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(please insert ref. above)

The Research Grants Council of Hong Kong
NSFC/RGC Joint Research Scheme
Joint Completion Report

(Please attach a copy of the completion report submitted to the NSFC by the Mainland researcher)

Part A: The Project and Investigator(s)

1. Project Title 3D Design Algorithms and Dexterous Robotic Sewing for Customized Garment Fabrication

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

	Hong Kong Team	Mainland Team
Name of Principal Investigator *(with title)*	Dr. PAN Jia	Prof. Zhang Xinyu
Post	Assistant professor	Associate professor
Unit / Department / Institution	Department of Computer Science, The University of Hong Kong	School of computer science & software engineering / East China Normal University
Contact Information	Dr. PAN Jia jpan@cs.hku.hk	Prof. Zhang Xinyu xyzhang@sei.ecnu.edu.cn
Co-investigator(s) *(with title and institution)*		

3. Project Duration

	Original	Revised	Date of RGC/ Institution Approval *(must be quoted)*
Project Start date	2017/1/1		
Project Completion date	2020/12/31		
Duration *(in month)*	48		
Deadline for Submission of Completion Report	2021/12/31		

Part B: The Completion Report

5. Project Objectives

5.1 Objectives as per original application

1. 2D Sewing pattern parsing and 3D sewing sequence generation;

2. Physical realistic sewing simulation;

3. Deformable object manipulation using robotic arms;

4. 2D/3D automated sewing using general robotic arms and sewing devices.

5.2 Revised Objectives

Date of approval from the RGC: _____

Reasons for the change: _____

_____

1.
2.
3. ....

6. Research Outcome

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

1. The grant has been used to train 5 PhD candidates (Part C 10) working on this project. Three research assistants and one postdoc fellow were also hired.
2. We have built a robot prototype for manipulating clothes. The system is then further extended to handle general 3D deformable objects, such as 3D sponge. The potential application includes robotic surgery where the robot needs to manipulate/interact with the soft body. During the development of the robotic prototype, we have solved many challenges including the tracking and reconstruction of deformable cloth status using computer vision, automatic parameter tuning for cloth simulator to minimize the difference between simulated results and the real cloth motion, and the learning-based control for manipulating deformable clothes to desired states.
3. We have built specialized hardware useful for deformable cloth grasping and manipulation. In particular, we have designed one dexterous gripper for deformable object grasping and manipulation. We have designed a new tactile sensor based on magnetic principle to provide high quality sensing to the deformable object, e.g., the sensor can distinguish the difference between different cloth materials.
4. One USA patent is applied and filed for this prototype.
5. We have done research around the topic of cloth manipulation. We have published 13 journal papers and 3 conference papers, all in the top robotics journals (IEEE Robotics and Automation Letters, International Journal of Robotics Research) and conferences (ICRA and Humanoids). We have 3 journal papers that have been submitted (2 to IEEE Robotics and Automation letters and 1 to Science Robotics) and are currently in the minor revision step.

In particular:

a) We have studied how to control and grasp general deformable object including clothes. The publication includes 4 journals (2018-B, 2019-C, 2019-E, 2021-A) and 1 conference paper (2018-E) summarized in part C.
b) We have solved the self-occlusion challenge of the deformable object manipulation by providing a real-time simultaneous tracking and reconstruction algorithm for deformable objects (2018-C)
c) We have studied how to accomplish real-time control of high-DOFs objects, which is important for cloth manipulation because it is a high-DOF object. We have published 2 journal papers, i.e. 2017-B, 2018-A in part C.
d) We have studied how to use deep reinforcement learning to accomplish intelligent control. This is critical for cloth manipulation and sewing task because the cloth's dynamics is so complex that we need to learn from data how to control it. We also applied the results in mobile robots with the output of 6 journal papers (2017-A, 2019-A, 2019-B, 2020-A, 2020-B, 2020-C in part C) and 1 conference paper (2019-D in part C). We recently also successfully applied our developed techniques in cloth grasping and sewing (2019-C, 2021-D)
e) We also studied how to let human help the robot to deal with the challenging cloth grasping and manipulation tasks. The output is 2 conference papers (2018-F, 2021-D).
f) We also studied how to develop specific hardware for the cloth manipulation, including the special gripper and tactile sensor. The outputs are 3 journal papers (2019-D, 2021-B, and 2021-C).

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

Future plan:

Our next step is trying to apply our technique in real-world industrial tasks for garment manufacturing. We have built a close collaboration with Rokae Robotics, a leading robotics company in mainland China. One of Rokae's products is a robotic platform for cloth sewing, which has been deployed in some factories. However, their system needs tedious low-level programming, careful controller parameter tuning and long-time debug for fixing the temporal logic issues, and thus is far from being convenient and robust for the garment industry. We will work with Rokae to further refine and improve our work on learning-based deformable object manipulation to meet the challenges in real industry.

