Research Assessment Exercise 2020
Impact Case Study

University: The Chinese University of Hong Kong

Unit of Assessment (UoA): 14 mechanical engineering, production engineering (incl. manufacturing & industrial eng

Title of case study: Robotic algorithm and technology development for surgical and logistics applications

(1) Summary of the impact (indicative maximum 100 words)

The impact of our research is evidenced in two areas: (i) visual-based robotic servoing algorithms for logistics and surgical applications; (ii) flexible robotic technology for early stage lung cancer diagnosis. As a direct result: Two technology start-ups were created with a total valuation of $XXM RMB and an annual revenue of $XXM RMB; Many internationally renowned companies have adopted this technology for their operations; In addition, two semi-autonomous assistive surgical robots were created and, for the first time in Asia, tested on human subjects; This flexible robotic technology laid the technological foundation of a system on early stage lung cancer diagnosis developed by another company.

(2) Underpinning research (indicative maximum 500 words)

In the past two decades, robotic algorithm and technology development have created a profound impact in the logistics industry and surgery. For example, vision-based, autonomous vehicles have become increasingly common in the warehouse to transport inventory, while surgical robots have been widely adopted in many surgical specialties and have been shown to improve clinical outcomes such as reducing blood loss. Nevertheless, existing visual-based robotic servoing systems still rely heavily on expensive vision systems and complex calibration processes to obtain precise depth information, slowing down the widespread adoption of this technology. On the medical side, existing surgical tools are predominantly straight and rigid, preventing them from reaching anatomical regions with low accessibility without opening a large incision. Current surgical robots also lack the advanced intelligence to support a more efficient clinical workflow by transferring time-consuming, repetitive tasks from the surgeon to a robot. Thus, the development of visual-based robotic servoing algorithms and flexible robotic technology have been paid a great deal of research attention, the outcomes of which will create significant social, economic, and clinical value to the society.

During 2013-2019, Prof. Y. H. Liu and Prof. Kwok Wai Samuel Au of the CUHK team have been conducting research on visual-based robotic servoing algorithms and flexible robotic technology for both logistics and surgical applications. Based upon the principle of the depth-independent image Jacobian matrix proposed by us in 2006[1], we developed the first adaptive visual servoing algorithms for autonomous tissue manipulation that does not require knowledge of the vision hardware or soft tissue models[2]. The research was first applied to logistics applications, leading to the establishment of two successful Shenzhen-based startup companies, which are currently worth over $XXM RMB in total. We also applied the algorithms to develop two semi-autonomous assistive surgical robots for laparoscopic hysterectomy and sinus surgery. For the first time in Asia, the CUHK team successfully conducted human trials (> 10 human subjects) using these assistive robots to validate their safety and efficacy (S4).

Since 2008, Prof. Au of the CUHK team has proposed various design and control methodologies for flexible robots that provide exceptional precision and stability through the use of a hybrid composite design and the fiber optics sensor feedback(S3, S7, S8)[4]. The proposed design and control algorithms were successfully applied to develop high performance soft robotic actuators, while also helping a company to develop a system for early stage lung cancer diagnosis (S3). The device received US FDA clearance in Feb 2019 and has been commercially available to patients in selected US hospitals. The success of this invention also impacted the product development strategy of that company by forming a $XXM USD joint-venture in 2016 to co-develop a device to tackle lung cancer in China. Recently, the CUHK team was awarded a prestigious InnoHK grant (~$500M HKD) to establish an international medical robotic centre in HK, in collaboration with Johns Hopkins University, Imperial College London, and ETH Zurich to further develop these technologies to impact patients' life (S6).

(3) References to the research (indicative maximum of 6 references)

[1]**Y. H. Liu**, H. Wang, C. Wang and K. K. Lam, "*Uncalibrated visual servoing of robots using a depth-independent interaction matrix*", IEEE Trans. on Robotics, vol. 22, no. 4, pp. 804-817, 2006.

[2]D. Navarro-Alarcon, **Y. H. Liu**, J. G. Romero, and P. Li, "*Model-free visually servoed deformation control of elastic objects by robot manipulators*", IEEE Trans. on Robotics, vol. 29, no. 6, pp. 1457-1468, 2013.

[3]K. Wang, **Y. H. Liu**, and L. Y. Li, "*Visually servoed trajectory tracking of nonholonomic mobile robots without direct position measurement*", IEEE Trans. on Robotics, vol. 30, no. 4, pp. 1026-1035, 2014.

[4]H-C Fu, Justin D-L Ho, K-H Lee, Y.C. Hu, **K. W. Samuel Au**, K-J Cho, K.Y. Sze, and Ka-Wai Kwok, "*Interfacing soft and hard: a spring reinforced actuator*", Soft Robotics (Accepted on Jul 10, 2019. Published on 5 Oct 2019, https://doi.org/10.1089/soro.2018.0118)

(4) Details of the impact (indicative maximum 750 words)

We treat each of the two findings from Section 2 separately in explaining the impact that has arisen from the research, along with evidence and indicators of the significance and reach of each impact area.

