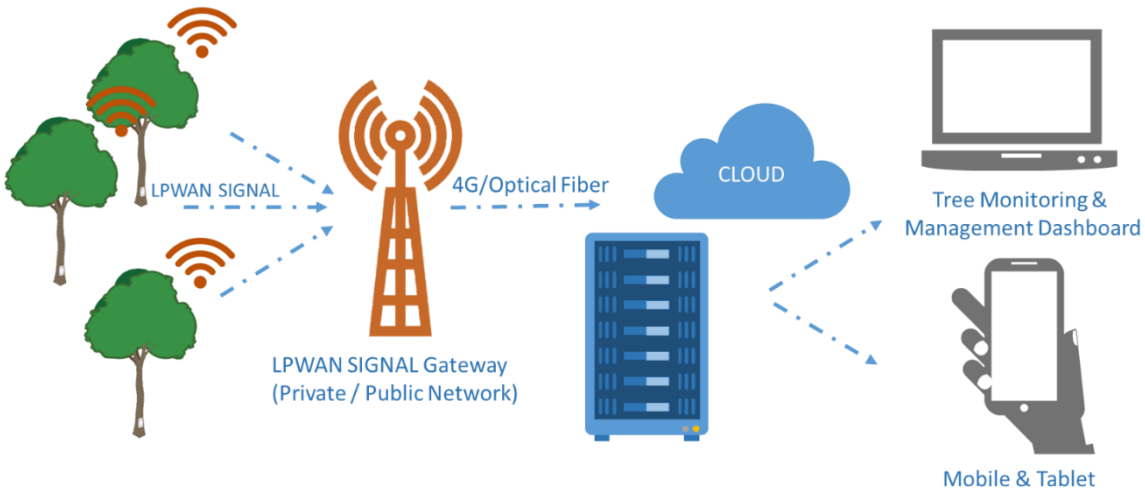


Figure 1: System Architecture of the Smart Tree Monitoring System

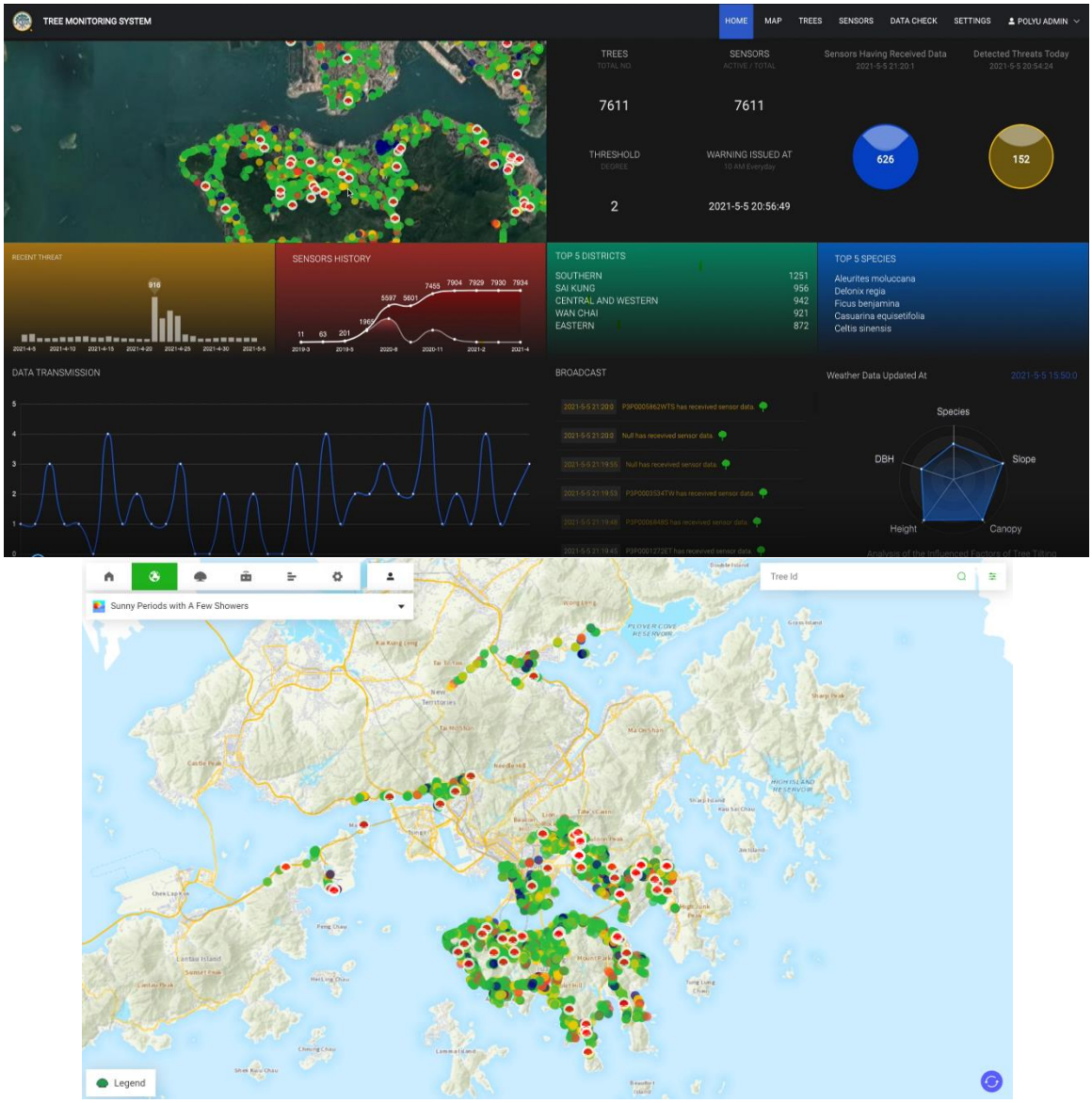


Figure 2: Dashboard Visualization showing the key information about the trees and sensors with the near-real-time tilting data

Figure 3: Compatible sensor installed at the lower tree trunk to collect the in-situ tilting and temperature data

Publications

Tree tilt monitoring in rural and urban landscapes of Hong Kong using smart sensing technology: https://www.sciencedirect.com/science/article/pii/S2666719320300303

Trees, Forests and People 2 (2020) 100030

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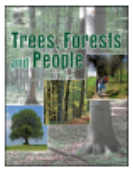

Tree tilt monitoring in rural and urban landscapes of Hong Kong using smart sensing technology

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ARTICLE INFO

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Hong Kong
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Tree failure
Tree monitoring system
Tree tilt angle

ABSTRACT

Urban trees are beneficial to our environment and important to human inhabitants. However, they are exposed to natural and anthropogenic stressors, such as strong windstorms, extreme wind events and accidents; inducing tree falling which can cause personal damages, economic losses and infrastructural destructions. The current study is the first of its kind, presenting a tree monitoring system, and using smart sensing devices installed on more than 8000 trees in Hong Kong's rural and urban landscapes. A description of the key components of the system, followed by big data analysis and three case studies of strong wind events over the past 2 years, are presented. A network of smart sensing devices was deployed to develop a large-scale, long-term, smart tree monitoring framework; to help identify potentially hazardous trees in urban areas, particularly during extreme weather events. The changes in tree tilt angle under natural wind loading were recorded. Patterns and responses of tree tilt angles were analyzed, with prediction using time series models based on the Seasonal Autoregressive Integrated Moving Average (SARIMA) and Extreme Gradient Boosting time series forecasting (xGBoost). The results showed the highest correlation for 1-hour forward forecasting, by applying xGBoost model on tree tilt data and weather observations (R^2=0.90). On the other hand, SARIMA model produced one-step-ahead prediction with correlation (R^2) ranging from 0.77 to 0.93, while lower correlation ($R^2 \leq 0.55$) was observed for long term prediction (15 days) of the tree tilt angles. Finally, a dashboard and mobile applications of tree monitoring systems were developed, to transfer knowledge and engage the public in understanding associated hazards with tree failures in the urban area.

