Applied Mathematical Modelling 36 (2012) 2178–2191

Contents lists available at SciVerse ScienceDirect

Applied Mathematical Modelling

journal homepage: www.elsevier.com/locate/apm

Motion measurement of a two-wheeled skateboard and its dynamical simulation

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ARTICLE INFO

Article history:
Received 25 February 2011
Received in revised form 2 August 2011
Accepted 9 August 2011
Available online 8 September 2011

Keywords:
Skateboard
Propulsion
Motion measurement
Dynamical model
Simulation

ABSTRACT

This study investigates the dynamics of the propulsion mechanism of a two-wheeled skateboard by measurements of human skateboard motion and computer simulations using a simplified model. This model expresses the board motion within the horizontal plane. The inputs of the model are the yaw moment about a vertical axis, horizontal force normal to the skateboard axis, and two-wheel orientations, while the outputs are the center of mass position in the horizontal plane and the board orientation. By selecting parameters of sinusoidal inputs to fit the measurement data, similar output data is obtained from the motion measurements and computer simulations. This result allows us to conclude that some sinusoidal motions and forces can robustly propel this type of skateboard.

1. Introduction

Mobility is an ability to move from one place to another and allows biological systems to enlarges their activity area. To achieve mobility, wheeled systems are occasionally utilized, which enable faster spatial movement than legged systems on a flat terrain.

Some wheels in automobiles are active, i.e., are directly driven by an engine or a motor. Although active wheels are convenient for controlling the speed, all the wheels should not be necessarily active; the active wheels require complex mechanisms for drive transmission, which not only increases the weight but also includes some parts causing mechanical troubles by wearing. More energies are required to drive many wheels. Therefore, passive wheels are partially adopted in some wheeled systems.

The rotation of the passive wheels requires some kinds of forces from the outside instead of the direct driving force of the wheel axis. A roller skate is an example of a device that consists of all passive wheels, where the propelling power is produced from the leg motion kicking the ground: the wheels under the supporting leg rotate by the propulsion of ground reaction force which the other leg generates by directly pushing the ground backward. However, the effective use of degrees of freedom (DOF) of motion of a mechanism mounted on passive-wheel systems can propel the wheeled system without kicking the ground. Skateboards [1,2], snakeboards [3] or other vehicles are examples of such systems [4–7]. Especially, the snakeboard was studied much by Ostrowski and Burdick [8–10], Marsden and Ostrowski [11], Ostrowski [12], Ostrowski et al. [13], McIsaac and Ostrowski [14], and was discussed much from viewpoint of dynamics reduction [15–17], structure of dynamics [18–23], controllability [24], stabilization of numerical solutions [25] or non-holonomic control [26–36].

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doi:10.1016/j.apm.2011.08.005

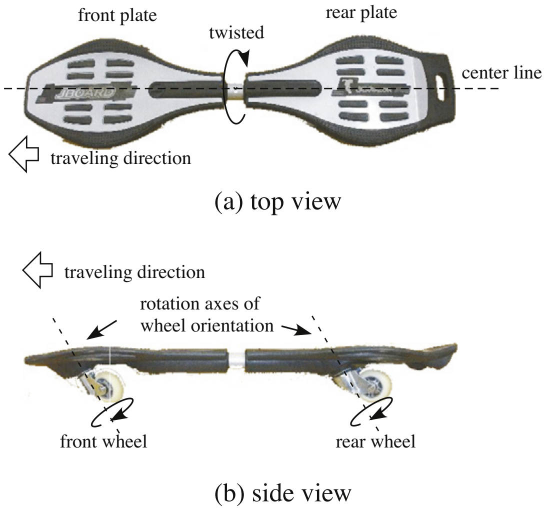

Fig. 1. Two-wheeled skateboard. It consists of two plates, front and rear, which can be twisted around the center line. The wheel is attached on the center line at each plate. The rotation axis of the wheel orientation inclines backward.

Recently, a new type of two-wheeled skateboard has become available in the market, which has an additional degree of freedom around its roll axis, as shown in Fig. 1. Two wheels are attached to the center line of the board: one to the front plate and the other to the rear plate. The rotation axes of each wheel orientation are inclined backward, which defines the traveling direction of the board (to the left in this figure) since wheel orientation is restricted. The rider who is facing sideways of the board places a foot on each plate. In this way, the board moves in the lateral direction of the rider. To propel the board, the rider repeatedly moves his foot back and forth alternatingly relative to the waist with keeping the contact to the board, which provides yaw moment to the board about a vertical axis. In addition, the two plates are twisted around the roll axis by changing the action point of the body weight at each foot. This twist affects the direction of the two wheels because of the backward inclination of the orientation axis.

This type of skateboard can be smoothly accelerated from a stationary state. For acceleration of the board, both the yaw moment from the rider on the board and the twist between the two plates are important. The twist around the roll axis allows one to change the orientation of the two wheels; such an active control of the wheel orientation seems to contribute to rapid traveling motion by facilitating steering actions, because the wheel orientation perpendicular to the propulsion prevents the board from running, while the parallel wheel orientation helps it to go ahead.

Based on the above characteristics, we are investigating the propulsion mechanism of this kind of two-wheeled skateboard. At the first step, the goal of this paper is set to clarify what kind of human inputs is crucial and what kind of input trajectories can successfully propel the board by considering how the yaw moment works and how the twist of the plate should be treated from the aspect of steering the wheel orientation. The replay of a successful skateboard motion is needed at first to investigate its propulsion mechanism, which follows the clarification of the inputs and their trajectories. Therefore, the goal in this paper is one of the important factors for our purpose.

2. Method

In this study, we take the following steps based on both motion measurements and dynamical simulations:

(1) The two-wheeled skateboard is described using a reduced-order model in order to focus only on the propulsion inputs to the board. In this reduced-order model, the "inputs" are yaw moment around the center of mass (CoM) of the board, normal force (the force exerted to the CoM that is normal to the board orientation), and wheel direction.
(2) To investigate what kind of input trajectory can propel the skateboard, skateboard motions are measured. This is a pilot experiment for rough estimation of the input trajectory.
(3) Using data from these measurements, trajectories of the inputs (except the yaw moment) are constructed by function approximation.
(4) Next, these input trajectories are applied to a computer simulation, whose dynamics are derived from a previous reduced-order model with the velocity constraints of the wheel (wheel does not slip to the wheel axis direction).
(5) Then, parameters of the yaw moment are selected, so that the simulation results match the measured data well.

Using these steps, we clarify the inputs from the rider that successfully propel the skateboard in the form of time-varying trajectories.