Adaptive Polar-Space Motion Control for Embedded Omnidirectional Mobile Robots with Parameter Variations and Uncertainties

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Abstract This paper presents an adaptive polar-space motion controller for trajectory tracking and stabilization of a three-wheeled, embedded omnidirectional mobile robot with parameter variations and uncertainties caused by friction, slip and payloads. With the derived dynamic model in polar coordinates, an adaptive motion controller is synthesized via the adaptive backstepping approach. This proposed polar-space robust adaptive motion controller was implemented into an embedded processor using a field-programmable gate array (FPGA) chip. Furthermore, the embedded adaptive motion controller works with a reusable user IP (Intellectual Property) core library and an embedded real-time operating system (RTOS) in the same chip to steer the mobile robot to track the desired trajectory by using hardware/software co-design technique and SoPC (system-on-a-programmable-chip) technology. Simulation results are conducted to show the merit of the proposed polar-space control method in comparison with a conventional proportional-integral (PI) feedback controller and a non-adaptive polar-space kinematic controller. Finally, the effectiveness and performance of the proposed embedded adaptive motion controller are exemplified by conducting several experiments on steering an embedded omnidirectional mobile robot.
Keywords  Adaptive control · Embedded · Omnidirectional · Polar coordinates · Stabilization · Trajectory tracking

1 Introduction

Omnidirectional mobile robots have attracted much attention in both academia and industry in the field of robotics. Comparing with several car-like robots [1–5], this type of omnidirectional mobile mechanism has the superior agile capability to move towards any position and to simultaneously attain any desired orientation, namely that such a mobile mechanism does not have so-called nonholonomic constraints. Modeling and control of omnidirectional mobile robot in Cartesian coordinates have been investigated by several researchers. Pin et al. [6] presented the concepts for a family of holonomic wheeled robots. Watanabe et al. [7] proposed a PI feedback control method for an omnidirectional mobile robot which is equipped with three lateral orthogonal-wheel assemblies. Kalmár-Nagy et al. [8] offered the dynamic model and the time-optimal control for an omnidirectional robot. Williams II et al. [9] developed a dynamic model for omnidirectional wheeled mobile robots, considering the occurrence of slip between the wheels and motion surface. Huang and Tsai [10] discussed how to construct a FPGA-based adaptive controller for a kind of omnidirectional mobile robot with parameter variations and uncertainties caused by slip and abruptly changeable payloads. Overall, the aforementioned methods did not directly cope with polar-space motion control problems.

Polar space is especially useful in situations where the relationship between two points is most easily expressed in terms of angle and distance. There are many simple polar-space equations which describe complex curves, for example, the Archimedes’ spiral, the rose curves and the Limacon of Pascal. The trajectory tracking problems for nonholonomic mobile robots in polar space have been investigated by several researchers. Park et al. [11] adopted the state-space exact feedback linearization method to achieve point stabilization of mobile robots. Yang and Kim [12] presented the sliding mode control for trajectory tracking of nonholonomic wheeled mobile robots. The polar-space sliding-mode tracking controller to steer a nonholonomic wheeled mobile robot incorporating its dynamic effects and external disturbances was developed by Chwa [13]. To date, there have been few studies related to polar-space omnidirectional mobile robot control. For example, Huang and Tsai [14] proposed a kinematic control approach for both tracking and stabilization of an omnidirectional mobile robot in polar coordinates. Based on [14], an adaptive polar-space kinematic controller for autonomous omnidirectional mobile robot was introduced in [15]. However, the method in [15] cannot be applied to address both polar-space trajectory tracking and regulation problems of an omnidirectional mobile robot incorporating with dynamic effect, parameter variations and uncertainties.

Recently, the new generation of FPGA technology has enabled an embedded processor intellectual property (IP) and custom application IPs to be integrated into an SoPC developing environment. This new SoPC technology has been bringing a major revolution in the design of integrated circuits [16–19]. Since both software and hardware are integrated into a single programmable logic device, the designers can easily combine the flexibility of software unit and high performance of hardware.