"Pedestrian in the Loop": An approach using augmented reality

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***Abstract*—A large number of testing procedures have been developed to ensure vehicle safety in common and extreme driving situations. However, these conventional testing procedures are insufficient for testing autonomous vehicles. They have to handle unexpected scenarios with the same or less risk a human driver would take. Currently, safety related systems are not adequately tested, e.g. in collision avoidance scenarios with pedestrians. Examples are the change of pedestrian behaviour caused by interaction, environmental influences and personal aspects, which cannot be tested in real environments. It is proposed to use augmented reality techniques. This method can be seen as a new *(Augmented) Pedestrian in the Loop* testing procedure.**

I. Introduction

Testing of autonomous vehicles for complex and uncertain environments has become one of the biggest challenges in the automotive industry. Automation and computational intelligence will increase abilities of the vehicle [1]. The environment perception and situation understanding will be covered, by computer algorithms. In addition to vehicle dynamics, the environmental states have to be incorporated into the test [2]. In order to ensure safety, it is required to test the intelligent vehicle in a reasonable way. It is also necessary to have prediction mechanisms to infer the consequences of decisions correctly. Conventional testing procedures are insufficient to ensure safety of increasingly complex future assistance functions involving machine perception and cognition [3]. The paper is structured as follows: The first chapter introduces testing for safety related systems. In the second chapter the state of the art of test environments is summarized and the third chapter rates their use in situations with pedestrians. In chapter four solutions are proposed and finally some conclusions for this new test environment are discussed.

The complexity of tests for autonomous vehicles is much higher, compared with conventional test procedures. Additional to vehicle states, information of the environment is incorporated in the decision making process of an autonomous vehicle. This leads to an increase of complexity, also because of predictions.

General requirements of test procedures for autonomous vehicles include:

- Clear and reproducible statements.
- As easy as possible, as complex as necessary.
- Possible and adequate for all environments and situations [1]
- Meaningful metrics (e.g. measures for the safety-risk-ratio) and suitable description forms
- Measures for robustness and redundancy for safety reasons
- Adequate for testing realistic driving scenarios [4]
- Comparison to human performance [5]

This document is intended as an extension of [6]. The key point of this study is to collect data of pedestrian behavior, analyze the bevavior in different environments and with different target groups. The results of this analysis can be incorporated in the development of motion planning with autonomous vehicles.

II. State of the Art

This chapter describes some test procedures and test environments.

A. Complex systems with interaction, Cybernetics and Locomotion

Many different aspects must be taken into account when a person moves. A human is an open, complex, biological system that interacts with its environment. Environmental influences are perceived by organs of perception and the movement is constrained by biomechanical prerequisites of the human body. In [7] the visual perception of drivers is examined for dynamic environments, especially concerning psychological aspects. The Max-Planck institute for biological cybernetics [8] conducts basic research dealing with signal- and information processing of the human brain specifically in the perception of the environment and the resulting actions. Many research projects in the field of cybernetics use virtual reality technologies [8], [7]. Another example is [9] focused on attention and gaze analysis. Mathematical models for a theory of cognitive communication are described in [10]. In [11] models for vision and scene understanding are analysed with virtual reality environments.

B. Test methods and environments

Testing safety of dynamic systems can be divided in different strategies [12]. To classify a system as a safe system (e.g. an autonomus vehicle), it is necessary to make sure that trajectories (path points of the vehicle with time labels) never reach unsafe states.

The validation of technical systems is often done by simulation and experiments. If the trajectory hits the unsafe state during a simulation, the system can be declared as an unsafe dynamical system (falsification). As long as a counterexample has not been found, there is no direct way to declare the system safe. There are some exploring techniques for the state space to find the counterexample systematically [12].

In conventional driving tests (e.g. testing vehicle dynamics), internal vehicle states have to be examined at specified manoeuvres. For autonomous driving functions, there are no standardized tests, because states of the environment are essential. It is not trivial to determine the external states and conditions that have to be used for tests in order to ensure a clear statement for the safety of the vehicle. Also, due to the diversity of situations, the number of tests for demonstrating safety is tremendous.

