Simulation of a Security Function Based on Vehicle-to-X Communication and Automotive Lighting

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***Abstract*—Crime and feeling of security are pervasive occurrences and can be influenced by lighting conditions. However, lighting improvements are generally concentrated on street lighting. Meanwhile, a vast variety of new technologies, including innovative lighting systems and connected mobility, are entering into the automotive field. Hence, opportunities are not limited only to provide traffic improvements, entertainment features or safety functions but also measures to tackle (vehicle related) crime and to increase the feeling of security. In this paper, we present an idea for a function which has the potential to tackle crime and increase drivers' feeling of security. Moreover, we explain our approach to measure the effectiveness of the function based on a proprietary simulation environment.**

***Index Terms*—security function, V2X-communication, simulation.**

I. Introduction

Advanced driver assistance systems (ADAS) and Vehicle-to-X (V2X) communication are on the advance. Meanwhile, a vast diversity of ADAS exists, where systems drawing on vehicle lighting are one part. ADAS like dynamic cornering lights, which light into corners, or adaptive high beam assistants, which detect oncoming traffic and adjust beams accordingly, actively intervene with the vehicle's lighting system. Additionally, lighting systems underlie a steady development so that incandescent systems are continuously replaced by LED systems, partly in combination with xenon lights [1]. Also, the penetration of mobile devices is increasing so that they have largely become our daily companion. Thus, connected mobility, which brings these new technologies together, has become a part of our life. In the last decades, there has been a lot of research on the influence of lighting, especially street lighting, on crime and the fear of crime [2]–[5]. A positive effect of lighting on fear of crime has been mostly assumed, whereas the research on the effect on crime has provided equivocal results.

We elaborate on a security function that makes use of vehicles' advanced lighting opportunities and vehicle-to-vehicle (V2V) communication to combat crime and mainly to increase drivers' feeling of security.

The rest of the paper is structured as follows. In Section II, we provide a short overview of automotive lighting systems followed by an explanation of our function's basic idea in Section III. In order to measure the effectiveness of our function, we are implementing a simulation environment, which is presented in Section IV. Then, we briefly show our implementation approach of the simulation in Section V before concluding our paper and providing an outlook on future work.

II. Lighting Systems

Dependent on the equipment level, vehicles, usually, posses at least the mandatory lighting systems for outside illumination. To avoid dazzling oncoming traffic, manual level adjustment exists besides the more sophisticated static and even dynamic automatic leveling. The static leveling system automatically adjusts the level dependent on vehicle loading. Dynamic systems additionally take into account vehicle's acceleration and deacceleration to adjust the tilt angle dynamically.

A further lighting feature, cornering light, occurs in a static and dynamic variant. The static cornering light usually turns on one of the front fog lamps to light into the according direction while turning. The static cornering light is intended to be used at lower speeds in urban areas. In contrast, the dynamic system is designed to be used in rural areas or on highways while driving through corners at higher speed. Low and high beams are actively moved horizontally into the corner with a maximum angle of commonly 15 degrees. Beams are usually controlled via electromotive actuators.

III. (Cooperative) Extended Coming / Leaving Home Function

Most OEMs provide a so called coming / leaving home function (CHF / LHF). Of course, the functionality differs by OEM specific adjustments but the basic idea is similar. When leaving the car, i.e., coming home (CHF), low beams, taillights and other available light sources keep on lighting (during darkness) for a specified period of time in order to light the driver the way "home". The duration can generally be adjusted by the vehicle owner. Referring to the LHF, the aforementioned light sources start lighting as soon as the driver remotely opens the vehicle.

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This described functionality has the drawback to be static. The lighting duration can only be adjusted in the vehicle and it is independent of the drivers position. That means, if the duration is to short, the illumination turns off before the driver even reaches the vehicle and vice versa respectively. Furthermore, the vehicle turns on all light sources although some light sources are probably unnecessary since the driver approaches the vehicle from one direction.

