The Eternity Bike - Bringing Active Safety to the Bicycle

FLORIAN MICHAHELLES, TU Wien, Austria
PHILIPP WINTERSBERGER, TU Wien, Austria

To meet humans' mobility needs in the future, cycling could become a relevant alternative to established transport modes. However, bicycles are increasingly involved in accidents, and they did not benefit from active safety technology as implemented in traditional cars. In this position paper, we present our vision of the *"Eternity Bike"*, a (partly) automated bike with active safety functions that will fully integrate into the automated and cooperative transport systems of the future. We discuss relevant challenges from a technical and a human factors perspective and propose a set of research questions which will guide us in its development.

ACM Reference Format:
Florian Michahelles and Philipp Wintersberger. 2021. The Eternity Bike - Bringing Active Safety to the Bicycle. In *Cycling@CHI: Towards a Research Agenda for HCI in the Bike Lane at CHI '21, May 8–13, 2021, Yokohama, Japan.* ACM, New York, NY, USA, 5 pages.

1 INTRODUCTION

Increased needs for mobility are colliding with restricted space on streets and carbon emission reduction goals. This requires to re-think mobility and management of traffic. However, most efforts are still centered around the automobile: four wheels, high speed and heavy weight. Cycling is free from most of these downsides – in comparison to cars, bikes are much more effective in terms of payload (rider/passenger mass divided by vehicle mass) or weight-to-power ratio (gross weight divided by power), they do not produce emissions (not counting electric bikes), and they occupy less public space, what is especially important in dense urban areas. Thus, cycling is a promising mode of transportation able to contribute to solving the important societal, economical, and environmental challenges of the near future.

However, cyclists, who belong to the class of so-called "vulnerable road users" (VRUs, including pedestrians, e/scooter, etc.), could hardly benefit from the traffic safety gain in the last decades. Although the total number of accidents decreases, the ratio of VRUs tends upwards (33% of all fatalities in 2014 [14]). These developments become even more critical given the raising number of electronic bicycles, which expose their riders to higher risk and can lead to more severe injuries [17]. Consequently, cyclist and VRU safety is becoming an increasingly relevant topic. While automobiles increasingly use technology to improve safety and/or mitigate crashes (such as automated driving and advanced driver assistance systems), cyclists still rely on passive safety (helmets, protective gear, etc.) only. Further, visions of future mobility include the implementation of "cooperative, intelligent transportation systems" (C-ITS), which mostly address vehicles but not VRUs like bicycles. In this position paper we want to break with this paradigm and, instead, propose the development of an assisted bicycle, referred to as *"Eternity Bike"*, that makes use of recent technological advances to foster rider safety and comfort. In particular, we imagine the *Eternity Bike* to comprise the following features:

- **Self-balancing Function:** According to Statistik Austria, 30% of bike accidents happen at intersections or are single user accidents, e.g., caused by a loss of balance. Due to self-balancing, the *Eternity Bike* provides active safety features to prevent such accidents, but it also allows releasing control to engage in other small tasks.

- **Improved Human-Machine Cooperation:** Cycling is a complex cognitive-motor task that has not yet been fully understood from a physical perspective, e.g., which are the major forces/processes that allow balancing a bike? In our vision of the the *Eternity Bike*, both the assistance system and the rider share control of the bike. This requires to either develop new, or adapt existing approaches for shared control to this novel scenario.
- **Device and C-ITS Integration:** The unsafe use of mobile devices is steadily increasing, even on bicycles [3]. The *Eternity Bike* will be able to connect to consumer devices like smartphones/wearables to allow using digital services in a safe way using rider-friendly modalities. In addition, future C-ITSs aim at improving traffic safety and throughput. Still, human VRUs will have to interact with these systems and/or automated vehicles [19]. The *Eternity Bike* will provide features for communication and C-ITS integration, but it will also allow yet undiscovered collaborative features for cyclists like grouping bikes with similar speeds, or "green wave" cycling.

Such developments are necessary to support a wider propagation of people on two wheels, which will result in a more balanced use of space among different social groups, fewer and less severe accidents, and improved social life due to more interaction in public spaces. In this work, we discuss relevant questions for realizing this vision.

2 RELATED WORK AND IMPORTANT CHALLENGES

Support systems for cyclists (beyond classical approaches like bike lanes or appropriate city planning) are increasingly addressed. Commercial products include helmets with light strips to indicate directions to other road users [11]. Recent studies have investigated features for navigation and safety [11, 12], or support with augmented reality [18, 19]. Although also self-balancing functions have already been investigated (see below), these projects have not evaluated the consequences on the involved human factors. Thus, the *Eternity Bike* will be the first project aiming to holistically address the development of an assisted bicycle with active safety features and C-ITS integration along with human factors. In the following, we discuss challenges relevant for the development of the proposed features.

