Mobility Assistance Robots Controlled by Servo Brakes

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I. Introduction

As societies age and experience a shortage of people for nursing care, handicapped people, including the elderly and blind, find it increasingly necessary to be self-supporting. However, many such people suffer from injuries, poor eyesight, or a general lack of muscular strength, and need the support of other people in daily activities. In recent years, we expect to utilize robot systems not only in industrial fields, but also in homes, offices and hospitals in cooperation with humans. Many robot systems have been researched to realize a physical support for human being.

This article especially focuses on mobility assistance robots such as walker-type walking support system and wheelchair, which work on the basis of the physical interaction between the robot systems and the user. Many intelligent systems based on robot technologies consist of servo motors and sensors such as force/torque and ultrasonic sensors. Information from many types of sensors controls the servo motors. By appropriately controlling the servo motors, these intelligent systems provide many functions, such as variable motion, obstacle avoidance, and navigation; thus, they provide a maneuverable system.

In this article, we consider a passive intelligent systems, which are not only simple structure and safe but also offers many functions similar to those found in active systems. We develop a passive intelligent walker called the RT Walker and a cycling wheelchair, which are controlled by servo brakes.

II. Passive Robotics

For practical use of intelligent systems in the real world, we need to consider two main points: achieving high performance and user safety. Most conventional intelligent systems have servo motors that are controlled based on sensory information from sensors such as force/torque sensor, laser range finder and ultrasonic sensor. The high performance of intelligent systems is realized in the form of functions such as power assistance, collision avoidance, navigation, and variable motion.

However, if we cannot appropriately control the servo motors, they can move unintentionally and might be dangerous for a human being. In particular, in Japan, legislation must be formulated for using them in a living environment. In addition, active intelligent systems tend to be heavy and complex because they require servo motors, reduction gears, sensors, a controller, and rechargeable batteries. Batteries present a significant problem for long-term use because servo motors require a lot of electricity.

Goswami et al. proposed the concept of passive robotics [1], in which a system moves passively based on external force/moment without the use of actuators, and used a passive wrist comprising springs, hydraulic cylinders, and dampers. The passive wrist responds to an applied force by computing a particular motion and changing the physical parameters of the components to realize the desired motion. Peshkin et al. also developed an object handling system referred to as Cobot [2] consisting of a caster and a servo motor for steering the caster based on passive robotics.

Dissipative haptic devices using either brakes or clutches have been developed to dissipate or redirect energy in the required direction [3], [4]. In this article we also introduce the other passive motion support systems controlled by servo brakes developed by us. These passive systems are intrinsically safe because they cannot move unintentionally under a driving force. The passive robotics will prove useful in many types of intelligent systems for supporting the human motion based on the physical interaction between the systems and humans.

III. Passive Intelligent Walker [5]

In this article, we pay special attention to the braking system, and propose a new passive intelligent walker (RT Walker), which uses servo brake control. The servo brakes can navigate the RT Walker, and its maneuverability can change based on environmental information or the difficulties and conditions faced by the user. The developed RT Walker is shown in Fig.1. This prototype consists of a support frame, two passive casters, two wheels with servo brakes (referred to as powder brakes), a laser range finder, tilt angle sensors, and a controller. The part of the rear wheel with the powder brake is shown in Fig.1; the brake torque is transferred directly to the axle. The brakes change the torque almost in proportion to the input current.

RT Walker is lightweight because its structure is relatively simple compared to active intelligent walkers, and it needs little electricity to operate the servo brakes. The driving force of the RT Walker is the actual force/moment applied by the user, and therefore, he/she can move it passively without using the force/torque sensor. By changing the torque of the two rear wheels appropriately and independently, we can control the motion of the RT Walker, which receives environmental information from its laser range finder and tilt angle sensors. Based on this information, the RT Walker can realize the collision avoidance, gravity compensation, and other functions.

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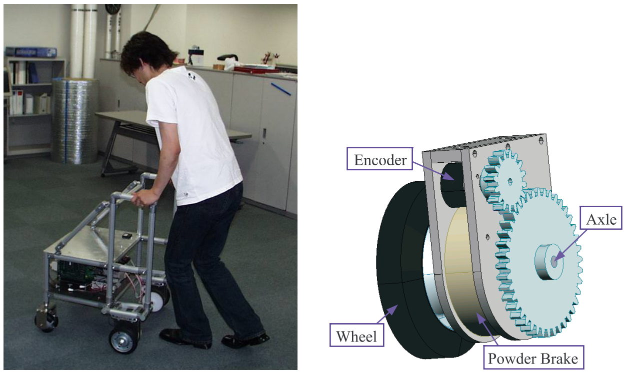

