Level of smartness and technology readiness of technologies affecting cycling safety: A review of literature

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Keywords: ICT on bicycles; cycling safety; smart bicycle; level of smartness; TRLs.

1 INTRODUCTION

Unlike motor-vehicle transport, the implementation of Information and Communications Technologies (ICT) and Cooperative Intelligent Transport Systems (C-ITS) in cycling has not been comprehensively investigated (Gadsby & Watkins, 2020). Cycling offers several benefits both to society and the environment and is one of the most sustainable and green transportation modes (Bucher et al., 2019). Many people worldwide have been switching to bicycles during the last decades, and this has increased even more due to the Covid pandemic (Nikitas et al., 2021). Furthermore, the number of people who ride an e-bike is also rising (Schepers et al., 2020). Thus, the number of cyclists is increasing and, in turn, the number of cycling accidents is increasing too. For instance, in the Netherlands, one of the most cycling-friendly countries, 31% of all road fatalities in 2019 were cyclists (203 fatalities), while in 2020, it was 37% (229 fatalities). One-third of these fatalities were e-bike users (Statistics Netherlands (CBS), 2021). Despite the constantly evolving landscape of cycling and electric bike adoption, applications of new technologies in bicycles are still immature.

In recent years, academic research on new technologies related to cyclists' comfort and safety is growing (Boularas et al., 2021; Muhamad et al., 2020; Shen et al., 2018). Furthermore, many studies focus on technologies affecting cyclists' road safety; however, it is unclear what type of technologies are implemented for bicycles. To the best of the authors' knowledge, a comprehensive review of such studies is lacking. Additionally, a clear definition of a "smart bike"- a concept gaining popularity nowadays, is missing in the literature. To address this gap, the objective of this paper is twofold: 1) to review the state-of-the-art technologies implemented in bicycles to improve cyclists' safety, and 2) to propose an original classification for the levels of smartness of newly emerging "smart bikes".

2 METHODOLOGY

This study adopted a systematic methodology for the search and selection process (Page et al., 2021) to make sure the full body of research on the topic is covered in the literature review, rather than snowballing and hand search, as well as to ensure reproducibility and transparency. A search query, focusing on new technologies associated to safety and different types of bicycles, including 29 keywords was developed and applied in Scopus and Web of Science databases, and the Google Scholar engine was used for grey literature. Only documents in English were included in the review and no geographical restrictions were applied. 1435 hits were screened, and only 36 were included in this review based on the specific predefined inclusion criteria.

3 RESULTS

Based on the reviewed literature, we propose a topology for the Bicycle Smartness Level (BSL) considering the dimensions of smartness as defined by Alter (2019), the automation levels of driving according to (SAE, 2019), and the Technology Readiness Levels (Mankins, 1995). With this topology, we wish to bridge the gap between the clear picture existing for automated vehicles and the less defined one in the more recently developed domain of smart bikes. Ideally, in this way, we can provide a foundation for a common language to be developed and used in future research to avoid confusion between the different capabilities and levels of smart bicycles.

More specifically, Figure 1 presents the BSL concerning the functionalities of these systems and their characteristics as follows: Level 0 contains the traditional bicycles, which cyclists pedal to use, and e-bikes with an electric motor and battery. Level 1 embodies systems that detect accidents and send emergency alerts as well as navigation systems. Level 2 consists of bicycles equipped with systems that can detect obstacles and warn cyclists to avoid a collision and cyclist monitoring system. Level 3 includes bicycles with cyclist assistance, including cruise control and automatic speed adjustment, to comply with the speed limits and reduce speed in critical locations. At this level Bike to Infrastructure (B2I) communication will be employed. Level 4 consists of systems that allow cyclists to receive notification of dangerous conditions through a connected environment where Bikes communicate with other Bikes (B2B), and Vehicles (B2V), achieving Bike to Everything (B2X) communication as well as braking assistance. Level 5 comprises an intervention ecosystem where, based on real-time data, governments or traffic authorities are able to influence user's behaviour, e.g., interventions in the operation of smart bicycles. C-ITS and advanced technologies are used as behavioural change instruments to achieve specific societal goals. With the development of the new technologies and the deployment of higher levels of smartness becoming a reality, bicycles and their systems are able to sense, process and act, providing advanced assistance to cyclists. Each level includes and builds on the features of the preceding levels. Note that the use of an electric motor is mandatory for speed interventions.

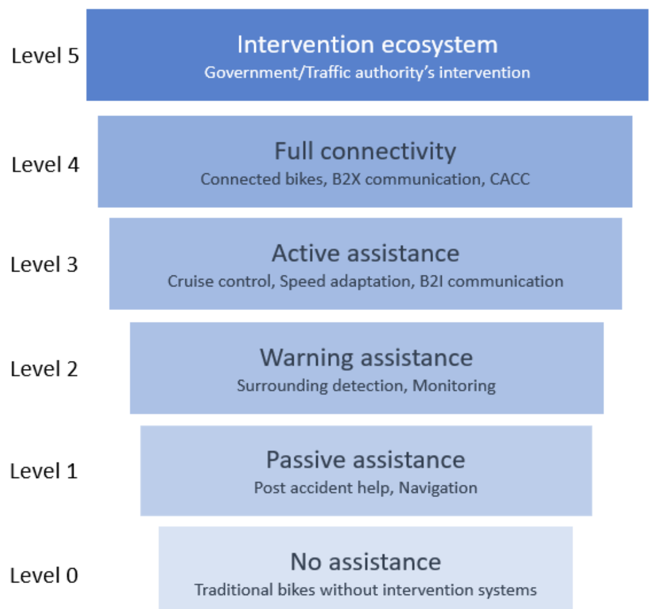

Figure 1: The proposed topology of the level of smartness on bikes

4 CONCLUSIONS

This study presents the current landscape of new technologies implemented on bicycles by reviewing studies focusing on applications and systems affecting cyclist safety. While there is a huge portion of recent literature concerning new technologies on bicycles, only a small part focuses on such technologies for safety purposes.

A topology of smart bicycle technologies is presented in this paper, aiming to give a clear image of the different levels of smartness. Based on the proposed topology, it is noteworthy that while research and prototypes reach up to BSL 4, the current state of the practice falls into BSL 2. The proposed BSL 5 is still theoretical, and will require the cooperation of various factors.

To assess the readiness level, we focused on the deployment of such technologies in the BSL - Level 5, since this is the level of interest for the future. As a result, we conclude that bicycle technologies currently fall into TRL 1 “Basic principles observed and reported” considering the maturity of technologies and lack of testing for the proposed systems.

The literature review showed that the majority of the studies investigated systems that mainly focused on warning systems for avoiding a collision, more commonly by using accelerometers/gyroscopes, LIDAR, sensors, and microcontrollers. These systems track obstacles such as vehicles and are limited to warning cyclists when they approach them. Although more than 50% of the studies included in this review employed e-bikes that could enable the implementation of speed intervention systems, the adoption of such systems was not investigated, demonstrating the lack of advanced technologies implemented in bicycles.

Among the reviewed studies, only a few collected and shared data through bicycle platforms, which clarifies that the level of communication technologies on bicycles is still underdeveloped.

To conclude, we would like to note that many studies developed smartphone-based systems, and currently, the B2B, B2V and B2I communication is mainly based on smartphones. This represents the current development in this domain and the efforts made to keep the cost for those systems on bicycles low. Thus, considering the rapid development of smartphones, an important question arises for future research: do we need new additional systems and technologies installed on bicycles to make cycling safer, or could this be achieved through smartphones since these devices are embedded with accelerometers, GPS, and wireless communication?

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