2.1 Self-Balancing Function

Machines are continuously getting equipped with sensors, such as acceleration, gyroscopes or even LIDAR in case of automated vehicles. Various projects have studied the physics and mechanics proving the feasibility of stabilizing unmanned bicycles either by applying an inverse control strategy of added rotors [20], or by left-right adjustments of the steering [10, 16]. We aim at using flexible computing resources available on the bicycle (e.g., user's smart phone or on-board-unit) and in the environment (e.g., 5G computational facilities on the road side units). The proposed *Eternity Bike* leaves the user in control in regular but takes over in critical situations like tipping over or getting caught in a complex traffic situation. Therefore, we plan to utilize deep learning for recognizing drivers' intent and reinforcement learning (RL) for keeping the bike upright and balanced. We will further utilize mobile computing approaches, in particular edge computing, for the provision of timely and reliable computational facilities for implementing this approach. As shown by [9] the driving force of keeping a bicycle balanced is continuously steering into the fall. A critical issue in this regard is that it must be determined how much input from the systems is required. For example, a strong tilt could result from an experienced rider on purpose, or it could be part of a fall from the perspective of a novice. Thus, the development of the *Eternity Bike* requires to include human factors/HCI research in all phases.

2.2 Improved Human-Machine Cooperation

Consequently, in this project we will study the interplay between system and user. While the user is keeping the bike balanced, a companion system is adding input to correct mistakes. Driver-vehicle cooperation as researched in automated driving predominantly addresses "traded control" (i.e., either the driver or the vehicle is in control, interrupted by handover) scenario. Although this is also relevant for the *Eternity Bike* in some situations, the scenario at hand incorporates "shared control" (i.e., both agents jointly perform the dynamic driving task, see [4]). Thus, the *Eternity Bike* can be seen as a collaborative system of rider and machine constantly steering into the fall. We want to study how users respond to interventions in such situations (i.e., both actors provide system input for stabilizing the vehicle), which requires a combination of methods from system sciences and human-machine interaction research.

2.3 Device and C-ITS Integration

The negative consequences of unjustified multitasking in the car are well documented and have led to various countermeasures, including both new laws but also technical solutions like Android Auto or Apple CarPlay. Also smart devices for bikes like AR helmets are in development. For the *Eternity Bike*, we aim at researching interaction methods that allow using digital services while cycling. One possibility in this regard could be the emerging field of "Earables" [15]. Further, a great variety of C-ITSs features have been proposed, such as platooning (reduced drag due to vehicles driving in platoons with very short headway) [8] or managed intersections (junctions without traffic lights that allow simultaneous passing of vehicles in different directions) [1]. We want to research how bikes can be integrated in a future where most vehicles are automated, and which additional cooperative features could be explicitly tailored for cyclists.

3 PROJECT IMPLEMENTATION

This project will be conducted in two branches. One will cover the self-balancing function while the other branch will address human factors already from the start. We will briefly discuss the planned work in those branches.

3.1 Setup of the Eternity Bike

First, we will implement a simulation of a bicycle in a virtual environment. Emphasis will be put on physics, i.e., it should behave like a real bike in terms of tilting and falling depending on the interplay of the handle bar and the speed. Then, we will train an RL algorithm that is able to balance the bike by actuating the handle bar based on the current speed an tilt, before building a working prototype. We will detach the physical coupling of handlebar and fork, allowing a motor unit to interfere with the rider's steering maneuvers ("drive-by-wire"). Additionally, we will distribute several gyro-sensors for measuring momentum and tilt of the bicycle. All data will be collected by an onboard Raspberry PI computer which also controls the steering interference motor. Finally, the bike will have to prove its capabilities in a real setting on a test track (for safety reasons, we will equip the bicycle with training wheels). In the course of the projects as the balancing mechanism progresses we expect to lift up the training wheels and finally eliminate them completely. We will test this setup in a secured environment such as indoor (i.e., on a loose roller trainer, see Figure 1) or closed parking lot. As a final step, we will apply LIDAR sensors at sides as well as back and front of the bicycle to recognize obstacles and surrounding traffic participants. This will allow us to conduct further research on more sophisticated safety functions, i.e., detecting and evading in dangerous traffic situations.

