Mechanical Systems and Signal Processing 38 (2013) 399–410

Contents lists available at SciVerse ScienceDirect

Mechanical Systems and Signal Processing

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

Vision-based measuring system for rider's pose estimation during motorcycle riding

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ARTICLE INFO

Article history:
Received 22 June 2012
Received in revised form
26 November 2012
Accepted 5 January 2013
Available online 13 March 2013

Keywords:
Pose estimation
Driver
Motorcycle dynamics
Vehicle interaction
Human pose
Vision

ABSTRACT

Inertial characteristics of the human body are comparable with the vehicle ones in motorbike riding: the study of a rider's dynamic is a crucial step in system modeling. An innovative vision based system able to measure the six degrees of freedom of the driver with respect to the vehicle is proposed here: the core of the proposed approach is an image acquisition and processing technique capable of reconstructing the position and orientation of a target fixed on the rider's back. The technique is firstly validated in laboratory tests comparing measured and imposed target motion laws and successively tested in a real case scenario during track tests with amateur and professional drivers. The presented results show the capability of the technique to correctly describe the driver's dynamic, his interaction with the vehicle as well as the possibility to use the new measuring technique in the comparison of different driving styles.

1. Introduction

The dynamic of road vehicles is affected by a number of parameters; a set of these variables have an effect on the vehicle response that is difficult to be estimated. Among them, we can mention the road surface [1,2], maneuvers imposed by the driver [3] and tire responses [4,29]. The analysis of two-wheeled vehicle dynamics is even more complex because this type of system is intrinsically unstable and it is therefore impossible to simulate open-loop maneuvers like for cars; on the contrary an accurate rider model is required in addition to the vehicle model [27].

Moreover, in the case of motorcycle dynamics, the contribution of the driver's mass on the overall vehicle–driver system is non-negligible [5], therefore the investigation of the human–motorbike mutual interaction is fundamental to correctly model the complete system [30]. Out of the three fundamental aspects of a motorcycle dynamics listed in Ref. [6], maneuverability, handling and stability, scientific literature shows a close link of the last two of them with inertial characteristics of the human body. As for maneuverability, different indexes of this characteristic were developed in literature, usually defined relating system input to system output. A commonly considered system input is the steering torque (see Koch [28] and Cossalter [26]) because it provides a good index of the effort that the driver has to make in order to impose trajectory change. The driver movements are another way for the rider to control the motorbike response, and the knowledge of these quantities would give useful information for further development in maneuverability estimation.

Studies related to the development of a model for motorbike stability began in the 1950s [7,8], but only 20 years later the first theoretical model able to take into account the driver's influence on the whole system dynamics was proposed [9], and the influence of driver's lateral displacement studied. In Ref. [10] the first experimental verification of the model is

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0888-3270/$ - see front matter
http://dx.doi.org/10.1016/j.ymssp.2013.01.009

provided, but the work neglects the experimental characterization of the driver's body displacement. In the 1980s, more complex approaches were suggested: Ref. [11] linearizes for the first time equations in a non straight trajectory, introducing a degree of freedom of the driver's trunk, and Ref. [12] focuses the system modeling on the inertial characteristic of the driver's body, developing a 20 d.o.f. dynamical model. In the 1990s, many complex numerical models were developed, generally based on multibody approaches, thanks to the increased computer computational power. A state of the art model is the one proposed in Ref. [13], where the displacement of the upper part of the driver's body is a key parameter.

The first experimental campaign related to motorcycle handling is the one presented in Ref. [14], where for the first time the driver's roll angle was measured by means of a linear variable differential transducer (LVDT) mounted on the vehicle and fixed to the driver's back. Successive numerical studies highlight the deep influence of the body motion on the system dynamics [12,15]. Recently, in Ref. [16] a system capable of reconstructing the relative motion between the driver and the vehicle is presented: six wire potentiometers measure the relative displacement of three points of the driver's back with respect to the vehicle and the collected data allows to estimate the 6 d.o.f. of the body. The main associated drawbacks are the high intrusiveness of the approach (six springs pull the driver's back) and the risks related to security issues in case of a fall.