In addition, as part of the AIR-InnoHK team made up of researchers from HKU and Tohoku University (Japan), we are developing novel robotic techniques to revolutionize and automize the traditional manufacturing process of clothes. The Hong Kong PI of this RGC-NSFC joint project is leading one project about human-robot collaborative garment manufacturing in the 0.4 billion Innovation Hong Kong project. We will use this great opportunity to improve the technique developed in this RGC-NSFC joint project to the level of being applicable to industrial tasks.

7. The Layman's Summary

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

This project provides a novel solution for garment manufacturing where sophisticated robots are augmented by intelligent algorithms and compliant grippers to achieve highly diversified, small-lot and personalized garments fabrication with high efficiency and flexibility. In our prototype system, the robot has combined a wide variety of techniques, including computer vision, machine learning, advanced tactile sensing, dexterous gripper design, and robotic control, to accomplish flexible and accurate manipulation of clothes.

Part C: Research Output

8. Peer-reviewed journal publication(s) arising <u>directly</u> from this research project

(Please attach a copy of each publication and/or the letter of acceptance if not yet submitted in the previous progress report(s). All listed publications must acknowledge RGC's funding support by quoting the specific grant reference.)

The Latest Status of Publications				Author(s) *(**bold** the authors belonging to the project teams and denote the corresponding author with an asterisk*)*	Title and Journal/ Book *(with the volume, pages and other necessary publishing details specified)*	Submitted to RGC *(indicate the year ending of the relevant progress report)*	Attached to this report *(Yes or No)*	Acknowledged the support of this Joint Research Scheme *(Yes or No)*	Accessible from the institutional repository *(Yes or No)*
Year of publication	Year of Acceptance *(For paper accepted but not yet published)*	Under Review	Under Preparation *(optional)*						
2017-A				Pinxin Long, Wenxi Liu, Jia Pan*	"Deep-learned Collision Avoidance Policy for Distributed Multiagent Navigation", IEEE Robotics and Automation Letters, 656-663, 2(2), 2017	2018	Yes	Yes	Yes
2017-B				Yajue Yang, Yuanqing Wu, Jia Pan*	"Parallel Dynamics Computation Using Prefix Sum Operations", IEEE Robotics and Automation Letters, 1296-1303, 2(3), 2017	2018	Yes	Yes	Yes

2018-A				Yajue Yang, Yuanqing Wu, Jia Pan*	"Unified GPU-Parallelizable Robot Forward Dynamics Computation Using Band Sparsity", IEEE Robotics and Automation Letters, 203-209, 3(1), 2018	2018	Yes	Yes	Yes
2018-B				Zhe Hu, Peigen Sun, Jia Pan*	"Three Dimensional Deformable Object Manipulation Using Fast Online Gaussian Process Regression", IEEE Robotics and Automation Letters, 979-986, 3(2), 2018	2018	Yes	Yes	Yes
2018-C				Tao Han, Xuan Zhao, Peigen Sun, and Jia Pan*	"Robust shape estimation for 3d deformable object Manipulation", Communications in Information and Systems, 18(2):107–124, 2018	2020	Yes	Yes	Yes

2019-A				Tingxiang Fan, Xinjing Cheng, Jia Pan*, Pinxin Long, Wenxi Liu, Ruigang Yang, Dinesh Manocha	"Getting Robots Unfrozen and Unlost in Dense Pedestrian Crowds", IEEE Robotics and Automation Letters, 1178-1185, 4(2), 2019	2018	Yes	Yes	Yes
2019-B				Zhe Hu, Jia Pan*, Tingxiang Fan, Ruigang Yang, Dinesh Manocha	"Safe Navigation with Human Instructions in Complex Scenes", IEEE Robotics and Automation Letters, 753-760, 4(2), 2019	2018	Yes	Yes	Yes
2019-C				Biao Jia, Zherong Pan, Zhe Hu, Jia Pan, Dinesh Manocha	"Cloth Manipulation Using Random-Forest-Based Imitation Learning", IEEE Robotics and Automation Letters, 4(2):2086–2093, 2019	2018	Yes	Yes	Yes
2019-D				Zhong Zhang, Tao Han, Jia Pan*, and Zheng Wang	"Design of anthropomorphic fingers with biomimetic actuation mechanism." IEEE Robotics and Automation Letters, 4(4):3465–3472, 2019	2020	Yes	Yes	Yes

2019-E				Zhe Hu , Tao Han , Peigen Sun , Jia Pan* , and Dinesh Manocha	"3D deformable object manipulation using deep neural networks." IEEE Robotics and Automation Letters, 4(4):4255–4261, 2019.	2020	Yes	Yes	Yes
2020-A				Tinxiang Fan, Pinxin Long, Wenxi Liu, and Jia Pan*	"Distributed multi-robot collision avoidance via deep reinforcement learning for navigation in complex scenarios." International Journal on Robotics Research, 39(7):856–892, 2020.	2020	Yes	Yes	Yes
2020-B				Zhiming Chen, Tingxiang Fan, Xuan Zhao, Jing Liang, Cong Shen, Hua Chen, Dinesh Manocha, Jia Pan*, and Wei Zhang*	Autonomous social distancing in urban environments using a quadruped robot. IEEE Access, 2020	2020	Yes	Yes	Yes

