Robust Control with Dynamic Compensation for Human-Wheelchair System

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Abstract. This work presents the kinematic and dynamic modeling of a human-wheelchair system, and dynamic control to solve the path following problem. First it is proposed a dynamic modeling of the human-wheelchair system where it is considered that its mass center is not located at the center the wheels' axle of the wheelchair. Then, the design of the control algorithm is presented. This controller design is based on two cascaded subsystems: a kinematic controller with command saturation, and a dynamic controller that compensates the dynamics of the robot. Stability and robustness are proved by using Lyapunov's method. Experimental results show a good performance of the proposed controller as proved by the theoretical design.

Keywords: Human-wheelchair system, dynamic control and dynamic modeling.

1 Introduction

In recent years, robotics research has experienced a significant change. The research interests are moving from the development of robots for structured industrial environments to the development of autonomous mobile robots operating in unstructured and natural environments. These autonomous robots are applicable in a number of challenging tasks such as cleaning of hazardous material, surveillance, rescue and reconnaissance in unstructured environments which humans are kept away from. Since it is foreseen that this new class of mobile robots will have extensive applications in activities where human capabilities are needed, they have attracted the attention of robotics researchers [1-3].

Therefore, the necessity of technological development in the field of medical and welfare equipment is cried out. By responding to this issue, different types of technologies have been developing by Engineering for the assistance of human [4-7]. Electrical wheelchair is an important means of transport for handicapped and aged people, who do not have the capability of walking, normally can move around using a commercially available wheelchair. However there are many people suffering from

X. Zhang et al. (Eds.): ICIRA 2014, Part I, LNAI 8917, pp. 376–389, 2014.

severe loss of motor function due to variety of accidents or diseases such as a Spinal Cord Injury (SCI) or Amyotrophic Lateral Sclerosis (ALS), in this cases is necessary to provide a new way to command such an electrical vehicle.

Human Machine Interface (HMI) based on electro-biological signal are present in [1,4,8,9]. Such interfaces allow commanding wheelchair robot governed by a computer. The literature shows that an autonomous wheelchair can be successfully driven by persons using only electrical signals generated by eye-blinks, voice, and others [1,2,10,11]. Then, a trajectory will be automatically generated and a trajectory tracking control will guide the wheelchair to the desired target. As indicated, the fundamental problems of motion control of wheelchair robots can be roughly classified in three groups [12]: 1) *point stabilization*: the goal is to stabilize the wheelchair at a given target point, with a desired orientation; 2) *trajectory tracking*: the wheelchair is required to track a time parameterized reference; and 3) *path following*: the wheelchair is required to converge to a path and follow it, without any time specifications; this work is focused to resolve the path following problem.

The path following problem has been well studied and many solutions have been proposed and applied in a wide range of applications. Let $\mathcal{P}_d(s) \in \Re^2$ be a desired geometric path parameterized by the curvilinear abscissa $s \in \Re$. In the literature is common to find different control algorithms for path following where is conseder $s(t)$ as an additional control input. In [13-16], the rate of progression ($\dot{s}$) of a virtual vehicle has been controlled explicitly. Another method for path following of wheelchair robot is the image-based control. The main objective of this method is to detect and follow the desired path through vision sensors [3]. Furthermore, it is important to consider the wheelchair's dynamics in addition to its kinematics because wheelchairs carry relatively heavy loads. As an example, the trajectory tracking task can be severely affected by the change imposed to the wheelchair dynamics when it is carrying a person, as shown in [17]. Hence, some path following control architectures already proposed in the literature have considered the dynamics of the wheelchair robots [11,19].

In such context, this work proposes a new method to solve the path following problem for a wheelchair robot to assist persons with severe motor diseases. Additionally, it is proposed a dynamic modeling of the human-wheelchair system which, which has reference velocities as input signals to the wheelchair, as it is common in commercial robots, and it also has adequate structure for control law designing [11]. The proposed control scheme is divided into two subsystems, each one being a controller itself: 1) the firts on is a kinematic controller with saturation of velocity commands, which is based on the wheelchair robot's kinematic. The path following problem is addressed in this subsystem. It is worth noting that the proposed controller does not consider $s(t)$ as an additional control input as it is frequent in literature; and 2) an dynamic compensation controller that considered the human-wheelchair system dynamic model, which are directly related to physical parameters of the system. In addition, both stability and robustness properties to parametric uncertainties in the dynamic model are proven through Lyapunov's method. To validate the proposed control algorithm, experimental results are included and discussed.

The paper is organized as follows: Section 2 shown the complete dynamic modeling of the human-wheelchair system, while Section 3 describes the path