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A novel method to monitor bicycling environments

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ABSTRACT

A bicycle is a promising human-powered and emission-free transportation mode to address growing transportation and environmental problems. Bike-friendly environments should be constructed to innovatively increase the use of bicycles as a significant transportation mode. From this perspective, the scientific and effective monitoring of bicycling environments is of keen interest. An important technical challenge for monitoring is to evaluate the performance of bicycling environments. This study proposes a novel monitoring method that can be used for evaluating bicycle performance in terms of safety and mobility. An instrumented probe bicycle (IPB), which is equipped with a set of sensors including a global positioning systems (GPS) receiver, accelerometer, and gyro sensor, was used to develop the proposed monitoring method. The IPB provides useful bicycle maneuvering data for identifying longitudinal, lateral, and vertical maneuverings of the bicycle, which are affected by environmental factors such as heavy vehicle volume, surface conditions, grade, crossings, humps, and curbs. Regarding safety monitoring, an index to predict bicyclist's perceived safety and comfort with the predictors derived from the measurements by the IPB was developed. A questionnaire survey was conducted to obtain actual responses from bicyclists for perceived safety and comfort during the field experiment. In addition, a method to evaluate the bicycle mobility using GPS speed data was devised. Then, a fault tree analysis (FTA) technique, which is a well-known technique for risk analysis, was adopted to integrate safety and mobility monitoring. As a result, the bicycling monitoring index (BMI) was proposed. Data derived from the proposed method is expected to be effectively used for promoting the bicycle use by supporting the development and evaluation of various bicycle-related policies.

1. Introduction

A variety of traffic monitoring and surveillance technologies have been developed and operated in practice. Useful information has been provided to the public, as real-time traffic information and as historical data for planning and design purposes. However, a limitation of current monitoring and surveillance systems is that they focus mainly on vehicular traffic. Less effort has been devoted to the application of sensor and information technologies for bicycle traffic. A question that then arises is, 'Can bicycles be monitored in more intelligent manner using recent sensor technologies?' This paper attempts to provide an answer to this question.

The bicycle is an important human-powered mode of transportation used to increase the sustainability of transportation systems. This is mainly due to the environment-friendly and emission-free characteristics of the bicycle. In addition to improving air quality, bicycles can alleviate traffic congestion and are a reasonably fast alternative for short-distance trips, in particular, in congested urban networks. Another notable feature of the bicycle is that it provides many health benefits for

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users. However, the safety and mobility issues for bicycling are still serious impediments to bicycle usage. For example, steep uphill and downhill grades have significant impacts that deter users from bicycling. Grava (2003) suggested that uphill grades that are greater than 3–5% and steep downhill grades each present bicycling safety concerns. Noël et al. (2003) also identified horizontal and vertical profiles as factors that affect safety. Based on the user perception analysis, Gatersleben and Appleton (2007) evaluated attitudes and perceptions for bicyclists and potential users. Attitudes and perceptions were compared by bicyclists and non-bicyclists. The perception of risk level was found an important factor for deciding bicycling travel. Similarly, Bordagaray et al. (2012) adopted an ordered probit model to identify factors affecting the service quality of public bicycles. It was found that safety was the most dominant factor affecting the service quality. Other factors affecting the use of bicycles include heavy vehicle volume, surface conditions, stops, humps, and curbs. Therefore, bicycle-friendly roadway environments should be provided to innovatively increase the use of bicycles as a significant mode of transport. One of the fundamentals for providing better environments for the bicyclist is to assess whether a road segment would accommodate safe and comfort bicycling. From this perspective, scientific and effective monitoring and evaluation of the roadway environment in terms of the bicyclist's perception for safety and comfort is of keen interest. This study aims at developing a methodology for evaluating the bicycling environment based on sensor technologies. An application of the proposed study using field experiments is presented with the lessons learned and future directions.