The driver's motion is clearly shown to be a key parameter in the study of motorcycle dynamic. If, on the one hand, numerical models are ready to easily implement this contribution on the system modeling, on the other hand, the experimental measures are still a critical point.

In the first part of this work, an innovative non contact measuring system able to reconstruct the 3D position and orientation of the driver's trunk is presented and validated. The system is composed by an on-board vehicle digital camera and a target placed on the driver's back. The motion measurement is obtained, analyzing the images of the target acquired by the camera. First, acquired images are analyzed in order to extract the position of significant points of the target and then a pose estimation algorithm is applied to get the three-dimensional translations and the rotations of the target with respect to the reference system of the motorcycle. Laboratory tests prove the reliability of the proposed system.

Successively, the system is tested in a real case scenario. Two different skilled drivers are asked to perform steady state and transited maneuvers on an instrumented motorcycle. The presented results show at first the capability of the measuring techniques to correctly describe the driver's dynamic and its interaction with the vehicle. Then, the comparison between data related to the two different volunteers illustrate the applicability of the proposed measuring procedure for the characterization of different driving styles.

2. Instrumented vehicle description

During experimental tests, an instrumented vehicle, able to measure the most significant quantities related to vehicle running condition and driver's posture, is used. The vehicle is the F4 1078 RR 312 produced by MV Agusta s.p.a. IT (Fig. 1a). To study the running stability and to characterize the interaction between vehicle and driver during riding, vehicle accelerations and rotations (later reported as Cardan angles) and relative movements between driver bust and vehicle are measured. To this aim, several instruments are installed on the vehicle (Fig. 1). An inertial platform, placed in correspondence of the filler cap of the tank of the vehicle, measures absolute accelerations and angular rates of the motorbike (i.e., its six degrees of freedom in the space). To fix the inertial platform to the tank a special support is used; this support places the vertical axis of the inertial platform coincident to the vertical plane of symmetry of the vehicle; moreover, high frequency vibrations due to the engine working are filtered by the support. Other quantities, necessary to identify the vehicle local accelerations and rotations, are the suspensions displacements; to measure these displacements a couple of linear potentiometer is used: one potentiometer for the front suspension displacement and one for the rear one. The transducer on the front suspension is fixed, maintaining the instrument axle parallel to the front fork axle: in this way the measured displacement corresponds to the front suspension stroke. The rear suspension presents a non-linear ratio between the wheel travel and the suspension one: it is a Pro-Link suspension. For this study, it is more convenient to measure the rear wheel vertical motion instead of the spring and damper displacement. For this reason, one end of the linear potentiometer is fixed to the rear wheel axle and the other end to the motorcycle main frame along a vertical axis.

A proximity sensor is mounted on the front wheel to reconstruct the instant speed of the vehicle and an RVDT measures the steering angle. Two strain gauges for every handlebar measure the steering torque.

To measure the relative translations and rotations between the driver's bust and the vehicle an innovative vision based measuring system is used. This technique uses the images acquired by a digital camera to define the 3D position and orientation of a defined object. To apply the technique, a camera (point E in Fig. 1a) is placed on the vehicle, fixed on the motorbike main frame behind the driver bust and a target is fixed on the driver's back (Fig. 1b), corresponding to his trunk center of gravity [17]. The used camera is a μeye equipped with a 640×480 pixel 1/4″ CCD sensor and with a 4 mm lens. Analog data are sampled at 1 kHz and low pass filtered at 5 Hz; the camera acquires images at 10 Hz. The two independent data acquisition systems are synchronized by a shared trigger signal. All the presented data are referred to the same reference system (Fig. 1a).

3. Description and validation of the vision-based measuring technique

Pose estimation algorithms are a group of methods able to estimate the three-dimensional position and orientation of a rigid body of know geometry, the "target", with respect to the reference system of a camera framing the object itself [18].