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研究課題名（和文）The Research on Human Robot Interface Enabled with High Bandwidth Force Servoing for Manipulation of Robotic Arm

研究課題名（英文）The Research on Human Robot Interface Enabled with High Bandwidth Force Servoing for Manipulation of Robotic Arm

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研究成果の概要（和文）：本研究では、高帯域幅なトルク制御を実現可能なヒューマン・ロボット・インタフェースの開発を行っている。現在、物理的なヒューマン・ロボット・インタラクションのためのハプティック・インタフェースはいくつか存在しておりますが、トルク制御の帯域幅の制限があるため、高感度なインタラクションの再現は困難である。本研究では、”新たな材料による直列弾性駆動”および”高精度なトルク感知”を基づき、高帯域幅なトルク制御可能なアクチュエータを開発した。インピーダンス制御も実現し、性能の評価を行った。

研究成果の概要（英文）：In this research we developed a Human-robot interface enabled with high bandwidth force servoing for robotic arm manipulation. There are several commercial-available haptic interface devices for user interaction, however, their bandwidth is limited to servo real force with high frequency components, thus limit their usage in more delicate tele-manipulation tasks. thus we developed a force servoing technology that could achieve a high bandwidth performance, implemented critically based on "new material based series elastic actuation" and "high resolution torque sensing". A impedance shaping method was also developed to evaluate advantages of our proposed method.

研究分野：知能機械学

キーワード：ヒューマン・ロボット・インタフェース

１．研究開始当初の背景

Human-robot interface device always plays a fundamental role in a tele-operated robot system. For example, an assistive robotic arm designed for human living support, requires an interface device that can be operated in an intuitive and effective way by its physical disabled user; a construction machine need a well designed interface device in order to raise its working efficiency; a robotic surgery system require a high performance haptic device for sensitive manipulation and palpation. Much research and engineering effect was also made in an attempt to develop a high performance interface device for different robotic applications. For example, the PHANToM is a force reflecting haptic interface commercialized by SensAble Technologies, and be extensively used in typical virtual environment and tele-robotics applications; the sigma.7 haptic device is designed by Force Dimension for the applications of robotic surgery; we also developed an oral interface, for upper limb disabled people to masterfully control an assistive robotic arm with only mouth usage.

However, these developed technologies and devices cannot yet be able to reflect a high fidelity "feel" to user for an effective and intuitive manipulation of robotic arm. The reason for that is the lack of a high bandwidth force serving technology, which is able to servo high-frequency force reference rapidly and reliably. During tele-manipulation of a robotic arm, the interaction force against environment and inertia force of robotic arm itself, should be calculated and then regarded as force reference to be reflected to the user through human-robot interface device, in this way, the user "feel" about the task and thus benefit manipulation effectiveness and intuition. However, the force reference calculated always contains high frequency components due to unpredictable physical interaction with environment and dynamic motion of robotic arm during task execution. These high frequency components are also regarded as subtle information about the manipulation task. Thus, high bandwidth force servoing technology becomes essential, for interface device to reflect a high fidelity "feel" about the task.

２．研究の目的

In this research, we attempt to develop a human-robot interface device enabled with high bandwidth force serving for robotic arm tele-manipulation, which might reflect more subtle information to user during task execution. The high bandwidth force serving will be implemented critically based on "gum metal based series elastic actuation" and "nonlinear state feedback controller". On the basis of high bandwidth force serving, a interface device will be designed in a "stick-mimic" manner which mimics manipulation of a robotic arm as the manipulation of a stick to achieve intuitive. Evaluation of our high bandwidth force serving technology and the interface device will also be conducted through experiments.

３．研究の方法

In order to achieve the research objective, firstly a one-DOF series elastic actuation test-bed will be designed and fabricated, for further implementation and verification of one-DOF version high bandwidth force servoing; then, using this test-bed as hardware platform, a state-feedback controller will be developed to achieve high bandwidth force servoing, it is based on the feedback of motor and link-side encoder measurements and their derivatives, roughly designed and verified through simulation, and finely turned through hardware-in-loop experiments; the passive element within series elastic actuation is critical to achieve high bandwidth performance, which is originally designed to be a gum-metal spring; these will be finished in the first year. In the second year, a stick-mimic interface device will originally be designed and fabricated, with each DOF enabled with high bandwidth force servoing, then it will be evaluated through tele-manipulation experiments using a virtual reality simulator and a real assistive robotic arm. The evaluation will be conducted through comparison with other commercial available devices, and comparison between its different force servoing bandwidth settings.

４．研究成果

During the period of this research, the hardware platform of a high performance robotic actuator was developed, which was enabled with high performance torque sensing, torque control, and impedance shaping, see Fig.1, as follows:

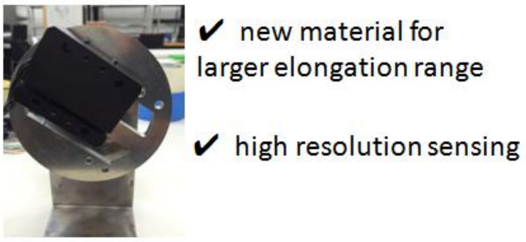


Fig.1 hardware platform of robotic actuator

The torque sensing performance of the designed actuator was evaluated, through the comparison with other methods, such as strain gauge and motor current based method, the performance evaluation was depicted in Fig. 2, as follows:

