Scoomatic: Simulation and Validation of a Semi-Autonomous Individual Last-Mile Vehicle

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Abstract

Micro-mobility concepts are becoming more popular recently. The boom of start-ups offering e-scooters in cities also discloses the disadvantages of the currently deployed vehicles. We try to encounter some of these problems by building an autonomous vehicle. Since the safety of such vehicles is generally a big concern, we are planning to use model-based test methods and virtual validation. As the first step towards such a vehicle, we built a demostrator and its digital twin. With the objective to virtually validate the autonomous driving, the digital twin is brought to CARLA. At the same time, we made the first steps towards a driving simulator for micro-mobility vehicles, to be able to test driving comfort for user and driver assistance systems. Therefore a platform is being developed that can replicate the operating concept of our current prototype.

1 Introduction

To relieve inner-city road traffic [1] and reduce carbon emission, it is necessary to further improve public last-mile transportation. For a cost-effective and easy realizable solution, the most important requirement is to keep the existing infrastructure mostly unchanged. Therefore, we study the possibilities of partially autonomous individual personal vehicles for micro-mobility which can be combined with existing public transportation services. Our concept (further referred to as “Scoomatic”) stipulates that the vehicle is driven manually and can navigate autonomously on sidewalks to reach its destination on its own. The manual ride can provide a certain joy of use and feeling of safety for the driver which can reduce inhibitions for new users. The driverless autonomous navigation on sidewalks has multiple advantages. Dynamic, autonomous re-localization of the Scoomatic allows reducing the total number of vehicles needed to maintain great coverage and availability compared to established micro-mobility concepts. Furthermore, it allows the Scoomatic to drive to a charging station by itself, which is making the “juicers” (colloquial term for people that collect and recharge empty scooters) unnecessary and leading to a shorter downtime caused by empty batteries. Therefore it increases efficiency and occupancy rate and should reduce the carbon footprint compared to currently deployed e-scooter concepts [2]. As some newspapers have reported, e-scooters are often targets of vandalism which can be contained by removing unused vehicles from public space [3]. This also provides a much cleaner cityscape and therefore helps to gain acceptance by a wider range of people.

2 Related Work

Similar concepts have recently been presented by several companies. *Scootbee* introduced a scooter that drives autonomously on sidewalks with a speed of approximately $1\,\mathrm{m\,s^{-1}}$ and can, therefore, be ordered to a specific location at a specific time. The scooter is then driven manually [4]. *Tortoise* currently provides Scooters that are relocating themselves to a city-approved parking spot [5]. The Kickscooter T60 by *Segway* offers a vehicle that is able to search for charging docks automatically [6]. Another concept by *Segway* is a self-balancing platform on two wheels called “Loomo”, that can be used as a personal vehicle, but also as an assistant that follows the user [7].

To continue researching and developing innovative concepts in this domain, a prototype of the Scoomatic has been built. The Scoomatic is based on a hoverboard [8], which is a self-balancing platform with two parallel wheels that are controlled independently by the pitch angle of the two feet that are standing on individual rotatable platforms. For obstacle detection, a two-dimensional LIDAR (light detection and ranging) and eight ultrasonic distance sensors are used. Currently, the prototype is being extended by an enhanced single-board computer and a stereo camera.

3 Simulation and Validation

As the concerns regarding the verification and validation of autonomous vehicles are commonly shared even by the leading roles in companies that are currently offering this technology [9], we consider it to be indispensable prerequisite to satisfy high safety requirements. In the context of autonomous driving on the street, the only viable way of releasing such a vehicle is to use simulation in verification and validation. Previously, the focus of vehicle simulators was not a detailed environment. Autonomous vehicles, however, react and interact with their environment, therefore an additional priority has been added to the simulation. Thus, some novel game engine based simulators focus on the environmental representation and conceivably neglect the physical correctness e.g. Deepdrive [10], LGSVL [11], AutoCITY [12] and AirSim [13]. In 2017 the open-source simulator for autonomous driving CARLA has been introduced, which is chosen to be the platform for the virtual development and validation [14]. Benefits of CARLA are the complex and diverse city environments, the active development and research community, and the possibility to modify everything thanks to the open-source code. While the environmental representation was undoubtedly improved, it remains unclear whether the physical level of detail remains sufficient for verification and validation. Based on the real Scoomatic prototype, we created a digital twin in the CARLA environment. Thereafter, we try to assess the abilities and limitations of a CARLA based verification and validation process in the long-term.