Relevant studies can be broadly categorized into two groups such as traffic engineering and use of sensor and detection technologies. Regarding the transportation engineering domain, existing studies in this group mainly deal with level of service (LOS) for bicycle traffic and attempt to develop indices to represent the quality of bicycle travel. Landis et al. (1997) presents a statistically calibrated LOS model based on user perception. Harkey et al. (1998) develops the bicycle compatibility index using user perception of presented video clips. Jones and Carlson (2003) develop an index to identify compatibility of bicycle travel on roadway segments, called the bicycle compatibility index (BCI). Petritsch et al. (2007) adopts a probit modeling approach to establish a LOS model for bicycle traveling on arterials. Klobucar and Fricker (2007) develop a network-wide assessment tool to quantify the bicycle friendliness of a street network based on perceived safety. Unlike the above studies, which use subjective measures and are based on the users' perceptions, Allen-Munley et al. (2004) develop an objective bicycle route safety rating model using actual crash data. The main purpose of these studies is to develop off-line decision making support tools for bicycle traffic. Therefore, aforementioned studies do not contain any method for intelligent on-site detection and evaluation of bicycling environments, which is a novel concept of this study. Regarding use of sensors and detection technologies, a research direction is to control the stability of bicycles based on detecting bicycle maneuverings using on-board sensors (Astrom et al., 2005; Iuchi and Murakami, 2006; Du et al., 2009; Lam, 2011; Suntharasantic and Wonsaisuwan, 2011). Another research branch is to detect bicycles using video image detection (Cho et al., 2010, 2011; Wu et al., 2010; Jung et al., 2011). The main purpose of using sensors in these studies is to control bicycles in a safer manner and to identify bicycle presence and movement, which are considerably different from those of our study. We are not aware of any existing studies to present useful insights in evaluating the bicycling environment based on sensor technologies. The bicyclists' perception of the roadway environment is affected by roadway alignment, obstacles, crossings, and pavement conditions. Therefore, identifying bicyclists' responses and interactions with roadway environment in support of sensor technologies provides valuable information to establish how friendly the bicycle environment is and should be.

This study proposes a novel method to monitor bicycling environment. A key issue is to evaluate the performance of bicycling environments. There are two types of performances, which include safety and mobility. The former is related to hazardous events that the bicyclist encounters while traveling on the road. These events include crashes, near-misses, and falling-off the bicycle. The latter is related to how fast the bicyclist travels from their origin to a destination. An instrumented probe bicycle (IPB), which is equipped with a set of sensors such as a GPS receiver, accelerometer, and gyro sensor, was used to develop the proposed monitoring method. A gyro sensor is able to track the angular position of a moving object and provide angular velocity that is defined as the rate of change of angular displacement. The IPB provides useful bicycle maneuvering data for identifying longitudinal, lateral, and vertical maneuverings of bicycling, which are affected by environmental factors such as heavy vehicle volume, surface conditions, grade, crossings, humps, and curbs. This study proposes a bicycling monitoring index that is based on a fault tree analysis (FTA) technique to integrate safety and mobility monitoring. FTA is a well-known technique for reliability evaluations for systems. A binary logistic regression (BLR) based safety monitoring index, referred to as cycling stability index (CSI) and bicycle speed data are used in the proposed monitoring framework.

The functionality of the proposed IPB and the characteristics of obtainable data are presented in the next section. Section 3 describes the methodology for monitoring bicycling environments for both safety and mobility. The derivation of CSI and a method to interpret GPS bicycle speed data are also discussed in Section 4. Details on field experiments and data collection are described in Section 4. Applications of the proposed method with data analyses are presented in Section 5. An approach that uses public bicycle sharing systems to fully engage the benefits of the proposed methodology is presented in Section 6. Finally, a summary of this study, further research directions and research issues are provided.

2. Instrumented probe bicycle

Bicyclists are exposed to various environments that are not bicycle-friendly. Roadway and traffic environments, which include frequent interaction with vehicles, stops, steep grades, and obstacles such as humps and curbs, significantly decrease bicycle usage. In addition, adverse weather conditions such as rain, snow, fog, and strong winds affecting bicycle usage.