BSafe-360

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Contributor: Suzana Duran Bernardes, Kaan Ozbay

The popularity of bicycles as a mode of transportation has been steadily increasing. However, concerns about cyclist safety persist due to a need for comprehensive data. This data scarcity hinders accurate assessment of bicycle safety and identification of factors that contribute to the occurrence and severity of bicycle collisions in urban environments. The BSafe-360, a novel multi-sensor device designed as a data acquisition system (DAS) for collecting naturalistic cycling data, which provides a high granularity of cyclist behavior and interactions with other road users.

Keywords: bicycle safety ; data acquisition system ; lateral passing distance ; sensing ; traffic safety

1. Introduction

Bicycle safety is a key aspect of sustainable and equitable transportation in urban environments. It has become a prominent concern for researchers in recent years, especially since the changes in society's priorities caused by the COVID-19 pandemic and the economic crisis. Since 2012, cities around the United States (U.S.) have adopted the Vision Zero program, the main goal of which is to achieve zero traffic fatalities and injuries. The program originated in Sweden and has been successfully implemented in various European cities, bringing the number of cyclists injured or killed to nearly zero in some countries [1]. However, bicycle fatalities are still on the rise in the US [2]. This scenario raises questions about what factors and guidelines truly contribute to improving bicycle safety in urban environments.

One particular concern is the lateral passing distance (LPD) between cyclists and motor vehicles. This distance can significantly affect cyclists' safety, as it determines the amount of space drivers must allow when overtaking cyclists. For example, 29% of the crashes involving motor vehicles and bicycles were due to these vehicles traveling adjacent to each other in New York City (NYC) [3]. However, current data on LPD are limited. They are often based on the drivers' perspective because of the wide availability of state-of-the-art data acquisition systems (DAS) for motorized vehicles (e.g., cars and trucks), especially for connected and autonomous vehicles, making it difficult to assess current bicycle safety measure effectiveness accurately.

Fortunately, the advancement and spread of technologies in sensing, the Internet of Things (IoT), and Big Data allowed the improvement of data collection in various areas of study, including bicycle safety. Researchers have begun to turn especially to smartphone data and the development of instrumented bicycles (IBs), that is, bicycles equipped with two or more sensors, to function as bicycle-specific DAS [4][5][6][7][8]. The main advantage of these new DAS is that they allow the collection of naturalistic cycling data, which provides detailed data about cycling behavior and infrastructure. Naturalistic cycling data correspond to cyclists' real-world behaviors and environmental interactions collected without any interference from researchers [9]. However, the current scenario of bicycle DASs for the collection of naturalistic cycling data is still in its early stages. It has room for improvement with respect to its reliability, precision, availability, size, monetary and time costs, and scalability. Such improvements in DASs to collect naturalistic cycling data can help answer long-standing research questions, such as what factors lead to higher collisions, injuries, and fatalities involving bicycles, or what is the optimal threshold for the safe LPD drivers should maintain from cyclists when overtaking them.

2. Bicycle Safety

Bicycle safety is a crucial concern, particularly in urban areas where more people are opting for cycling as a means of transportation. Although there has been extensive research on specific issues such as collision severity and bicycle network, it is important to conduct further studies on bicycle safety to address a wider range of factors that contribute to improving bicycle safety [10]. One critical area of research that requires exploration is the collection of naturalistic cycling data, as this type of data can be crucial for advancing several niches of bicycle safety [11][12]. By gathering data in actual cycling conditions, researchers can gain a better understanding of the different factors that contribute to bicycle collision, injuries, and fatalities [13]. This method allows a more comprehensive and holistic approach to studying bicycle safety as it captures information on the interactions between cyclists, motorists, pedestrians, and the surrounding environment [14].

Furthermore, such data can help researchers define cyclist behaviors and comprehend the factors that influence cyclists' decision-making process while on the road [15]. Finally, naturalistic cycling data can provide insights into how conditions of the road are associated with cyclist safety and comfort [16]. In recent times, technological advancements have made collecting naturalistic cycling data more feasible.

In the last two decades, several methods have been introduced for collecting naturalistic and non-naturalistic cycling data, including surveys and GPS [17], video footage [18][19], virtual reality [20], and other sensors (e.g., LiDAR and ultrasonic sensor) [21][22], the latter being the use of commercial sensors installed on a bicycle (i.e., instrumented bicycles) [4][5][6][21] or combined in one device that can be mounted on bicycles [23][24][25].