Figure 1 Scoomatic prototype

The current sensor setup includes a two-dimensional Light Detection and Ranging sensor (LIDAR), an ultrasonic sensor array, a Global Positioning System (GPS), an Inertial Measurement Unit (IMU) and wheel odometry. Some sensors use an Arduino Nano to provide pre-processed measurement data. The coordination of all measurement data is performed within the logic module, which is implemented on a Raspberry Pi 3B [19] with Ubuntu 18.04 LTS [20] across several ROS nodes [21].

In the future, the added platform will be removed or detachable. A detachable "trailer" could be helpful to transport additional luggage, passengers, batteries for range extension or sensors during the prototyping phase. Additionally, the Raspberry Pi will be supported by a Nvidia Jetson AGX Xavier [22] to increase the mobile computing power. The enhanced computing power is used for better perception of the environment. Additionally, at least one Intel RealSense Depth Camera D435i [23] will be added to the prototype for better scene analysis. With the release of the first LTS version of ROS 2, Foxy Fitzroy in May 2020 [24], a migration from ROS 1 will be considered. Research aspects that need to be studied more thoroughly in the future include reliable prediction of pedestrian behavior, crossing roads without traffic lights, reliably overcoming curbstones, detecting fast traffic participants on the cycle path (e-bikes, racing bikes) in time, reliable identification of edge cases and a profound validation of an autonomous vehicle without environment boundaries.

4 Scoomatic Prototype

The micro-mobility sector is growing rapidly and has high market potential [15]. Many challenges are still unsolved and require further investigation. A self-developed prototype is used as the foundation for these analyses, which makes it easier to assess preliminary test scenarios.

The complete building instructions for the Scoomatic can be found at [16]. Not all details will be presented here, but a short feature summary of the prototype will be given. The finished prototype is shown in **figure 1**. The Scoomatic is based on a commercially available hoverboard, as this provides electric motors with high torque, motor control units, and a battery supply at a low price (150 €). Additionally, the hoverboard software was modified according to [17]. Furthermore, the hoverboard was disassembled and attached to a strut profile with grooves. Based on this attachment, the Scoomatic can be expanded flexibly and modularly. Initially, a platform was added to the two traction wheels. This platform is supported by two additional caster wheels which stabilize the vehicle so that it is in its current state not a mobile wheeled inverted pendulum (MWIP) [18] during the first development phase. In general, a MWIP would increase the agility, but it is also an unstable system.

5 Scoomatic Simulation

While the prototype is very helpful in several cases, many aspects are cumbersome to test in reality. Automobile manufacturers have long recognized that the efficient development of autonomous vehicles cannot succeed without simulation [25]. A virtual environment provides a safe space to explore and expand the limits of the Scoomatic. In addition, the simulation offers the possibility of a comprehensive analysis of rare events [26]. To provide an accessible simulation environment, Toyota and Intel developed CARLA [14], which is based on the Unreal Engine, as an open-source project. CARLA provides extensive urban scenarios including cars, traffic lights, bicycles and pedestrians. The simulation of pedestrians and cyclists is particularly helpful for the present project, as it provides an interesting test environment for the Scoomatic, which in the future will move autonomously on sidewalks and cycle paths. To enable the Scoomatic to be used in the simulation, a model of the prototype was created in a CAD program. The model is displayed in **figure 2**.

Figure 2 Scoomatic CAD model

Thereafter, the digital twin of the Scoomatic prototype was imported into CARLA. An example with the pedestrian agents can be seen in **figure 3**, where the virtual Scoomatic prototype is located on the sidewalk.

Figure 3 Scoomatic CAD model

Similar approaches to a virtual development were already pursued by [27]. In addition to the extensive scenarios provided by Carla, the simulation environment offers several sensor models [28]. The following sensors are used by the Scoomatic prototype and are implemented in CARLA: IMU, GPS, LIDAR, ultrasonic sensor. Furthermore, CARLA provides a ROS interface. Therefore, the Scoomatic logic module will be able to interact with either the real sensors or the simulation in the future. **Figure 4** shows the structure of the logic module, which is connected to ROS. Using either the CARLA messages or the messages from the real sensors and actuators is interchangeable.