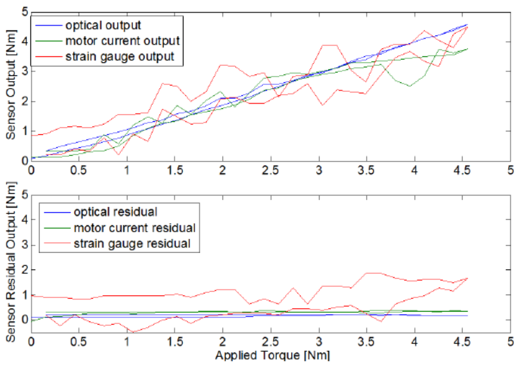
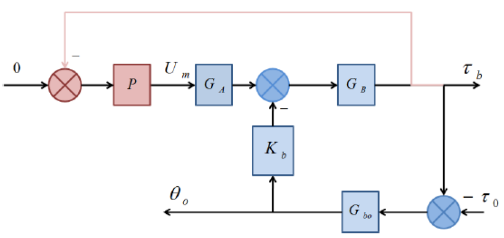


Fig.2 performance comparison

Based on the hardware platform, an impedance control method was implemented to achieve high performance physical human robot interaction, see Fig. 3. An experimental comparison for impedance control between the proposed method, motor current, and strain gauge is also conducted and investigated. The result shows that the proposed method lead to a larger range of impedance shaping compared with motor current and strain gauge based method.

Fig.3 impedance control diagram



５．主な発表論文等

（研究代表者、研究分担者及び連携研究者には下線）

〔雑誌論文〕（計 2 件）

(1) Kenjiro FUJII, Hiroaki ARIE, Wei WANG, Yuto KANEKO, Yoshihiro SAKAMOTO, Alexander SCHMITZ, and Shigeki SUGANO, “Improving IMES Localization Accuracy by Integrating Dead Reckoning Information,” Sensors, Vol. 16, Issue 2, 2016; doi: 10.3390/s16020163 査読有

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〔学会発表〕（計 7 件）

(1) Yushi Wang, Alexander Schmitz, Kento Kobayashi, Javier Alejandro Alvarez Lopez, Wei Wang, yuki matsuo, Yoshihiro Sakamoto, Shigeki Sugano, ″Exploiting the Slip Behavior of Friction Based Clutches for Safer Adjustable Torque Limiters″, in Proceeding of the 2017 IEEE/ASME International Conference on Advanced Intelligent Mechatronics (AIM'17), July 3-7, 2017, Munich, Germany. 査読有

(2) Kent Kobayashi, Yushi Wang, Javier Alejandro Alvarez Lopez, Wei Wang, Alexander Schmitz, shigeki sugano, “The Controllability of Friction Clutches for Variable Damping Actuators,” in Proceedings of the 17th SICE System Integration Division Annual Conference, paper no.3C3-5, December 15-17, 2016, Sapporo, Japan.

(3) Fujii, K., Kawaguchi, T., Matsumoto, H., Tanikawara, M., Toyama, T., Sakamoto, Y., Wang, W., Arie, H., Schmitz, A. and Sugano, S. Methods for Improving IMES Transmitters: Transmission Diversity, Variable Beamwidth Antenna, and Leaky Coaxial Cable. IEEE/SICE International Symposium on System Integration (SII 2015), December 11-13, 2015, Nagoya, Japan; doi: 10.1109/SII.2015.7404941 査読有

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〔図書〕（計　0　件）

〔産業財産権〕

○出願状況（計　5　件）

（１）名称：接触力調整エンドエフェクタ
発明者：汪 偉, 許 晋誠, シュミッツ アレクサンダー, オルガド アレクシス カルロス, 小林 健人, アルバレス ロペス ハビエル, 菅野 重樹
権利者：学校法人 早稲田大学
種類：特許権
番号：特願 2017-053824
出願年月日：平成 29 年 3 月 19 日
国内外の別：国内

（２）名称：機械装置の動力伝達システム
発明者：シュミッツ アレクサンダー, 汪 偉, オルガド アレクシス カルロス, 許 晋誠, 小林 健人, アルバレス ロペス ハビエル, 王 語詩, 菅野 重樹
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種類：特許権
番号：特願 2017-055173
出願年月日：平成 29 年 3 月 19 日
国内外の別：国内

（３）名称：トルクリミッタ
発明者：シュミッツ アレクサンダー, 汪 偉, オルガド アレクシス カルロス, 許 晋誠, 小林 健人, アルバレス ロペス ハビエル, 王 語詩, 菅野 重樹, 菅野 重樹
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種類：特許権
番号：特願 2017-053823
出願年月日：平成 29 年 3 月 19 日
国内外の別：国内

（４）名称：ロボットアームの制御システム
発明者：シュミッツ アレクサンダー, ババラジュ ソウミヤ, 坂本 義弘, アギーレ ドミンゲス ゴンザロ, 佐藤 立樹, 汪 偉, 菅野 重樹
権利者：学校法人 早稲田大学
種類：特許権
番号：特願 JP16/65125
出願年月日：28 年 5 月 23 日
国内外の別：国際

（５）名称：ロボットアームの制御システム
発明者：シュミッツ アレクサンダー, ババラジュ ソウミヤ, 坂本 義弘, アギーレ ドミンゲス ゴンザロ, 佐藤 立樹, 汪 偉, 菅野 重樹
権利者：学校法人 早稲田大学
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国内外の別：国内

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