3.2 Setup of a Physical Bike Simulator

To be able to test the concept with users we will setup a bike simulator. Inspired by [13, 19] we use a basic bicycle with a low top tube for easy entry suited also for less sporty users and mount it to a bike trainer platform. We will use the API of the bike trainer for measuring speed to create a plausible experience. This platform will be extended by a motor-controlled tilt to left/right and back/front in order to simulate forces, similar to a "hexapod" driving simulator (see Figure 1). A realistic simulation of tilting is important so that study participants can experience interventions of the planned safety mechanisms. We will fixate the front fork of the bicycle and insert a motor mimicking the handover of control for balancing the bike if needed. Additionally, we will place speakers (to simulate sound of surrounding traffic) and fans (simulating air drag) around the bicycle. We will use a simulation software, e.g. SILAB[1] for modeling intersections, roads, and other traffic participants. Additionally, we will mount different actuators such as vibromotors at the handlebar and handheld projectors on the rear rack. Finally, we will build a see-through projection into a bike helmet in order to overlay the field of view of the user with navigation information and cues for hand-over of control.

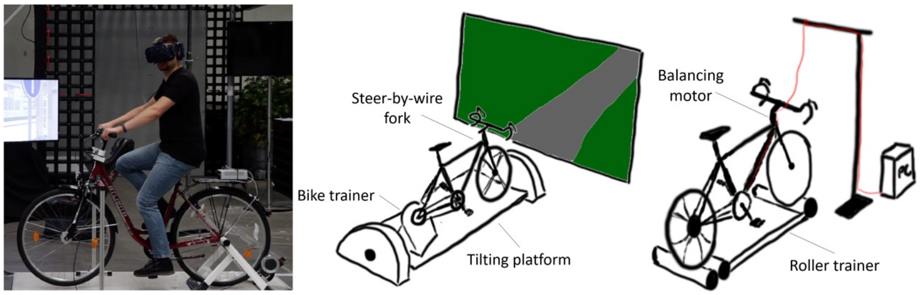

Fig. 1. We plan a biking simulator for user studies, similar to [19] (left), including a tilt of the bike (center). Simultaneously, we will develop the self-balancing function using an instrumented prototype on a roller trainer (right).

3.3 User Studies

To test the *Eternity Bike* – both in the lab, we will conduct multiple user studies. The users' tasks will be to follow navigational cues and react to interventions. We will vary between user control and system control auto-navigating around obstacles and measure driving (i.e., lane keeping) performance and error rates. In addition, we will assess psychological concepts such as cognitive demand (using NASA Tlx [5]), technology acceptance [2], user experience [6], and trust [7] using scales. At the end of the studies, we will conduct interviews to collect more insights about perceived issues and personal preferences. We plan to setup several studies, the actual modalities (vibration of the handle-bar, projection of cues on the floor, overlay of line of sight of the cyclist, audio-cues, etc.) are still to be developed within the project. We plan multiple iterations of collecting user feedback and revisions to better meet users' needs.

4 CONCLUSIONS AND OUTLOOK

We have presented our vision of improving bicycles, arguing mobility requires more disruptive alternatives than electrifying and automating cars. In particular, we have described our vision of a self-balancing bike which could adapt benefits of automated/assisted driving to a more sustainable mode of transportation. In summary we propose following research questions as relevant for the development of the *Eternity Bike*:

---

[1] https://wivw.de/en/silab

RQ 1 How can we recognize the intent of the rider as well as upcoming hazards to determine which actor (rider or assistant system) must act as control authority in a given situation?

RQ 2 How can we design a seamless handover of control between the rider and an assistant service, and can such a handover mechanism act as generics for similar situations, for example human-robot cooperation?

RQ 3 How can we gracefully exit dangerous traffic situations with the support of mobile computing?

RQ 4 How can we support riders to make use of digital services (such as communication, social media, etc.) while riding a bike (for example, utilizing principles of Earable computing [15])?

RQ 5 How can we optimally integrate bicycles into future C-ITS systems (for example, to communicate/interact with automated vehicles), and which possibilities for collaborative cyclist applications arise?

REFERENCES

[1] Tsz-Chiu Au, Shun Zhang, and Peter Stone. 2015. Autonomous intersection management for semi-autonomous vehicles. *Handbook of transportation* (2015), 88–104.

[2] Fred D Davis. 1993. User acceptance of information technology: system characteristics, user perceptions and behavioral impacts. *International journal of man-machine studies* 38, 3 (1993), 475–487.

[3] Dick De Waard, Paul Schepers, Wieke Ormel, and Karel Brookhuis. 2010. Mobile phone use while cycling: Incidence and effects on behaviour and safety. *Ergonomics* 53, 1 (2010), 30–42.

[4] Frank Flemisch, David A Abbink, Makoto Itoh, M-P Pacaux-Lemoine, and Gina Weßel. 2019. Joining the blunt and the pointy end of the spear: towards a common framework of joint action, human–machine cooperation, cooperative guidance and control, shared, traded and supervisory control. *Cognition, Technology & Work* 21, 4 (2019), 555–568.