(a) Prototype of RT Walker (b) Wheel with Servo Brake

Fig. 1. Passive Intelligent Walker [5]

(a) Commercial Product (b) Developed System

Fig. 2. Cycling Wheelchair [6]

IV. Cycling Wheelchair Controlled by Regenerative Brakes [6]

This section introduces a new wheelchair named "Cycling Wheelchair" shown in Fig. 2(a). The cycling wheelchair moves via a pedal-driven system similar to that of a bicycle. Typical wheelchair users have severe impairment of the lower extremities; thus, it is natural to assume that they cannot pedal a cycling wheelchair. However, the pedal can be easily rotated by wheelchair-bound patients with even slight leg mobility. Such a wheelchair would especially benefit hemiplegia patients, who can generate a large pedaling force with a healthy leg. We note that the disabled leg responds smoothly to the pedaling motion of the healthy leg without disturbing the pedaling motion.

Having learned to self-maneuver the cycling wheelchair after short-term training, patients wish to participate in the outdoor environment. However, the outdoor environment presents problems that are not encountered in hospital environments. Although the patients can generate a large pedaling force, their lower-limb disability prevents them from achieving precise velocity control of the pedaling motion. On downward slopes, patients cannot properly apply the braking force to the pedal. This inability to slow the wheelchair presents a dangerous situation. For safety reasons, the cycling wheelchair is equipped with a bicycle-like handbrake. Although users can halt the wheelchair by gripping the handbrake lever, they may panic in dangerous situations, consequently losing control of both pedaling force and handbrake.

On the other hand, because a large pedaling force is required for uphill travel, a single healthy leg may generate insufficient power for climbing a slope unassisted. If users stop on the upslope, gravity may prevent them from restarting the wheelchair. Other barriers in the outdoor environment are steps and obstacles. Falling from steps presents an especially perilous threat.

In this study, we propose a new cycling wheelchair supplemented with several assistive functions for use in the outdoor environment. Assistive functions are realized by a new control method using DC servo motors as a regenerative brake system. The braking control is safer than active control systems such as power assistance; moreover, the regenerative brake can charge a battery during the braking control process.

In special situations such as steep uphill climbing, the DC servo motors generate an active force that compensates for insufficient user force by extracting energy from the battery, which has been charged under braking control. Even under active force generation by the DC servo motors, the wheelchair motion is controlled passively by the applied force of the user. Such passive behavior has been shown to increase the safety of robotic systems using actuators.

V. Conclusions and Future Works

In this article, we introduced a concept of passive robotics and proposed a passive intelligent walker and a passive cycling wheelchair controlled by the servo brakes. Realizing the many functions of these systems is challenging, because we control mainly the brakes. We proposed motion control algorithms considering the brake constraints and realized the several functions, which change the apparent dynamics of the passive systems to adapt to the states of the user and the environment.

In future work, we will consider the human adaptive and environmentally-adaptive motion control algorithms in more detail to improve the maneuverability of the passive systems.

References

[1] A. Goswami, M. A. Peshkin, J. Colgate, "Passive robotics: an exploration of mechanical computation (invited)", *Proceedings of the IEEE International Conference on Robotics and Automation*, pp. 279-284, 1990.

[2] M. A. Peshkin, J. E. Colgate, W. Wannasuphoprasit, C. A. Moore, R. B. Gillespie, P. Akella, "Cobot Architecture", *IEEE Transactions on Robotics and Automation*, Vol. 17, No. 4, 2001.

[3] D. Gao, W. J. Book, "Steerability in Planar Dissipative Passive Robots", *The International Journal of Robotics Research*, Vol. 29, No. 4, pp. 353-366, 2010.

[4] B. Dellon, Y. Matsuoka, "Path Guidance Control for a Safer Large Scale Dissipative Haptic Display", *Proc. of the IEEE International Conference on Robotics and Automation*, pp. 2073-2078, 2008.

[5] Y. Hirata, A. Hara, K. Kosuge, "Motion Control of Passive Intelligent Walker Using Servo Brakes", *IEEE Transactions on Robotics*, Vol. 23, No. 5, pp. 981-990, 2007.

[6] Y. Hirata, K. Kawamata, K. Sasaki, A. Kaisumi, K. Kosuge, E. Monacelli, "Regenerative Brake Control of Cycling Wheelchair with Passive Behavior", *Proceedings of IEEE International Conference on Robotics and Automation*, pp. 3858-3864, 2013.