The development of IBs and devices for the collection of naturalistic cycling data has brought important contributions to the field of naturalistic cycling, ranging from improving performance tracking to improving traffic safety. Some of the first instrumented bicycles were introduced by Joo and Oh (2013) [4] to monitor cycling infrastructure and by Dozza, Werneke, and Fernandez (2012) [5] and Dozza and Werneke (2014) [6] to identify factors that influence cyclist safety. As IBs depend on the installation of several sensors to the bicycle, the quantity of sensors that could be used is limited by the space available on the bicycle. The study budget could also limit the number of sensors used. Therefore, the number and type of sensors utilized to instrument a bicycle highly depend on the objective of the study, which hinders the application of the same IB to different studies. For example, while Joo and Oh (2013) [4] equipped a bicycle with a GPS computer and an IMU board, Dozza, Werneke, and Fernandez (2012) [5] and Dozza and Werneke (2014) [6] equipped a bicycle with six sensors (e.g., HMI, GPS, IMU, Brake Force sensor, Speed sensor, Start-Stop sensor), a wireless modem, and a camera. However, all authors combined the data acquired using a separate software, which required synchronization and interpolation of the data. In another study, Dozza, Rasch, and Boda (2017) [7] introduced the use of an RPi as data logger to integrate the data collected from an IMU, a speed sensor, and an angle sensor installed in a bicycle. The introduction of the RPi contributes to reducing the costs involved in performing data integration post-processing, but the configuration of the IB is still bulky and can interfere with how the volunteer would normally ride.

The most recent iterations of IBs include the adoption of more advanced sensing technologies such as LiDAR [7][26] and virtual reality [27]. The concept of IBs has also been adapted to other non-motorized vehicles, such as electric bicycles and e-scooters [14][28]. Pérez-Zuriaga et al. (2022) [28] equipped an e-scooter with two ultrasonic sensors, an IMU, a video camera GPS, and an RPi to collect LPD and the vibrations experienced by the e-scooter users when riding on a bicycle lane. A study by Ma et al. (2021) [29] used similar components but replaced the ultrasonic sensor with a LiDAR sensor. Although LiDAR improved the accuracy of distance measurements, it required a larger case and odd positioning on the e-scooter than the configuration suggested by Pérez-Zuriaga et al. (2022) [28]. However, most IBs and instrumented e-scooters result in sensors taking up a lot of space on the bicycle, which can interfere with the natural user behavior. Thus, other researchers started to look into alternatives to develop DAS that can be customized to support the same sensors as IBs but are portable and can be easily mounted and un-mounted on bicycles for collecting naturalistic cycling data, especially LPDs [23][24][25].

The first efforts to produce an all-in-one device to provide an alternative to instrumenting a bicycle were made in 2019 with the first prototypes of MetreBox [23] and BSafe-360 (referred to as a portable multi-sensor platform back then) [24]. Both devices contained GPS and ultrasonic sensors and were enclosed by a customized 3D printed case. The main difference between the devices is that while the MetreBox used only one ultrasonic sensor and an Arduino microprocessor, the portable multi-sensor platform used two ultrasonic sensors, one on each side of the bicycle, and a Raspberry Pi 2 B microcomputer.

Since then, other researchers have attempted to create new versions of all-in-one devices. For instance, Henao et al. (2021) [25] developed an open-source naturalistic cycling data collection DAS (1M+) using an RPi, a time-to-flight sensor, a GPS, a camera, and a custom 3D printed case. Nolan et al. (2021) [30] introduced the PassBox, a DAS which is a combination of the all-in-one device with IBs approaches. The authors used a device composed of two commercial ultrasonic sensors and a GPS receiver connected to an Arduino board enclosed by a plastic project box. This device has the potential to become an all-in-one DAS. However, they also used two Garmin Virb X action cameras attached to other parts of the bicycle to obtain additional video, GPS, accelerometer, and gyroscope data, which is more similar to the IB approach. Finally, Rudolph et al. (2022) [31] implemented the use of the OpenBikeSensor for measuring LPD. The OpenBikeSensor is an all-in-one DAS with two ultrasonic sensors and a GPS receiver connected to a printed circuit board (PCB) created by their research team. The DAS also has a separate small monitor connected to the main board via external cables that allow for setting up internet connection, privacy zones, and user identification of vehicles overtaking the bicycle [32].

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