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論 文 内 容 の 要 旨

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論文題目　**Control and Analysis of Robot Arm using Flexible Pneumatic Cylinders and Embedded Controller**

Recently, it has been desired strongly to develop a system to aid in nursing care and to support the activities of daily life for the elderly and the disabled. The actuator required for such a system needs to be flexible so as not to injure the human body. The purpose of our study is to develop a flexible robot arm for wrist rehabilitation by using the flexible pneumatic cylinders. In this study, a master-slave attitude control and a trajectory control of the flexible robot arm will be proposed and tested. This robot arm has three degree-of-freedom; bending, extending and contracting. And this robot arm will be applied to a rehabilitation device for human wrist. The master-slave control is necessary when a physical therapist gives a rehabilitation motion to a patient. The trajectory control is necessary when a sequential rehabilitation motion is applied to a patient. In this study, an analytical model of the flexible robot arm will be presented for the master-slave and the trajectory control. For the trajectory control system, two analytical models for trajectory controls are proposed. The difference between two proposed models is as follows. One is needed to linearize the equations which is commonly used in a robot arm and another does not need a linearization that is called the direct method. Then, a compact and inexpensive control system is constructed and tested. The system consists of a flexible robot arm, a microcomputer, accelerometers, potentiometer and small-sized quasi-servo valves developed in our laboratory using tiny on/off control valves. The development of the master device with the pneumatic brake mechanism will also be presented and discussed. The experiments were executed in order to find the best value of the deviation displacement for the pneumatic brake mechanism to work and the validity of the control performance were confirmed. The trajectory control were also realized for circle, spiral and square trajectory by using an analytical model and a compact control system. The experimental results also show that the attitude control of the master-slave and the trajectory control of robot arm have been improved compared with previous study. Furthermore, in order to improve the control performance, to simulate the movement of the proposed robot arm, and to investigate the influence of a non-linear friction, control schemes, and so on, on the performance of the robot arm, the overall analytical model of the robot arm was proposed. The dynamic model of the three pneumatic cylinders with slide stages and six quasi-servo valves are proposed and described. The simulation of the master-slave control, the trajectory control by using the linearized model and the trajectory control by using direct model were executed by using Matlab Simulink with Runge-Kutta method. As a result of comparison, the calculated results agreed with the experimental results. In the simulation, the influence of non-liner friction in the flexible cylinders on the control performance were investigated. It was confirmed that the non-linear friction largely affected to the positioning accuracy of the control. As a result, the validities of the proposed analytical model and the identified system parameters were confirmed.

発 表 論 文 ：

1. 学術論文（査読有）

[1] Mohd Aliff, Shujiro Dohta, Tetsuya Akagi and Hui Li, "Development of a Simple-structured Pneumatic Robot Arm and its Control Using Low-cost Embedded Controller", Journal of Procedia Engineering, Vol. 41, (2012), pp. 134-142.

[2] Mohd Aliff, Shujiro Dohta and Tetsuya Akagi, "Control and Analysis of Robot Arm using Flexible Pneumatic Cylinder", Mechanical Engineering Journal, Vol. 1, No. 5, dr0051, (2014), pp. 1-13.

[3] Takafumi Morimoto, Mohd Aliff, Tetsuya Akagi and Shujiro Dohta, "Development of Flexible Pneumatic Cylinder with Backdrivability and Its Application", International Journal of Materials Science and Engineering, Vol. 3, No. 1, (2015), pp. 7-11.

[4] Mohd Aliff, Shujiro Dohta, Tetsuya Akagi, and Takafumi Morimoto, "Control of Flexible Pneumatic Robot Arm using Master Device with Pneumatic Brake Mechanism", JFPS International Journal of Fluid Power System, Vol. 8, No. 1, (2015), pp. 38-43.

[5] Mohd Aliff, Shujiro Dohta and Tetsuya Akagi, "Simple Trajectory Control Method of Robot Arm using Flexible Pneumatic Cylinders", Journal of Robotics and Mechatronics, Vol. 27, No. 6, (2015), pp. 698-705.

2. Proceedings など（査読有）

[1] Mohd Aliff, Shujiro Dohta, Tetsuya Akagi and Hui Li, "Development of a Simple-structured Pneumatic Robot Arm and its Control Using Low-cost Embedded Controller", Proceedings of International Symposium on Robotics and Intelligent Sensors, (2012), 1569617387.pdf, pp. 1-9.

[2] Tetsuya Akagi, Shujiro Dohta, Hisashi Matsushita and Mohd Aliff, "Development of Flexible Pneumatic Actuator using Sliding Mechanisms and Its Application", Proceedings of the 5th International Conference on Positioning Technology, (2012), pp. 15-18.

[3] Hui Li, Shujiro Dohta, Tetsuya Akagi and Mohd Aliff, "Improvement of Flexible Linear Encoder for Wearable Actuator", Proceedings of The 5th International Conference on Positioning Technology, (2012), pp. 227-230.

[4] Shujiro Dohta, Tetsuya Akagi, Mohd Aliff and Ayaka Ando, "Development and control of simple-structured flexible mechanisms using flexible pneumatic cylinders", Proceedings of 2013 IEEE/ASME International Conference on Advanced Intelligent Mechatronics (AIM), (2013), pp. 888-893.

[5] Tetsuya Akagi, Shujiro Dohta, Mohd Aliff, Yoshinori Moriwake and Feifei Zhao, "Application and Analysis of Flexible Pneumatic Cylinder Driven by Low-cost Quasi Servo Valve", Proceedings of International Research Conference on Engineering and Technology (IRCET), (2013), pp. 55-63.