The first impact area of vision-based robotic control algorithm development is significant because existing visual-based robotic servoing relies heavily on expensive vision systems and complex calibration processes to obtain precise depth information. Based on the principle of the depth-independent image Jacobian matrix proposed by us in 2006[1], we have created an innovative method to address this problem without requiring precise knowledge of the vision hardware or the properties of soft objects/tissues during manipulation. We applied these methods to develop novel devices and products for both industry and medical applications. On the industry side, the CUHK team has applied the technology to develop high precision 3D imaging, vision-based SLAM and motion control technologies for the logistics industry, leading to the birth of two CUHK Shenzhen-based startup companies. The technology licensed to Company A has made a crucial impact to their company's product development. Their products have been widely adopted by major companies in the logistics and manufacturing industries. Up to now, the company has attracted over XX million USD investment and has XX employees (S1). Company B (S2) applied our technology to develop real-time high-resolution 3D imaging solutions for product inspection, parcel sorting, material feeding, etc. With our underpinning research [1][3], company B developed the world-largest FOV 3D system with 1mm accuracy and also formed partnerships with the industry leaders. The company has attracted huge investment and create job opportunities in Hong Kong and Shenzhen. The success and impact of their product is further evidenced by the fact that they were champions in the innovation and entrepreneurship contest held by the Innovation & Entrepreneurship Education Alliance of China(S2).

On the medical side, the same technology also led to the development of two semi-autonomous assistive surgical robots for laparoscopic hysterectomy and sinus surgery. These robots were designed to replace the physician/assistant to position the uterus during total laparoscopic hysterectomy or position the endoscope in regular Functional Endoscopic Sinus Surgery procedures, providing a more efficient clinical workflow by transferring time consuming, repetitive tasks from the physician to a robot. In the period of 2016-2018, the CUHK team was the first in Asia to successfully perform human trials (> 10 human subjects) in Hong Kong using these assistive robots to validate their safety and efficacy (S4).

Prof. Au of the CUHK team has also made significant contributions in the development of flexible robotics technology for medical interventions. Since 2008, Prof. Au and other researchers have filed multiple patents (S3, S7, S8)[4] on the use of distal fiber optics feedback to actively improve the precision and stiffness of a surgical instrument with inherent compliance and friction. This groundbreaking technology enables physicians to perform interventional tasks in confined anatomical areas with much higher precision and dexterity than they could before, laying the technological foundation for robot-assisted catheter system development. The General Manager and VP of Engineering at Company C also praised that (S3): "*The technology first developed by Prof. Au of the CUHK team is one of the key differentiators for robot-assisted catheter system for accurate lung nodule biopsy*". In 2018, 2.09 million new cases of lung cancer occurred globally and the 5-year survival rate (~18%) of the patients remains low compared to other prevalent cancers in part due to the delay in diagnosis (S5). Precise early stage lung cancer diagnosis is often hard to obtain because early stage lung nodules are small and located deep within the peripheral lung regions. Conventional biopsy solutions such as the CT-guided percutaneous and the transoral bronchoscopic approaches either expose a great risk of pneumothorax or have a low diagnostic yield. The underpinning research helps to develop a robotic catheter system that provides doctors with the high degree of stability and precision required for accurate tissue biopsy [4] (S3, S7, S8). This device underwent a 30-patient clinical trial in Brisbane, Australia (2017) with good results and later received the US FDA clearance in Feb 2019. Since September 2019, selected hospitals in the USA have started to commercially offer robotic lung biopsy to their patients (S3). Nevertheless, this invention also impacted the company's business plan that potentially helps to battle the sharp rise in China's lung cancer rate. The General Manager of Company C stated that (S3): "*Due to the success of the project, in 2016, our company formed a $XXM USD joint-venture with another company to co-develop this device to tackle the lung cancer in China*."

In May 2019, the CUHK team was awarded a prestigious InnoHK grant (~ $500M HKD) to establish an international medical robotic centre in HK in collaboration with Johns Hopkins University(USA), Imperial College London (UK), and ETH Zurich (Switzerland) to further develop these technologies to impact patients' life (S6). As of now, this grant is considered as one of the largest research and development grants in Hong Kong

(5) Sources to corroborate the impact (indicative maximum of 10 references)

S1 – Letter received from CEO of Company A
S2 – Letter received from CEO of Company B
S3 – Letter received from VP of Company C
S4 – PHD Thesis

S5 – Maomao Cao and Wanging Chen, "Epidemiology of lung cancer in China," Thorac Cancer, 10(1), pp. 3-7, Jan 2019.
S6 – Approval letter from Hong Kong Innovation and Technological Commission for the admission to the InnoHK
S7 – Prof. Au's patent on flexible robot technology. Patent Num: US XX.
S8 – Prof. Au's patent on flexible robot technology. Patent Num: US XX.