For the reproducibility of real-world tests, some strategies are known. Steering robots are already used in experimental settings. Another strategy is to collect a large amount of data during long-term studies to ensure that the system is tested for all possible situations [13]. Hereby the problem of missing trajectories plays an essential role.

Soft-crash-targets and passable target robots can be used to model accident scenarios. These crash target robots are already used because they can be precisely coordinated [13].

The decision making process is influenced by the interaction with other road users. The intention estimation and the prediction for the future movement of road users is vital for the motion planning of the ego-vehicle [2].

III. Problem description

In this chapter the challenges in predicting and testing safety critical situations with pedestrians are discussed. In section III-A the need for new testing environments is shown and in section III-C an example of a pedestrian's environment recognition is presented.

A. Need for new testing environments

Currently, driving situations with pedestrians are often tested in observational statistical studies rather than in a randomized control experiment, due to safety reasons. This has an enormous impact on the development of motion planning strategies (conservative configuration) in autonomous vehicles and the usage for real scenarios (low generalizability, some aspects are not tested, i.e. intention, environmental aspects). The behaviour of pedestrians can be detected by onboard-sensors of the vehicle, wearables, smartphones, or cloud services and sensor networks (e.g. webcams). The problem of observational studies is that the reasons for a pedestrian's specific behavior and the question "why" a pedestrian behaves like he/she does cannot answered directly. This is because the causality of a situation has not be decoded (e.g. causes are unknown). In [6] a new test environment was introduced as a randomized control experiment with the incorporation of virtual reality technologies. The advantage is that real test persons can be incorporated in an experiment (Pedestrian in the Loop). It is easily possible to change the virtual environments, incorporate realistic environments and to stimulate the perception of the test person. Deterministic mechanics of the human body (i.e. joint angles) can be measured with motion capture systems. Experiments with different persons offer new perspectives for the development of autonomous vehicles. Examples are tests for risky and safe motion planning and analysis of influences of interventions described in [14]. To extend the whole experiment it is also proposed to incorporate real world events and network systems (e.g. online games, world wide web). Engineers could incorporate safety critical systems for performance testing in real world scenarios which would help accelerate the transition to autonomous vehicles. Problem of the approach in [6] is that the whole perception of the test person has to be stimulated. Computationally expensive rendering and realistic modelling is not possible or too costly in many cases. Therefore a solution is proposed to address this problem.

B. Comparison to conventional test procedures

In conventional testing procedures, radar and video systems are used to detect a moving pedestrian. Normally the performance of the vehicle is tested by the car manufacturer, where the vehicle is the test object. In this testing procedure the test object is the human. If there is a scenario where the pedestrian is behind an obstacle, the relationship between obstacle and the pedestrian can be analyzed. This information can be used for the motion planning. The accuracy and performance under different light conditions (e.g. night with weak vision) depends on the performance of the augmented reality glasses. The validation of the mentioned system is a research problem which will be addressed in the future. The key point of this study is to describe possible solutions for the testing of motion planning/collision avoidance systems of autonomous vehicles and the collection of pedestrian behaviour (like personal aspects, perception, and interaction).

C. Example of human environment recognition

In the left picture of Fig. 1, a Google Earth [15] model of the campus of the University of Technology Graz is visualized. The center picture shows the same location, but extracted from OpenStreetMap. The three positions marked in the map show the positions from which pictures were taken with a smartphone and visualized with Mapillary [16] (right picture). Humans have the capability to abstract visual information to different levels of signal forms and associate it with semantic meanings (example in Fig. 2). The differentiation between static and dynamic obstacles on one hand and free space on the other hand happens naturally.