1. Introduction

Urban trees are important. They exhibit a wide range of ecosystem services that have long been unveiled and increasingly reported (Fares et al., 2017; Grote et al., 2016; Nowak et al., 1996), which benefit our environment and human inhabitants in multi-faceted dimensions. These include reducing urban heat island effect, enhancing biodiverse habitat for wildlife, increasing the aesthetic value of the street view, and relieving mental distress (Gómez-Baggethun et al., 2013). Yet, trees growing in urban and surrounding areas are subject to considerable environmental stress, requiring proper maintenance to avoid potential hazards, no matter to life or property, in order to cultivate a sustainable urban ecology. During strong windstorms and extreme wind events, accidents relating to failures of urban trees cause personal damages, economic loss and infrastructural destruction (Lopes et al., 2009; Mortimer and Kane, 2004; Peltola, 2006). Therefore, continuous monitoring of the stability of urban trees is imperative in ensuring a sustainable urban design. Numerous tilt sensors have been developed, attaching to tree trunks which continuously collect dynamic data, to measure the tilt angle of root plate movement and wind-induced tree failures (Ancelin et al., 2004; Gardiner et al., 2000; Hale et al., 2012; James et al., 2013a, 2013b). A monitoring system based on analysis of dynamic tree tilt movement data can help devise effective management practices, to reduce tree failures and associated risks in a cityscape during extreme wind events (Heinonen et al., 2009).

To assess and predict tree falling, tree tilt monitoring in association with weather observation is mandatory. Apart from tree species, health and growing conditions (Bartens et al., 2010; Cannon et al., 2015), the critical wind speed for tree failure varies with structural attributes of a tree, such as diameter, age, height, inclination, size, canopy spread, and wood density (Lopes et al., 2009). Trees with lesser diameter at breast height (DBH) are more susceptible to strong winds. Thus, the

A Review of Dynamic Tree Behaviors: Measurement Methods on Tree Sway, Tree Tilt, and Root–Plate Movement: https://www.mdpi.com/1999-4907/12/3/379/htm

forests

MDPI

Review

A Review of Dynamic Tree Behaviors: Measurement Methods on Tree Sway, Tree Tilt, and Root–Plate Movement

Zi Yang [1], Ka Wai Hui [1], Sawaid Abbas [1], Rui Zhu [1], Coco Yin Tung Kwok [1], Joon Heo [2], Sungha Ju [2] and Man Sing Wong [1,3,*]

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Abstract: Urban forest ecosystems are being developed to provide various environmental services (e.g., the preservation of urban trees) to urban inhabitants. However, some trees are deteriorated asymptomatically without exhibiting an early sign of tree displacement, which results in a higher vulnerability under dynamic wind loads, especially during typhoon seasons, in the subtropical and tropical regions. As such, it is important to understand the tilt and sway behaviors of trees to cope up with the probability of tree failure and to improve the efficacy of tree management. Tree behaviors under wind loads have been broadly reviewed in the past literature, yet thorough discussions on the measurement methods for tree displacement and its analysis of broadleaf specimens are lacking. To understand the behavioral pattern of both broadleaf and conifer species, this paper presents a detailed review of sway behavior analysis from the perspectives of the aerial parts of the individual tree, including tree stem, canopy, and trunk, alongside a highlighted focus on the root–plate movement amid the soil-root system. The analytical approaches associated with the time-space domain and the time-frequency domain are being introduced. In addition to the review of dynamic tree behaviors, an integrated tree monitoring framework based on geographic information systems (GIS) to detect and visualize the extent of tree displacement using smart sensing technology (SST) is introduced. The monitoring system aims to establish an early warning indicator system for monitoring the displacement angles of trees over the territory of Hong Kong's urban landscape. This pilot study highlights the importance of the monitoring system at an operational scale to be applicable in the urban areas showcasing the practical use of the Internet of Things (IoT) with an in-depth understanding of the wind-load effect toward the urban trees in the tropical and subtropical cities.

