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Model-based control for an innovative power-assisted bicycle

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Abstract

This paper presents an activity concerning the development of a control strategy for power-assisted electric bicycles, also called pedelecs. A common assistance algorithm available on commercial pedelecs consists in providing predefined constant assistance electric power. This approach is lack of flexibility with respect to environmental condition and generally does not provide a good driving comfort. The proposed control method has been designed to minimize the tracking error between the actual bike velocity and the desired one, in the presence of external disturbances. The assistance electric motor torque consists of a feedforward torque integrated with a feedback one. The feedforward contribution is a nonlinear torque based on the pedelec model. The feedback action has the function to compensate the tracking error due to model uncertainties and unknown disturbances. The performance of the methodology has been evaluated applying the controller to an innovative pedelec prototype. To this aim, a mathematical model of the vehicle has been developed. Different human torque models have been implemented in order to study the influence of the rider on the pedelec dynamics. The results of a comparative analysis between the proposed algorithm and a common assistance method have demonstrated that the proposed controller provides improvements in terms of riding comfort and energy utilization.

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Keywords: pedelec, power-assisted bicycle, control, quality of riding, energy consumption

1. Introduction

Continuous improvements in technology and ways to make vehicles more environmental friendly has led to an increase of so-called green vehicles [1]. Among the latters, light electric vehicles, such as electric bicycles, are very effective for city commuters [2, 3].

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Electric bicycles, also called e-bikes, can be a viable solution to the world's energy crisis because they can substitute motor vehicles for midrange transportation needs with zero emission. Indeed, a vehicle as the e-bike [4, 5] constitutes an alternative vehicle for both personal mobility and goods delivery, especially for small and medium distances. The e-bike, in all its forms, two or three wheels (tricycle), is able to move with an average speed equal to the typical one of the town traffic and, at the same time, it requires energy for its mobility that is very close to the necessary energy just for the displacement of the transported people.

There are two kinds of electric bicycle. A first kind includes an electric motor into bicycle frame or wheels, and it is driven by motor using a handlebar throttle [6, 7]. A second kind is a power-assisted bicycle, also called pedelec [9], which is a human–electric hybrid bicycle [10] that supports the rider with electric power only when the rider is pedaling. Typical e-bikes are equipped with an electric motor, a battery, a control unit and sensors to detect rider torque and bicycle speed. The motor torque, determined by the control unit, plays a crucial role in ensuring the comfort and the safety of pedelec riding.

This paper is dedicated to developing a pedelec velocity control (PVEC) with both the electric torque from the motor and assistant torque from the rider. The ultimate objective of the PVEC is to follow a given velocity command under the limited motor electric torque, the rider torque and the inevitable disturbance actions caused by environmental conditions such as the wind and the road surface.

In [11 – 13], an e-bike velocity control, based on a fuzzy logic control approach, has been investigated. The studies in [14, 15] inspected the effect of the human assistant torque from the rider. In [16, 17], an e-bike velocity control has been proposed in terms of optimization of H^{∞} performance.

For this study of velocity control for pedelec, the torque control law has been obtained with a feedforward control integrated with a feedback one. The feedforward control law is a nonlinear torque obtained from the vehicle mathematical model. The feedback action is based on a proportional-integral-derivative (PID) control that has the function to compensate the tracking error due to model uncertainties and unknown disturbances. The PVEC has been applied to a pedelec prototype and the results have been compared with the ones resulting from a classical assistance method. The performance of the PVEC, in terms of velocity tracking, stability and disturbance rejection, have been optimized by properly setting the PVEC coefficients. The quality of riding for the two different assistance methods has also been evaluated.

The rest of the paper is organized as follows: in section 2 the vehicle description is presented; the derivation of the pedelec mathematical model is showed in section 3; the PVEC development is described in section 4; finally, simulation results are illustrated in section 5.

2. Vehicle description

A prototype of an innovative power-assisted bicycle has been adopted for the research. The vehicle has been designed at the Department of Industrial Engineering of the University of Naples Federico II [18]; its scheme is shown in Fig. 1, where two components are highlighted: the electric motor and the chain force sensor.

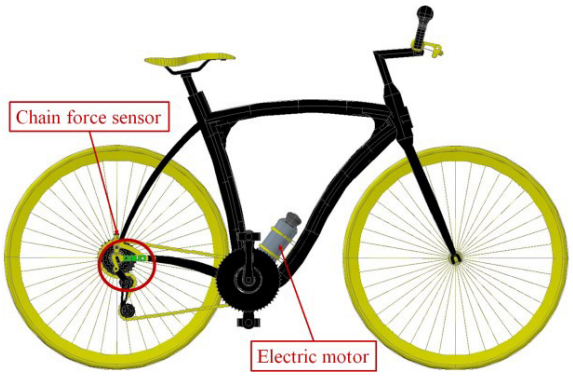

Fig. 1. Pedelec prototype scheme.