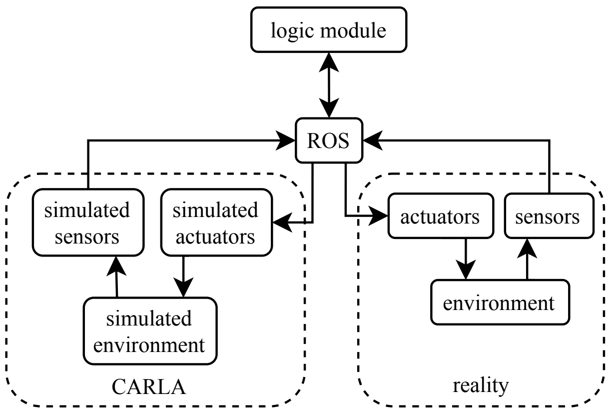

Figure 4 ROS as Scoomatic middle ware

CARLA provides a substantial foundation for the realization of numerous simulative investigations. Especially the ongoing development of CARLA offers new possibilities for improvement. An analysis of the physical level of detail is still pending. There is reason to assume that situations with demanding driving dynamics have to be examined carefully for their plausibility. In addition, the virtual system consisting of Unreal Engine, CARLA and ROS is currently not deterministic, which hampers a precise analysis.

6 Driving Simulator

The current design of existing vehicles for micro-mobility solutions varies a lot. The amount of possible designs is also very high, which makes it pretty difficult to develop the most beneficial solution to provide joy of ride as well as safety features. We consider it to be crucial to extensively test the design in terms of comfort, driving experience and safety features. However, it is not possible to virtually test aspects that largely depend on human perception. Building prototypes is not ideal as well because it is quite expensive while being also inflexible to new ideas. To create an opportunity to test designs without building a prototype, a dynamic simulator that can simulate the specific designs and control of personal transport vehicles like hoverboards, scooters and mobile wheeled inverted pendulums is planned. In addition to that, it will also be possible to develop and test driver-assistance systems that can further improve the safety of such vehicles. The overall concept of a dynamic driving simulator is to give a realistic driver-vehicle-environment, with realistic visual, audio, kinematic senses and tactile impression [29]. The first step towards a dynamic simulator is to build a static simulator which simulates the operating concept of the vehicle and has a virtual reality for audio-visual impression.

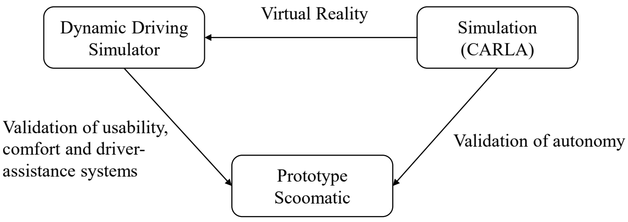

Figure 5 Connection between the simulation for virtual validation, the driving simulator and the prototype

The virtual reality is the same that is used for virtual validation. Therefore the first vehicle to be simulated is our prototype Scoomatic, of which a digital twin has already been implemented.
To recreate the control scheme of the Scoomatic, a gimbal-mounted platform is planned for each foot. Although the rotation around two axes is not necessary for the Scoomatic, it increases flexibility for simulating different vehicles. Before building the first prototype, some model-based test methods shall be performed. A significantly simplified construction of the platform has been developed and imported in Matlab Simscape. The model is now used to determine the required force or rather torque and velocity of the actuators to realistically simulate the food movement.
The connection between the prototype, the simulation, and the dynamic driving simulator is shown in figure 5. The simulation in CARLA can be used to validate the safety features virtually, at the same time it brings the virtual reality to the dynamic driving simulator, which can then be used to validate the usability, comfort and driver-assistance systems.

7 Conclusion

In this work a vehicle for micro-mobility is proposed, that is able to drive autonomously to charging stations, relocate itself for better availability and can be driven like e-scooters that are currently deployed in many urban areas. Due to challenging requirements in terms of safety, virtual validation is considered. Therefore a demonstrator with a specific sensor configuration is built and transferred in a virtual environment. To improve driving dynamics, drive comfort and to test driver assistance systems, a driving simulator is planned. In order to reproduce the control mechanism of our own demonstrator, first constructions are examined using simscape.

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