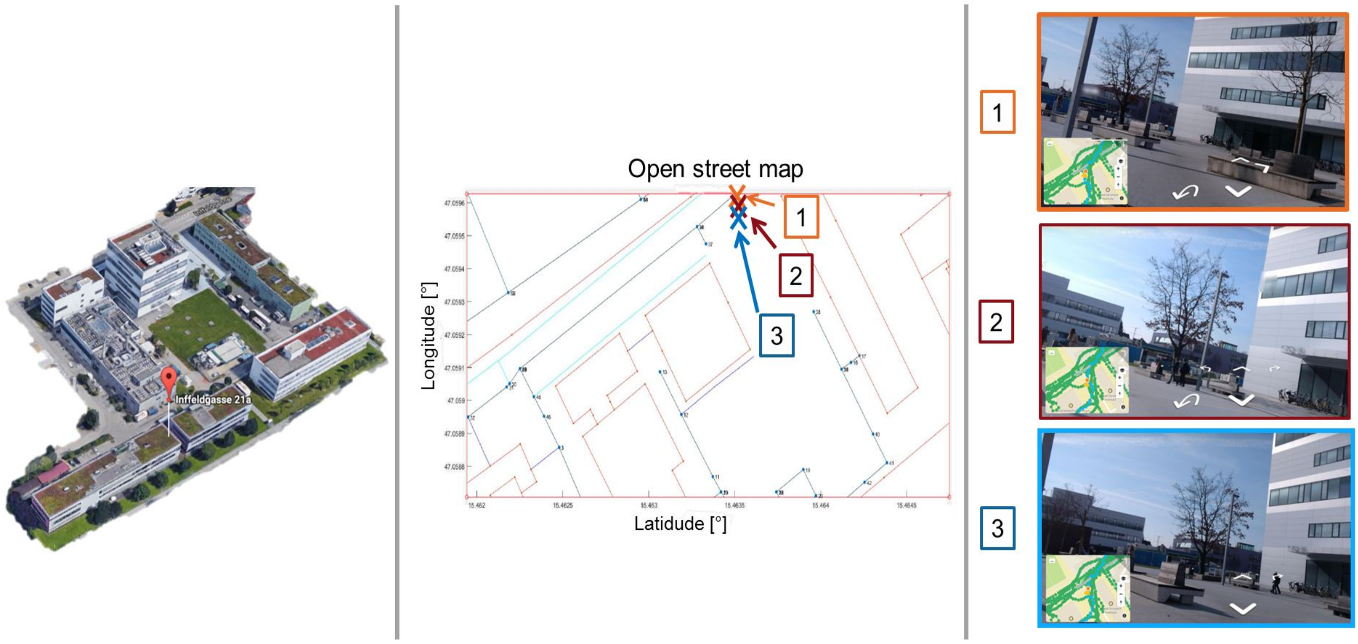

Fig. 1. Left: Campus of University of Technology Graz captured with Google Earth [15]: Middle: Open Street Map with three selected coordinates Right: Three different perspectives captured with Mapillary [16]

Fig. 2. A manually segmented illustration of the campus in the University of Technology Graz. The perspective is captured with Mapillary [16] and classified in four coloured segments. Purple: movable area; Black: nearby static obstacles; Orange: far static obstacle; Red: Corridor for walking to the intended target (e.g. office in Inffeldgasse 21)

Fig. 3. Vehicle in Unity3D [17]

IV. Proposed solutions

From chapter III following facts are revisited to propose a new test concept:

- There is no absolute certainty in pedestrian movement prediction due to a lack of knowledge.
- Environmental understanding and human behaviour is a core challenge for automated vehicles.
- Many situation predictions for pedestrians might be plausible.
- Motion planning with pedestrians is a safety critical application; environmental influences, intention changes, perception, interaction and personal aspects are not directly testable in a randomized controlled experiment.
- Personal aspects, interaction, perception, intention changes and environmental influences on pedestrians must be tested.

A virtual vehicle model from SketchUp [18] is visualized in Unity3D [17] (Fig. 3). Camera perspective, appearance and movement can be configured with Unity3D. The software package can be converted for the use of augmented reality glasses.