[6] Yasuko Matsui, Tetsuya Akagi, Shujiro Dohta, Mohd Aliff, and Changjiang Liu, "Development of Portable Rehabilitation Device using Flexible Spherical Actuator and Embedded Controller", Proceedings of 2nd International Conference on Intelligent Technologies and Engineering System, (2013), pp. 231-238.

[7] Mohd Aliff, Shujiro Dohta and Tetsuya Akagi, "Trajectory Control of Simple-Structured Flexible Mechanism using Flexible Pneumatic Cylinders", Proceedings of 2013 IEEE/SICE International Symposium on System Integration, SA1-1.4, (2013), pp. 19-24.

[8] Yasuko Matsui, Tetsuya Akagi, Shujiro Dohta, Mohd Aliff and Changjiang Liu, "Development of Portable Rehabilitation Device using Flexible Spherical Actuator and Embedded Controller", Lecture Notes in Electrical Engineering 293, Springer, Vol. 1, (2014), pp. 231-238.

[9] Mohd Aliff, Shujiro Dohta, Tetsuya Akagi and Takafumi Morimoto, "Control of Flexible Pneumatic Robot Arm using Master Device with Pneumatic Brake Mechanism", Proceedings of the 9th International Symposium on Fluid Power, JFPS, (2014), pp. 822-829.

[10] Takafumi Morimoto, Mohd Aliff, Tetsuya Akagi and Shujiro Dohta, "Development of Flexible Haptic Robot Arm using Flexible Pneumatic Cylinders with Backdrivability for Bilateral Control", Proceedings of 3rd International Conference on Intelligent Technologies and Engineering Systems, (2014), pp. 1-6.

[11] Mohd Aliff, Shujiro Dohta and Tetsuya Akagi, "Trajectory control of robot arm using flexible pneumatic cylinders and embedded controller", Proceedings of 2015 IEEE/ASME International Conference on Advanced Intelligent Mechatronics (AIM), (2015), pp. 1120-1125.

[12] Mohd Aliff, Shujiro Dohta and Tetsuya Akagi, "Trajectory Controls and its Analysis for Robot Arm using Flexible Pneumatic Cylinders and Embedded Controller", 2015 IEEE International Symposium on Robotics and Intelligent Sensors (IRIS), (2015), pp. 48-54.

審査結果の要旨

この研究の目的は、将来、手首のリハビリテーション機器に応用するために、軽量・安全な柔軟空気圧シリンダ、小型・安価な疑似サーボ弁、マイコンなどを用いた空気圧ロボットアーム制御システムを開発し、シミュレーションや最適設計のために構成要素およびシステム全体の解析モデルを構築することである。学位論文は、序論と結論を含む８つの章から構成されている。第２章の「解析モデルを用いたマスター・スレーブ制御」では、柔軟空気圧シリンダ、小型疑似サーボ弁、加速度センサ、マイコンなどから成る空気圧駆動ロボットアームのマスター・スレーブ制御システムを構築し、解析モデルを用いた制御方法を提案し、マスター・スレーブ制御実験により提案した制御方法の有効性を明らかにした。第３章の「空気圧ブレーキ機構を有するマスター装置」では、スレーブアーム（患者側）に及ぼす外力などをマスターアーム（理学療法士側）にフィードバックする疑似バイラテラル制御を実現するために、簡便な空気圧駆動ブレーキ機構を有するマスター装置を提案し、制御実験によりマスター装置の有用性を示した。第４章の「線形化方程式を用いた軌道制御」では、ロボットアームの非線形モデルを線形化し、それを用いたロボットアーム手先の軌道制御法（手先サーボシステム）について述べ、制御実験結果を示した。第５章の「非線形方程式を用いた軌道制御」では、もう一つの軌道制御法として、非線形方程式を用いた直接法（関節サーボシステム）を提案し、制御実験によりそれらの有効性を示した。第６章の「全ロボットアームの解析モデル」では、柔軟空気圧シリンダ単体やそれを３つ用いたロボットアーム、小型疑似サーボ弁、センサなどシステム全体の解析モデルを提案し、システムパラメータの同定を行った。第７章の「ロボットアームのシミュレーション結果」では提案した解析モデルと同定したシステムパラメータの値を用いて、マスター・スレーブ制御や軌道制御の計算機シミュレーションを行い、実験結果と比較し、提案モデルや同定パラメータの有効性を確認した。そして、２つの軌道制御方法の軌道精度、周波数特性、ロバスト性、モデル化の容易さなどを比較し、非線形方程式を用いた直接法（関節サーボ）の優位性を明らかにした。さらに、計算機シミュレーションにおいて、柔軟空気圧シリンダチューブとスライドステージ間に存在する非線形摩擦（クーロン摩擦や静止摩擦）の大きさを変えることで、これらの摩擦が制御性能（軌道精度）に及ぼす影響を理論的に明らかにした。

本研究の成果は、ロボティクス・メカトロニクス分野や空気圧制御機器分野の問題に関連した優れた知見を含んでおり、これらの分野の研究発展や技術開発に資するものである。これらの研究成果は５編の論文として学術論文誌に公表され、複数の国際会議において口頭発表されている。これらのことを総合的に審査した結果、本論文は博士学位論文として合格であると認め、論文提出者のモハマド アリフ（Mohd Aliff）は博士（工学）の学位を受ける資格があるものと認める。