Research Assessment Exercise 2020
Impact Case Study

University: The Hong Kong Polytechnic University
Unit of Assessment (UoA): 14 - Mechanical engineering, production engineering (incl. manufacturing & industrial engineering), textile technology and aerospace engineering

Title of case study: Research and development of 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, 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, which were required for building a model to plan the rovers' progression. The CPS are still functioning on the front and far sides of the moon, 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, valued at over HK$ 80 million. The CPS has also attracted additional industrial research funding of more than HK$ 60 million for several civil projects. Moreover, it was transferred to NISI (HK) Ltd., a start-up, which then raised investment and now employs over 140 staff members.

(2) Underpinning research

The Hong Kong Polytechnic University (PolyU) research underpinning the development of the camera pointing system (CPS) 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 CPS was developed after 20 years of research in several diverse areas, such as precision engineering, mechatronics, materials, design optimization, thermo-modelling, and micro/nano fabrication [R3], integrating the findings 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 a panel of experts who examined every detail 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.

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.

(3) References to the 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) Details of the impact

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 pressure plus extreme temperatures (hot and cold) and surface roughness; lubricant migration in vacuum, under different pressure, speed of interaction; and surface crack generation and propagation of cable coating installations such as Kapton and PTFE under extreme temperature (hot and cold) in vacuum to determine the amount of bending radius sustainable by a particular cable and its life expectancy. The industrial applications include the micro-moulding of transdermal hollow microneedles (a new domain of medical robotics), high reliability UAV (unmanned aerial vehicles), and new robots capable of repairing water supply pipelines.

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 K.L. Yung, 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, with funding in excess of HK$ 80 million: Chang'e-5, Chang'e-6, and Mars 2020. 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 in excess of HK$ 50 million from industries and grants of over HK$ 10 million 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. 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. Growing rapidly since 2013, this startup now employs over 140 staff in Hong Kong and mainland China [S3] and is focused entirely on development of this surgical system.

This system has created gained significant interest among surgeons and the general public [S8]. As confirmed by the CEO, Bio-medical Engineering have "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]. The CEO confirms this would not have been possible without Professor Yung's pioneering work.

(5) Sources to corroborate the impact

[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. David T. Wong, 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