Keywords: urban trees; tree tilt; tree motion sensor; tree–wind interaction; smart sensing technology

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Newsletter - Tree Monitoring System: Early Tree Preservation

Appendix 4: PolyU InnoHub / Entrepreneurship Activities

Event	Date	Partnering Organisation(s)
Term Sheet Bootcamp 2020	31 Jul - 1 Aug 2020	Taiwan Startup Stadium
PolyU InnoHub x Poly-preneurs Webinar: Venture Talk with Alibaba Entrepreneurs Fund	2 Aug 2020	Alibaba Entrepreneurs Fund
LLP Bootcamp	5 & 12 Sep 2020	-
PolyU InnoHub x Booost Incubator Webinar: Sealing the Deal with Catalyst Ventures x TripGuru	24 Sep 2020	Booost Incubator
PolyU Entrepreneurship Society x JUMPSTARTER IdeaPOP! 2021 Webinar: Student Startup Award Secrets!	9 Oct 2020	Alibaba Entrepreneurs Fund
PolyU InnoHub x Poly-preneurs Webinar: Venture Talk with Fresh.fund	29 Oct 2020	Fresh.fund
Cyberport Entrepreneurship Programme Briefing Session	11 Nov 2020	Cyberport
PolyU InnoHub x AWS Educate: Cloud Career Pathways Competition 2020 Webinar- Cloud Computing: Must-knows for Future Co-founder!	19 Nov 2020	Amazon Web Services (AWS) Educate
PolyU InnoHub x AWS Educate: Cloud Career Pathways Competition 2020	19 Nov 2020 -19 Feb 2021	
Woofoo CARS x POC Briefing	10 Dec 2020	Woofoo
Hong Kong Techathon 2021	2-9 Jan 2021	HKSTP & six local universities
POC Briefing Session (The 7th HK University Students Innovation & Entrepreneurship Competition and City I&T Grand Challenge)	8 Feb 2021	-
Start-up Digital Marketing: Must-knows in 2021 and More	19 Feb 2021	-
PolyU Micro Fund 2021 – Online Briefing Session	2 Mar 2021	-
PolyU InnoHub x HKAI Lab AI Technology and Career Opportunities	11 Mar 2021	HKAI Lab
PolyU Micro Fund Scheme 2021 x HKDC Design Incubation Programme – Online Briefing Session	12 Mar 2021	HKDC
InnoHub Startup Consultation Clinic (Mar 2021)	23 Mar 2021	-
PolyU Micro Fund 2021 Briefing Session	30 Mar 2021	-
PolyU InnoHub Academy: Academic Entrepreneurship Series	31 Mar 2021	-
GBA Startup Postdoc Programme 2021 - Online Briefing Session	12 May 2021	-
PolyU Makerthon 2021	28 - 30 May 2021	-
InnoHub Startup Consultation Clinic (Jun 2021)	7 - 11 Jun 2021	-
Online Briefing Session for PolyU Maker Fund Programme 2021	11 Jun 2021	-

