論 文 内 容 の 要 旨

The improvement in living conditions and the increasing life expectancy have led to the gradual aging of the population worldwide, resulting in a significant increase in the incidence of age-related health issues. Declining motor function (e.g., decreased muscle strength, coordination, and dexterity) is commonly associated with aging and can lead to potentially disabling falls. However, the workforce of healthcare providers and nurses is decreasing and, therefore, cannot meet the demands of the people who require physical rehabilitation; as the birth rate drops, this situation is likely to worsen. Therefore, the author's laboratory has been focusing on the development of rehabilitation robots for many years. The main contribution of this paper is to design suitable control algorithms to improve the rehabilitation effect of the omnidirectional rehabilitative training walker (ORTW).

In order to make the ORTW has the same therapeutic effect as therapist, it must imitate the training prescription provided by therapist. Then, the ORTW needs to track the trajectory designed by the therapist with high precision. However, some problems affect the precision of trajectory tracking, which makes accurate trajectory tracking impossible. Thus, we should solve these problems by improving the control algorithm, to enhance the effect of rehabilitation training.

Firstly, when the ORTW works together with its user, the center of gravity of the ORTW will be shifted. It will further lead to some parameters in the system to change randomly. In order to solve this problem, we construct a reasonable stochastic model to describe the motion of the robot. Based on this model, we design an appropriate controller to converge the tracking error of the robot. Additionally, by designing appropriate control parameters, we make the error system is asymptotically stable.

As we know, the ORTW usually works in a narrow and complex environment. Therefore, in this study, three omniwheels are mounted on the ORTW to allow it to move omnidirectionally; however, this also present a challenge in the control of the robot. Unlike vehicles with standard wheels, omnidirectional vehicles suffer from noticeable jitter in the orientation angle. Most of the previous studies neglected the problem while others attempted to reduce this jitter by adjusting the gains in the controller. Here, we also investigate the structure of the omniwheels touchdown characteristics to reveal the cause of the vibration in the orientation angle. Then, we apply an adaptive technique to eliminate this vibration.

A limitation of the previously published tacking methods is that they require at least the measurement of velocity on the link side or motor side. However, in robotic applications, velocity sensors are frequently omitted because of their considerable the production cost, and the size and the weight of the servo-drives. Moreover, in practical robotic systems, the velocity measurements obtained through tachometers are easily perturbed by noise. Therefore, to align with the economic and/or physical constraints, the ability to control robots without velocity measurements is of great importance. A high-gain observer is designed to take place the unmeasurable speed as the feedback information of controller.

The previous trajectory tracking methods relied on the measurements of position output that are typically assumed as complete or perfectly available. Unfortunately, this assumption is not always practically plausible. Measurement information is incomplete (i.e., missing, delayed, quantized, or faded) in many engineering, biological, and chemical systems because of several reasons such as intermittent sensor failures, sensor aging, abrupt structure changes, and network induced noises that can result in performance degradation or even instability. A state observer is designed to estimate the incomplete measurements of position output.

Owing to omniwheel has a complex structure (in general, an omniwheel is composed of a driven wheel and several follower wheels.), the omnidirectional wheel can move in any direction. However, this complex structure compromises the structural strength of the machine. For instance, the bearings of the follower wheels must be grinded sufficiently thin to be equipped on the driven wheel. Therefore, to ensure regular tasking and normal service life of the machine, constraints are required on the control inputs. The control constraints guarantee the safety of the omniwheels and the ORTW training process. In this study, the saturation function is approximated by a hyperbolic tangent function, which guarantees the smoothness and boundedness of the controller.

Since each problem does not exist independently, we will discuss them gradually in each chapter of the paper. In addition, in each chapter, we also give the steps of controller design, stability analysis and its proof. In order to ensure the reliability of the proof, we use some mathematical tools, such as. Lyapunov function, stochastic stability theory, Young's inequality, Frobenius norm, Markov's inequality, Lagrange mean value theorem, and so on. In the process of stability analysis, we also discuss the relationship between the control parameters and the mean absolute of the errors, which makes that asymptotical trajectory tracking is achievable with a certain probability. Therefore, we can adjust the parameters of the controller according to this rule to reduce the tracking error. At the end of each chapter, we give the corresponding simulation, which proves the effectiveness of the controller.