[5] Sandra G Hart and Lowell E Staveland. 1988. Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. In *Advances in psychology*. Vol. 52. Elsevier, 139–183.

[6] Marc Hassenzahl, Sarah Diefenbach, and Anja Göritz. 2010. Needs, affect, and interactive products–Facets of user experience. *Interacting with computers* 22, 5 (2010), 353–362.

[7] Brittany E Holthausen, Philipp Wintersberger, Bruce N Walker, and Andreas Riener. 2020. Situational Trust Scale for Automated Driving (STS-AD): Development and Initial Validation. In *12th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*. 40–47.

[8] Maryam Kamali, Louise A Dennis, Owen McAree, Michael Fisher, and Sandor M Veres. 2017. Formal verification of autonomous vehicle platooning. *Science of computer programming* 148 (2017), 88–106.

[9] J. D. G. Kooijman, J. P. Meijaard, Jim M. Papadopoulos, Andy Ruina, and A. L. Schwab. 2011. A Bicycle Can Be Self-Stable Without Gyroscopic or Caster Effects. *Science* 332, 6027 (2011), 339–342. https://doi.org/10.1126/science.1201959 arXiv:https://science.sciencemag.org/content/332/6027/339.full.pdf

[10] S. Matsuzawa, N. Sato, and M. Iwase. 2012. Control design of electrically-assisted steering systems for bicycles with child restraint seats. In *2012 American Control Conference (ACC)*. 2749–2754. https://doi.org/10.1109/ACC.2012.6315458

[11] Andrii Matviienko. 2020. *Designing Multimodal Assistance Systems for Child Cyclists*. OlWIR.

[12] Andrii Matviienko, Swamy Ananthanarayan, Shadan Sadeghian Borojeni, Yannick Feld, Wilko Heuten, and Susanne Boll. 2018. Augmenting Bicycles and Helmets with Multimodal Warnings for Children. In *Proc. of the 20th Int. Conf. on Human-Computer Interaction with Mobile Devices and Services* (Barcelona, Spain) *(MobileHCI '18)*. ACM, New York, NY, USA, Article 15, 13 pages. https://doi.org/10.1145/3229434.3229479

[13] Andrii Matviienko, Swamy Ananthanarayan, Abdallah El Ali, Wilko Heuten, and Susanne Boll. 2019. NaviBike: Comparing Unimodal Navigation Cues for Child Cyclists. In *Proc. of the 2019 CHI Conference on Human Factors in Computing Systems* (Glasgow, Scotland Uk) *(CHI '19)*. Association for Computing Machinery, New York, NY, USA, 1–12. https://doi.org/10.1145/3290605.3300850

[14] OECD/ITF. 2014. *Road Safety Annual Report*. Technical Report. OECD Publishing.

[15] Tobias Röddiger, Michael Beigl, and Anja Exler. 2020. Design space and usability of earable prototyping. In *Proceedings of the 2020 International Symposium on Wearable Computers*. 73–78.

[16] Naroa Sanchez. [n.d.]. The MIT Autonomous Bicycle Project. https://www.media.mit.edu/posts/the-mit-autonomous-bicycle-project/.

[17] Maya Siman-Tov, Irina Radomislensky, Kobi Peleg, H. Bahouth, A. Becker, I. Jeroukhimov, I. Karawani, B. Kessel, Y. Klein, G. Lin, O. Merin, M. Bala, Y. Mnouskin, A. Rivkind, G. Shaked, G. Sivak, D. Soffer, M. Stein, and M. Weiss. 2018. A look at electric bike casualties: Do they differ from the mechanical bicycle? *Journal of Transport Health* 11 (2018), 176–182. https://doi.org/10.1016/j.jth.2018.10.013

[18] Tamara von Sawitzky, Thomas Grauschopf, and Andreas Riener. 2020. No Need to Slow Down! A Head-up Display Based Warning System for Cyclists for Safe Passage of Parked Vehicles. In *12th Int. Conference on Automotive User Interfaces and Interactive Vehicular Applications*. 1–3.

[19] Tamara von Sawitzky, Philipp Wintersberger, Andreas Löcken, Anna-Katharina Frison, and Andreas Riener. 2020. Augmentation Concepts with HUDs for Cyclists to Improve Road Safety in Shared Spaces. In *2020 Conference on Human Factors in Computing Systems, Extended Abstracts*. 1–9.

[20] Y. Yavin. 1999. Stabilization and control of the motion of an autonomous bicycle by using a rotor for the tilting moment. *Computer Methods in Applied Mechanics and Engineering* 178, 3 (1999), 233 – 243. https://doi.org/10.1016/S0045-7825(99)00016-X