Appendix 5: List of Awards Won by PolyU Startups

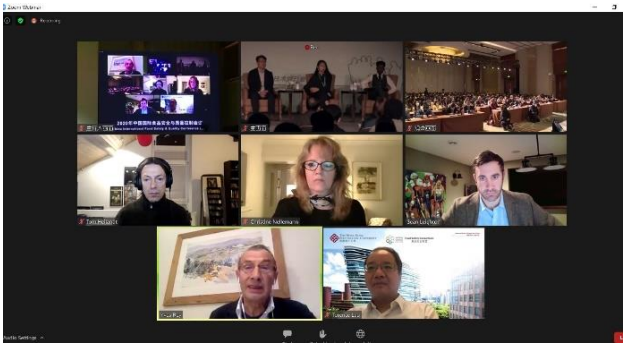
Startups / Startup Founders	Awards
Building Integration Perfection Limited (STEFG-PolyU China Entrepreneurship Fund Scheme 2018; PolyU Micro Fund Scheme 2012)	第十七屆世界華商創新獎 優異獎
Pokeguide Limited (PolyU Tech Launchpad Fund (TLF) Scheme 2017-18 & 2019-20; PolyU Micro Fund Scheme 2016)	Asia Smart App Awards 2020 - Public Sector Distinction Category - Gold Award
Mosi mosi Design Limited (PolyU Micro Fund Scheme 2018)	DFA Design for Asia Awards 2020 - Merit Award (Communication Design & Packaging)
Medmind Technology Limited (PolyU Micro Fund Scheme 2018)	Asia Social Innovation Award 亞洲社企創新獎 - HKIF Better Living Hong Kong Award 香港創新基金—香港好生活獎
Blue Pin Consulting (HK) Limited (PolyU Tech Launchpad Fund (TLF) Scheme 20-21; PolyU Micro Fund Scheme 2019)	2021 Geneva International Exhibition of Inventions (IPS Project) - Gold Medal 2021 Geneva International Exhibition of Inventions (Guess Services Robot Solution) - Silver Medal Hong Kong ICT Awards 2020 Smart Living (Smart Lifestyle) Certificate of Merit
OssPoly Limited (PolyU Micro Fund Scheme 2019)	China (Shanghai) International Exhibition of Inventions - Certificate of Award
Walkpner (PolyU Micro Fund Scheme 2019)	HKSEC 2019-20 - Champion
One Pair Straw (PolyU Micro Fund Scheme 2019)	Bright Future SME's Youth Creative Entrepreneurship Award Industry Cares 2020 - Outstanding Caring Awards 2020 Smart Design Award (Bronze)
Gabi Education Limited (PolyU Micro Fund Scheme 2020)	The 7th Hong Kong University Student Innovation and Entrepreneurship Competition - 1st Prize
Battery-free Electronics Limited (PolyU Micro Fund Scheme 2020)	National Exhibition of Inventions - Bronze Award

Startups / Startup Founders	Awards
Aprintlab Limited (PolyU Micro Fund Scheme 2020)	The 7th Hong Kong University Student Innovation and Entrepreneurship Competition - Merit Award
Innospire Technology Limited (PolyU Micro Fund Scheme 2020)	2021 Geneva International Exhibition of Inventions - Silver Medal Asia Smart App Awards 2020 - Bronze Prize HKSEC 2019-20 - 1st Runner-up
Bonejoy limited (PolyU Micro Fund Scheme 2020)	2021 Geneva International Exhibition of Inventions - Silver Medal
ZHIZI AI Education (Shen Zhen) Limited (PolyU Micro Fund Scheme 2020)	第六屆中國國際“互聯網+”大學生創新創業大賽 - 銅獎 中國深圳創新創業大賽深港澳高校預選賽暨第二屆深圳虛擬大學園創新創業大賽 - 深港澳高校預選賽(“深創賽)：團隊組入圍獎)
K farm social enterprise (PolyU Micro Fund Scheme 2020)	EASE Fund 2019/20 –和富可持續發展目標獎 - 銀獎 第七屆粵港澳台大學生創新創業大賽 - 優勝獎
CLAIRE Clinical AI Research Limited (PolyU Micro Fund Scheme 2020)	Innovate For Future 2020 (Innovation & Technology Competition) - Champion TechConnect - Global Innovation Awards
Guangdong Moogoo Biotechnology Ltd (PolyU Tech Launchpad Fund (TLF) Scheme 2021-22; PolyU Micro Fund Scheme 2020)	The 7th Hong Kong University Student Innovation and Entrepreneurship Competition - Third Prize 第十二屆“挑戰杯”中國大學生創業計畫競賽全國決賽 - 銀獎 第六屆中國國際“互聯網+”大學生創新創業大賽 - 金獎 2020 年廣東“眾創杯”創業創新大賽之大學生啟航賽：團隊組銅獎 中國深圳創新創業大賽深港澳高校預選賽暨第二屆深圳虛擬大學園創新創業大賽 - 深港澳高校預選賽(“深創賽)：團隊組優秀獎)
Sightfeeling Limited (PolyU Micro Fund Scheme 2020)	HKSEC Best Presentation (Semi Final) Award
深圳市锵盛数码有限公司 (STEFG-PolyU China Entrepreneurship Fund Scheme 2014)	2020 胡潤 Under30s 創業領袖

