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Article / Book Information

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Title(English)	A Novel Design of Parallel Continuum Robot with Enhanced Dexterity and Rigidity
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Category(English)	Doctoral Thesis
種別(和文)	論文要旨
Type(English)	Summary

（博士課程）
Doctoral Program

論 文 要 旨

THESIS SUMMARY

系・コース： Department of, Graduate major in	機械 系 機械 コース	申請学位（専攻分野）： Academic Degree Requested	博士 （ 工学 ） Doctor of
学生氏名： Student's Name	LEI YUHANG	審査員主査： Chief Examiner	武田 行生

要旨（英文 800 語程度）
Thesis Summary（approx.800 English Words ）

In this work, the author proposed a novel design of a Parallel Continuum Robot (PCR) that achieves both high dexterity and rigidity which are two essential characteristics for expanding the application scope of PCRs in fields such as minimally invasive surgery, industrial automation, and space exploration. This thesis presents a systematic investigation into the design, modeling, and experimental validation of the proposed PCR design(s), focusing on enhancing twisting motion and structural rigidity as well as other features.

In 'Chapter 1: Introduction', the thesis started with a thorough introduction about PCRs by introducing the state of the art of the continuum robots and the parallel robots of which their combination leads to the PCR concept. Then the motivation of the thesis was introduced which lies in enhancing the twist motion ability of conventional PCR design and the corresponding objective was set as 'to develop a Parallel Continuum Robot design that achieves high dexterity, with a focus on enhancing twisting motion capability while maintaining slender shape and substantial rigidity'.

In 'Chapter 2: Methodology, Mechanism, and Modeling', two types of proposed PCR designs were introduced which are the 3-DOF mechanism labeled as 3PFS-FR and the 6-DOF mechanism labeled as 6PFS-PFS/FS (contains two variations, i.e., 6PFS-PFS and 6PFS-FS). The detailed introduction of the mechanism and the prototypes were given as well as the theoretical foundation for modeling the robots which is the Cosserat/Kirchhoff rod theory. The kineto-static models for the proposed designs were derived, and the equations are solved using numerical methods, i.e., the shooting method. As a result, the theoretical models of the proposed robots were developed successfully.

'Chapter 3: 3PFS-FR Robot Analysis and Experiments' focuses on the analysis and validation of the 3PFS-FR robot. Specifically, the orientation workspace, compliance and twisting singularity were analyzed through MATLAB simulation and the motion accuracy was validated through experiments. Besides, comparisons with similar design variations revealed the influence of the type of the joints used for connecting the driving rods to the end disc and the number of the intermediate discs.
The results showed that the 3PFS-FR robot exhibits significantly improved dexterity (specifically the twisting motion ability) compared to conventional PCR designs. However, the results also revealed its limitation of twisting motion singularity, low structural rigidity and low motion accuracy when twisting motion included.

In 'Chapter 4: 6PFS-PFS/FS Robot Analysis and Experiments', building on the insights gained from the 3PFS-FR robot, the author introduced the 6PFS-PFS/FS robot which was designed to achieve higher rigidity while preserving high dexterity. Similarly, this chapter introduced the result of reachable/orientation workspace analysis, singularity compliance analysis, motion accuracy experiments and wrench sensing experiments. The results showed that both 6PFS-PFS and 6PFS-FS robots have enhanced structural rigidity compared with the 3PFS-FR robot while still preserving higher dexterity than conventional PCRs. Besides, other advantages were revealed including no twisting singularity, higher motion accuracy and wrench sensing ability. More specifically, the comparison between 6PFS-PFS and 6PFS-FS robots indicated that better performance can be achieved by properly

choosing between the two types (work modes).

As summarized in 'Chapter 5: Conclusion and Future work', this thesis introduced novel 3-DOF and 6-DOF parallel continuum robot designs that address the limitations of existing PCRs. The proposed designs achieved a significant increase in dexterity, particularly in twisting motion, while improving structural rigidity. The combination of simulations and experimental validations demonstrated the effectiveness of the designs and their potential for practical applications. Future work can focus on further optimizing the control algorithms to improve computation speed, detect and prevent rod collision, and find miniaturization strategies.