In Fig. 4 and in Fig. 5 a collision avoidance scenario is visualized. The illustration is based on the configuration depicted in Fig. 3. The approaching vehicle for the collision avoidance scenario is visualized with a Microsoft HoloLens

Fig. 4. Left: Microsoft HoloLens [19]; Right: Approaching vehicle in indoor environment

[19]. Real environments can be incorporated in Fig. 5, but the light conditions for visualizing the vehicle are more convenient in indoor environments (Fig. 4). As described in [6] motion capture systems and other technologies can be incorporated to test the interaction, environmental influences and personal aspects in safety critical scenarios. Examples are the position of the pedestrian and the orientation, where the pedestrians looks. More advanced scenarios can incorporate the joint angles of the human body. The collected data can be used to analyze the environment dependence of the pedestrian. The results of the analysis can be incorporated in the decision making process of autonomous vehicles. The data explains the vehicle, why a pedestrian moves on this direction in a certain environment. Other advantages of this approach compared to the virtual reality solution [6] is that real environments can be incorporated and cost intensive computations for visualization of static obstacles (e.g. buildings) are not necessary. Motion capture systems, geolocation techniques for position estimation, and dynamic measurements can be integrated.

In Fig. 6 an approach is illustrated to incorporate real environments and safety critical systems in a large scale environment [6]. This approach might be suitable for long-term studies, where test persons forget the experimental nature of the testing environment.

V. Conclusion

A new test environment for indoor and outdoor environments is proposed with incorporation of augmented reality glasses. Safety critical systems can be tested like [6]. Advantage of this approach is the incorporation of real environments. Also the amount of virtual models can be reduced compared with a virtual reality approach.

Acknowledgement

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[1]Interdisciplinary Training Network in Multi-Actuated Ground Vehicles.

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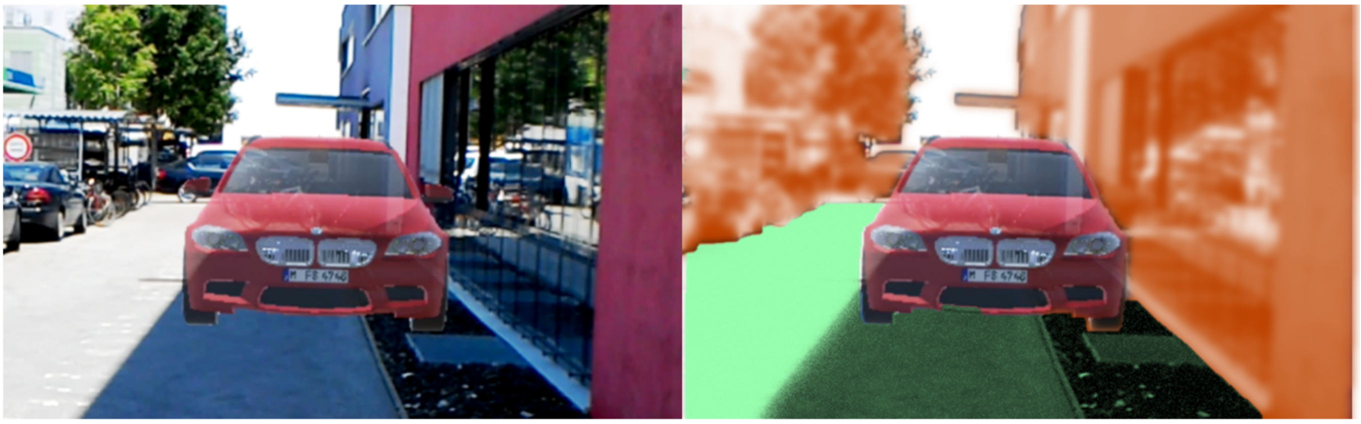

Fig. 5. Left picture: Outdoor environment: Approaching virtual vehicle; Right picture: Segmentation of the environment: Green: street, where pedestrian can walk; Orange: static obstacles

Fig. 6. Solution with augmented reality glasses

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