Startups / Startup Founders	Awards
深圳帕格精密系统有限公司 (PolyU Tech Launchpad Fund (TLF) Scheme 2017-18; STEFG-PolyU China Entrepreneurship Fund Scheme 2014)	中國 40 位 40 歲以下的商界精英
RR Fun Creative Lab Limited (PolyU Micro Fund Scheme 2020; PolyU Student Entrepreneurial Proof-of-Concept (POC) Funding Scheme 2019)	YDC Dare to Change Business Pitch Competition - HKSTPC Bronze Technopreneur Award
Evergreen Wearable Technology Limited (PolyU Micro Fund Scheme 2020; PolyU Student Entrepreneurial Proof-of-Concept (POC) Funding Scheme 2019)	Chun Wo Innovation Student Awards - Silver Award & The Best Business Potential Award
Project "Adopting VR and AR technology to minimize human casualty in construction site" (PolyU Student Entrepreneurial Proof-of-Concept (POC) Funding Scheme 2020)	The 7th Hong Kong University Student Innovation and Entrepreneurship Competition - Merit Award
FJ005 Limited (PolyU Student Entrepreneurial Proof-of-Concept (POC) Funding Scheme 2019)	The 7th Hong Kong University Student Innovation and Entrepreneurship Competition - Third Prize
Project "Milky assistant" (PolyU Student Entrepreneurial Proof-of-Concept (POC) Funding Scheme 2020)	The 7th Hong Kong University Student Innovation and Entrepreneurship Competition - Merit Award
Project "Slide 2 Dry" (PolyU Student Entrepreneurial Proof-of-Concept (POC) Funding Scheme 2020)	2020 Global Student Innovation Challenge - Merit Award
Project "Bedman" (PolyU Student Entrepreneurial Proof-of-Concept (POC) Funding Scheme 2020)	2020 Global Student Innovation Challenge - Best Presentation Award
Advwhere Limited (HKSTP-PolyU Tech Incubation Fund (TIF) Scheme 2015-16)	Forbes 30 UNDER 30 Asia 2021

Startups / Startup Founders	Awards
Zunosaki Limited (HKSTP-PolyU Tech Incubation Fund (TIF) Scheme 2015-16)	Hong Kong ICT Awards 2020 - Smart Living (Smart Healthcare) Silver Award
ASA Innovation & Technology Limited PolyU Tech Launchpad Fund (TLF) Scheme 2018-19 & 2019-20; HKSTP-PolyU Tech Incubation Fund (TIF) Scheme 2017-18)	iF Gold Award 2021 Best of Hong Kong 2021 TOP 25 Building Technology Hong Kong ICT Awards 2020 Smart Living (Smart Home) Silver Award
Qualife Hong Kong Limited (PolyU Tech Launchpad Fund (TLF) Scheme 2019-20)	第十七屆世界華商高峰會 創意新星獎
Active Biotechnology (Hong Kong) Company Limited (PolyU Tech Launchpad Fund (TLF) Scheme 2020-21)	第十七屆世界華商高峰會 創意新星獎
Grand Rise Technology Limited (PolyU Tech Launchpad Fund (TLF) Scheme 2020-21)	2021 Geneva International Exhibition of Inventions Gold medal
WIN VICTORY ENTERPRISES (PolyU Tech Launchpad Fund (TLF) Scheme 2020-21)	HKICTA Smart Mobility Award – Certificate of Merit Hong Kong Retail Innovation Award Winner 零售商 / 科技供應商 / 初創科技公司; 2020 逆境表揚獎
Eieling Medical Limited (PolyU Tech Launchpad Fund (TLF) Scheme 2021-22)	2021 Geneva International Exhibition of Inventions Silver medal

