

Thesis Summary

論文の内容の要旨

HUMAN-FRIENDLINESS OF ROBOTS IN HUMAN ENVIRONMENTS: MOBILITY, MANIPULATION, AND REHABILITATION PERSPECTIVES

(人間環境で働くロボットの人間親和性に関する研究：モビリティ、マニピュレーション、
リハビリテーションの観点から)

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Recent advances in the field of robotics are remarkable. With cutting-edge technologies being implemented, more and more robots have been commercialized and launched onto the market to help humankind in many ways. The demands for robots, that could help, for example, clean the house, communicate with people, carry heavy things, and work in dangerous environments with or instead of humans, are expected to increase rapidly in the immediate future regarding that the average world population is getting old, and as the working conditions and perimeters of human activities are changing and expanding. As robots are coming into our society, guidelines for robots and ourselves must be set to prevent problems of any kind in living with robots. However, the discourse has not reached any consensus yet despite its long history. That said, it must be important and timely to discuss how robots should treat humans and how humans treat robots in terms of engineering.

Ever since Isaac Asimov, the American science fiction writer, first devised the Three Laws of Robotics in 1942, the ethics regarding human-robot relationship has been discussed and amended over the last seventy years in social domains. In 2006, the British government sponsored a speculative paper suggesting that robots one day might demand equal rights to humans, which was the first government-level action on the issue. In the following year, the Ministry of Commerce, Industry and Energy of the Republic of Korea came to announcing that it would draft a Robot Ethics Charter to address and prevent "robot abuse of humans and human abuse of robots." On the other hand, in contrast to the development of the argument in social domains, the issue concerned with human-robot interactions in the field of robotics and engineering is still in its infancy. Regarding the fact that robots in reality cannot think or act like humans as described in Asimov's stories and many other science fiction movies, it might be rather a matter of course. But now is the time.

A wide spectrum of issues involving robots' body and mind has to be addressed for safe and dependable human-robot interactions. Generally, it is said that there are six engineering domains where the research frontiers of robotics lie on. Those are design, control, biomimetics, sensors, software, and planning. In this dissertation, among the six domains, the body components -- robot design, control, and biomimicry -- are mainly focused and dealt with. Answering questions about how robots should be designed, how should they be controlled, and what human aspects should be considered, the guidelines for the robots working in human environments are provided. Moreover, the guidelines are applied to mobility, manipulation, and cooperation solutions for verification, which gives implications for how future robots should be. Indeed, it eventually provides the interpretation of Asimov's laws in the context of engineering.

The consistent argument, which forms the background of the design concepts and control strategies for the applications introduced in this dissertation, is that the robots working in human environments must be: (1) designed to have light weight and high compliance with low cost; (2) controlled to ensure safety and performance at all times; and (3) concerned with the human metrics and the human-robot interface.

Robots must be light in weight and mechanically compliant so that they are safer and more dependable in living with us and not to harm the environment including humans. At the same time, they must not be expensive. By reducing the complexity of system and designing them cost-effective, robots will be more affordable, and thus more people will be able to enjoy the benefits. Robot control systems must be designed in a way that they guarantee safety and performance in human command at all times. Utilizing filters, observers, and up-to-date control theories will provide robots with high manipulability, elaborate responses, and ability to adapt to the environments where they belong. Additionally, more considerations on human metrics and human-robot interface should be given. Robots have evolved and will evolve on by mimicking animals, especially humans, who are the most efficient mechanisms on the planet in terms of energy consumption, power dissipation, and so on. Also, the human parameters and the human-robot interfaces should be paid much attention and centered on humans because the unchangeable factor in the system is humans, not the robots.

Based on these ideas, three different kinds of robotic applications are introduced to prove their validity in functions of mobility, manipulation, and cooperation, which are the basis of all robotic applications anticipated to appear in the future. Each system is uniquely designed, controlled, and examined to meet the requirements suggested above. In this dissertation, a novel mobility platform which consists of two independent driving motors and two castor-wheel-attached steering motors, a biologically inspired manipulator arm which has six motors in pairs based on 3-pair-6-muscle model of human limb, a biologically inspired robotic leg which is operated by a mono-articular motor and a bi-articular spring, and a novel type exoskeleton based on human bio-mechanical characteristics are introduced and evaluated.

Firstly, a novel mobility platform, CIMEV, is proposed and examined. It is designed in an attempt to provide an appropriate and unique structure for the independent motor driven mobility platforms to enhance manipulability and controllability. Underpinned by the studies on wheel placements and their effects on the vehicle behavior, a novel chassis structure using caster wheels and independent driving motors is proposed. Provided with four wheels the system is designed to be statically stable, and with caster wheels on the front axle the proposed system is able to use the two kinds inputs -- the steering and the direct yaw moment -- effectively for two-dimensional motion control, which enables the proposed system suitable for applications in human environments. Then, a biologically inspired robot manipulator, BiWi II, is introduced. The system's high compliance that bi-articular muscles provide enables safe, human- and environment-friendly motion of robot manipulation. The homogeneity in output force characteristics of bi-articular actuation helps to improve the performance of the robots in human environments. BiWi II is a 3-pair-6-motor-actuated system which experimentally shows the advantages of bi-articular actuation. Introducing bi-articular actuation in robot manipulators around us will enhance the safety, performance, and dependability of the robots around us in the future. And an under-actuated biologically inspired robotic leg, JUMPBIE, is proposed. Use of passive bi-articular muscles, which is a spring in this system, effectively can reduce the cost, decreasing the number of actuators required, and thus it makes robots more affordable and accessible to more latent users. The novelty of the mechanical configuration which enables reduction of the number of actuators and thus in the complexity of control while keeping the advantages of bi-articular actuation, is one of the most important contributions of this work. Finally, a novel type exoskeleton, HFEX, based on human bio-mechanical characteristics is proposed. Based on a thorough study on human locomotion and leg muscle activation, a novel design and a control method for the exoskeleton for rehabilitation are proposed. By using the muscle activation estimation algorithm and following power assist control, HFEX shows improved safety and performance in conducting given tasks, which are shown by simulations and experiments.

We are entering a new era of the human-robot coexistence. Many robotic applications are doing works together with us or instead of us already. And in the immediate future, more and more robots will come into our society and share our daily lives with us together. That said, it is very essential and significant to discuss and set the guidelines about how robots of the future should be and how we humans deal with them. In this dissertation, the requirements for robots working in human environments are provided, and they are backed by theoretical and experimental verification using relevant applications. Regarding that mobility, manipulation, and cooperation are the basis of all robotic systems, the findings and suggestions of this dissertation must be helpful and inspiring in engineering 'human-friendly' robots.