2020-C				Tingxiang Fan and Pinxin Long and Wenxi Liu and Jia Pan* and Ruigang Yang and Dinesh Manocha	"Learning resilient behaviors for navigation under uncertainty environments", In IEEE International Conference on Robotics and Automation (ICRA), 5299-5305, 2020.	2020	Yes	Yes	Yes
2021-A		2021, in minor revision		Hu Zhe, Yu Zheng*, Jia Pan*	"Living Object Grasping using Two-Stage Graph Reinforcement Learning", Submitted to IEEE Robotics and Automation Letters	2021	Yes	Yes (in the final accepted version)	Not yet
2021-B		2021, in minor revision		Youcan Yan, Jia Pan*	"Fast Localization and Segmentation of Tissue Abnormalities by Autonomous Robotic Palpation", Submitted to IEEE Robotics and Automation Letters	2021	Yes	Yes (in the final accepted version)	Not yet
	2021-C			Youcan Yan Zhe Hu, Zhengbao Yang, Wenzhen Yuan, Chaoyang Song, Jia Pan*, Yajing Shen*	"A soft magnetic skin for self-decoupled and super-resolved tactile sensing", submitted to Science Robotics	2021	Yes	Yes	Not yet

2021-D		2021, in submission		Xuan Zhao, Tingxiang Fan, Yanwen Li, Yu Zheng, Jia Pan*	"An Efficient and Responsive Robot Motion Controller for SafeHuman-Robot Collaboration", submitted to IEEE Robotics and Automation Letters	2021	Yes	Yes (in the final accepted version)	Not yet

9. Recognized international conference(s) in which paper(s) related to this research project was/were delivered *(Please attach a copy of each delivered paper. All listed papers must acknowledge RGC's funding support by quoting the specific grant reference.)*

Month/Year/ Place	Title	Conference Name	Submitted to RGC *(indicate the year ending of the relevant progress report)*	Attached to this report *(Yes or No)*	Acknowledged the support of this Joint Research Scheme *(Yes or No)*	Accessible from the institutional repository *(Yes or No)*
May/2018/Brisbane 2018-D	Towards Optimally Decentralized Multi-robot Collision Avoidance via Deep Reinforcement Learning	IEEE International Conference on Robotics and Automation	2018	Yes	Yes	May/2018/Brisbane
May/2018/Brisbane 2018-E	Manipulating Highly Deformable Materials Using a Visual Feedback Dictionary	IEEE International Conference on Robotics and Automation	2018	Yes	Yes	May/2018/Brisbane
Nov. 6-9, 2018, Beijing 2018-F	Collaborative Human-Robot Motion Generation using LSTM-RNN	IEEE International Conference on Humanoid Robots	2018	Yes	Yes	Nov. 6-9, 2018, Beijing

10. Student(s) trained *(Please attach a copy of the title page of the thesis.)*

Name	Degree registered for	Date of registration	Date of thesis submission/ graduation

Zhe HU	PhD.	2017/9	2021/9
Yajue YANG	PhD.	2018/1	2022/1
Zhong ZHANG	PhD.	2017/9	2021/9
Tingxiang Fan	PhD.	2018/11	2022/11
Dawei Wang	PhD.	2018/9	2022/9

11. Other impact *(e.g. award of patents or prizes, collaboration with other research institutions, technology transfer, etc.)*

USA Patent:

1. Jia Pan, Zhe Hu, System and Method for Manipulating Deformable Objects, 6 Feb 2018, Filed, Priority No. 15889,490, USA patent

Collaboration with other research institutes:

1. Collaborating with the Fuzhou University on computer vision techniques for deformable object
2. Collaborating with the Guangdong university of technology on human-robot collaboration and industrial robots
3. Collaborating with Rokae Robotics Inc. on cloth manufacturing system development
4. Collaborating with the robotics institute at SUSTECH (Southern University of Science and Technology) general robotic manufacturing research

Other Grants:

As a part of the AIR-InnoHK team made up of researchers from HKU and Tohoku University (Japan), we are developing novel robotic techniques to revolutionize and automize the traditional manufacturing process of clothes. The Hong Kong PI of this RGC-NSFC joint project is leading one project about human-robot collaborative garment manufacturing in the 0.4 billion Innovation Hong Kong project. Our goal is to improve the technique developed in this RGC-NSFC joint project to the level of being applicable to industrial tasks.

12. Statistics on Research Outputs *(Please ensure the summary statistics below are consistent with the information presented in other parts of this report.)*

	Peer-reviewed journal publications	Conference papers	Scholarly books, monographs and chapters	Patents awarded	Other research outputs (Please specify)
No. of outputs arising directly from this research project [or conference]	13 (plus 1 accepted and 3 in submission)	3	0	1	Collaboration with Fuzhou University, Guangdong university of technology, Rokae Robotics, and Southern University of Science and Technology; Contribute to the successful application of Innovation Hong Kong Project.