別紙４（課程博士）

Date of Submission:

平成 29 年 07 月 10 日

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Abstract

論文内容の要旨　（博士）

Title of Thesis 博士学位論文名	Design and Control of a Redundant Wheeled Drive System for Fail Safe Motion and Energy Saving (フェイルセーフ動作と省エネルギー化のための冗長車輪駆動系の設計と制御)

(Approx. 800 words)

(要旨　1,200 字程度)

Mobile robots are widely used in many different applications and areas such as transportation, military domain, medical, searching and rescue, guidance, hazard detection, and carpet cleaning. Wheeled mobile robots are considered as the most widely used class of mobile robots. This is due to their relatively low mechanical complexity, simple controllers and energy consumption. Robots usually carry limited power sources, such as rechargeable batteries. In addition, it is generally impossible to add new power supply while working, and the battery capacity determines the operating time of mobile robots. Energy saving is a significant topic in mobile robots for increasing the operating time under the limited capacity.

With increase in the number of elderly and disabled people, there is growing demand for mobility support devices and care equipment to improve their quality of life. Nowadays Japan's declining birthrate and aging population are having a profound impact on the society, economy, and culture. Hence, an essential task for Japan society is the improvement of the quality of life for the elderly and disabled people and to support their self-movement.

A differential wheeled mobile robot (WMR) involves two independently driven wheels on a common axis. The robot moves straight forward or backward when the wheels rotate at the same speed, and the robot follows a curved path along the arc of an instantaneous circle, around the instantaneous center of rotation (ICR) when one wheel rotates faster than the other. The robot turns about the midpoint of the two driving wheels when both wheels rotates at the same velocity in opposite directions. When one of the motors breaks down or has damage for some reasons, the robot rolls around the wheel which is connected to the damaged motor. Eventually, there will be a risk of the passenger's life because the passenger cannot continue the motion.

This work presents a design of a new system consisting of a redundant drive system to continue its motion safely when one of the motors breaks down and also able to operate over a longer period of time due to energy saving consumption property. This provides the use of each motor at its efficient operating condition. The system has two drive wheels with three motors and two planetary gears. Motors 1 and 2 are connected to right and left wheels through each planetary gear. Motor 3 is connected to both right and left planetary gears, and it supplies power for both wheels. Planetary gears consist of a planetary carrier and an outer gear that revolve around a sun gear. In this system, the sun gear connects to motor 3, the outer gear connect to motor 1 and 2, and the planetary carrier connects to each wheel.

This dissertation mainly consists of three parts. The first part of considers the dynamic modeling of a redundant wheeled drive system. In addition, we assume that, like personal mobility vehicle such as electrical wheelchairs, desired linear and angular velocities of the vehicle are given by operators. These velocities are typically transformed into desired velocities of left and right wheels. Next, these wheel velocities are transformed into angular velocities of three motors by using a distribution controller. In addition, a fixed ratio d of angular velocities of a wheels to the velocity of motor 3 is introduced. The optimum value of d depends on actuator specifications, and it is found by simulation/experiment.

The second part of this thesis describes the possibility of the proposed new drive system for energy saving and fail safety by applying two controllers. The distribution and state feedback controllers are applied for the wheeled drive system. The distribution controller creates the reference angular velocity of motors. In addition, by assuming that commercial motor controllers are based on PD control, a state feedback controller is applied to the proposed WMR as the feedback controller. Feedback gains of that controller are obtained by the pole placement method (PPC). Experiment was conducted to verify the effectiveness of the proposed method, and a distribution ratio $d=2$ provides 20.45 % and 13.05 % reduction of the consumed energy compared to the case that only two motors operate for the linear and circular motion, respectively.

The third part of this thesis considers robust tracking and energy saving control for a redundant wheeled drive system using sliding mode control (SMC). A comparative study with LQR and PPC was conducted. Computer simulations are performed to verify the effectiveness of the proposed method, and there is no significant difference between the SMC, LQR and PPC approaches. Effectiveness and reliability of the proposed method in the real environment with disturbance are evaluated by performing multiple times experiments. The minimum mean energy required was 50.08 J by using SMC (d=1.5), 38 J by SMC with sat (.) (d=2), 59.89 J by LQR (d=2), and 63.43 J by PPC (d=2) for linear motion. For circular motion the minimum mean energy required was 50.92 J by using SMC (d=1.5), 41.32 J by SMC with sat (.) (d=2), 57.3 J by LQR (d=1.5), and 59.37 J by PPC (d=2). Experimental result show that the SMC provides robust tracking performance with less energy.
Finally the dissertation is concluded and future works are described.