Appendix 6: Marketing, Networking and Engagement Activities

Date	Event	Photo
Sep-Nov 2020	**Booting Re-industrialisation Webinar Series** This series comprised four webinars to explore Hong Kong's innovation ecosystem and technological readiness for re-industrialisation, and showcased PolyU's research excellence in AI, Big Data analytics, textile technology and biotechnology.	
Oct 2020-Mar 2021	**Virtual Innovation and Entrepreneurship Tour for Freshmen** This virtual tour introduced PolyU's innovative research achievements and wide-ranging entrepreneurship support to students upon their entry to the University, sowing the seeds of entrepreneurship among them.	
Nov 2020	**China Hi-Tech Fair 2020** PolyU showcased its textile and smart sensing technologies, along with the expertise, professional services, research outputs and entrepreneurship facilities at PolyU Shenzhen Base. The exhibition helped to strengthen its foothold in GBA market.	
Nov 2020	**China International Food Safety and Quality Conference 2020** PolyU's Food Safety Consortium (FSC) participated in the conference to showcase PolyU's expertise and research excellence in food safety and quality. FSC has been in regular communication with European partners of the DISH Global Centre for Food Safety and Quality to explore research collaboration opportunities.	

Date	Event	Photo
Nov 2020	**Thematic Seminar on Smart Manufacturing during SmartHK in Chengdu** Speakers from PolyU and potential partners GS1HK and Danone Greater China shared the latest technological development and integration in smart manufacturing with the industry players in Mainland China.	
Nov 2020-Apr 2021	**Enlighten@PolyU Webinar Series** The webinar series enhanced alumni and partner engagement as well as to showcase PolyU's research excellence in specialised expert areas, attracting extensive participation from Hong Kong, Mainland China and overseas.	
Dec 2020	**Smart Sensing and Innovative Communication Technology Sharing Forum (智能傳感和創新通訊技術交流對接會)** A joint effort by PolyU and SUSTech, the technology sharing forum held in Shenzhen aimed to attract investments by promoting its research excellence and reaching out to the GBA markets.	
Dec 2020-Feb 2021	**CEO Shadowing Programme** CEO Club, PolyU and CEO Club jointly organised the "CEO Shadowing Programme" to enable PolyU students to learn about leadership and entrepreneurial process through mutual connection and interaction, preparing them for their future entrepreneurial pursuits.	

Date	Event	Photo
Jan 2021	**The 5th Asia-Pacific Food Safety International Conference (APFSIC)** Organised by PolyU's Food Safety Consortium, APFSIC brought together over 80 experts from supranational bodies, government, industry and academia to discuss the latest trends and technology challenges in food safety globally and across the Asia Pacific region.	
Mar & May 2021	**Special Edition 2021 Inventions Geneva Evaluation Days – Virtual Event and Chief Executive Reception** PolyU participated in competitive virtual event with two academic-led startups and four academic projects from different disciplines, garnering six awards. The result generated wide publicity coverage. The award-winning teams were honoured at the Chief Executive Reception dedicated to winners from Hong Kong.	
Jun 2021	**PolyU Tech Salon 2021 Webinar on FashTech** Featuring PolyU experts in the textiles and clothing domain, the kick-off webinar raised awareness of PolyU's expertise in developing novel textile technologies and entice collaboration. It also enlightened the audience on the potential of FashTech which extends beyond the textiles and clothing industry.	
Jun 2021	**Sustainability Lecture Series in Collaboration with Consulate General of France in Hong Kong and Macau** PolyU researchers from Department of Building and Real Estate, and Department of Civil and Environmental Engineering presented their projects on smart cities, while those from Department of Electrical Engineering, Research Institute for Smart Energy, and Research Institute for Sustainable Urban Development gave talks on 'Power the Future: Potential and Challenges, from Energy Storage to Green Building'.	

Date	Event	Photo
Jun 2021	**BIO Digital 2021** PolyU participated in the BIO Digital 2021 to promote the University's domain expertise in life sciences and healthcare. One-on-one partnering meetings will be arranged to identify industry needs and explore possibility of collaboration.