Our idea is to extend the existing CHF / LHF by the opportunities of advanced sensors, sophisticated light systems and V2X communication. We suggest to use the opportunity that low beams can be swiveled vertically and horizontally to light the driver's direct route to the vehicle, of course within the mechanical limits of the beams. Additionally, only light sources are turned on which directly influence the illumination of the route so that energy consumption is reduced.

To realize the extended CHF / LHF (ECHF / ELHF), a bidirectional communication between the vehicle and a sophisticated key fob is assumed. The key fob is a smart device, such as a smartkey or smartphone, and must be in possession of the driver. Since the key only communicates with the own vehicle, the common IEEE 802.11a/b/g [6] standard is suitable for communication. Furthermore, position estimation of the key relatively to the vehicle is necessary. This challenge can be faced by localization based on ultra-wideband (UWB) technology [7]. Thereby, it is irrelevant whether the position is calculated by the key or by the vehicle since position data is continuously synchronized between both participating partners via bidirectional communication.

The ELHF is activated as soon as the doors are remotely unlocked. Both, the two-way communication between the key and the vehicle as well as the location estimation of the key are triggered. The position of the key is updated at regular intervals so that the vehicle can evaluate the position. Movable low beams are aligned in the direction of the driver. Other non-moveable light sources are only turned on when they illuminate the direct path of the driver. Since the driver of the vehicle is moving, the direct route to the vehicle is constantly changing. Therefore, low beams are continuously adjusted. Turned off light sources are turned on when they become relevant for the direct path of the driver to the vehicle. In return, turned on light sources are turned off when they lose relevance for illuminating the direct path. Further, there is no need to consider the time to turn off lighting because it is turned off with reaching and entering the vehicle or even after having closed the door. Nonetheless, a specific run-time can be defined as fallback option.

When exiting the vehicle (ECHF), the driver's path is illuminated analogously to the ELHF. The duration of illumination can be determined by a defined delay time. However, there is also the possibility to deactivate the illumination after the driver has left a certain radius around the vehicle. An irregular surface around the vehicle is also possible since the effectiveness of involved light sources is different. The function can be disabled with the key as well.

Due to the physical and mechanical constraints, the own vehicle is not always in a position to illuminate the direct path of the driver. Therefore, the ECHF / ELHF can use vehicle-to-vehicle (V2V) communications to be enhanced to a cooperative function (CECHF / CELHF). Vehicles in the surrounding environment are included to illuminate the driver's path. The own vehicle broadcasts a request to ask for lighting help. Surrounding vehicles being willing to support in lighting reply by providing their pose (position and heading) as well as lighting capabilities. This way, our vehicle is able to create a local map of participating vehicles with the aforementioned information. Since our vehicle is continuously aware of the driver's position, it continuously requests participating vehicles to light specific areas.

To realize inter-vehicle communication, we suggest to consider standardization provided by IEEE [6] and ETSI [8]. Thereby, V2V communication is based on IEEE 802.11p [6]. This way, designated communication and security mechanism are used. Further, positions of vehicles are either estimated in the traditional way with the help of GPS and compass or by making use of UWB technology, which is also suitable for indoor use, e.g., for parking garages. Research projects, such as AIM [9] or V-Charge [10], also partly address localization challenges to estimate vehicle positions within parking facilities.

IV. Simulation Environment

Our goal is to model diverse parking constellations of vehicles and diverse routes the driver goes to or from the vehicle. This way, we aim to compare the effectiveness of the different forms of (CHF / LHF) under different constellations. Our effectiveness criteria is the driver's duration in a lighted area when approaching or leaving the vehicle. Additionally, referring to the cooperative form of the (CHF / LHF), we want to investigate several equipment rates of vehicles being able to participate in V2V communication and see which penetration rates are necessary to achieve a gapless lighting of the driver's route. A further criteria is energy consumption. Under certain circumstances, it is not necessary to involve all V2V communication capable vehicles to light the route since several vehicles are eventually able to light the same area.

To the best of our knowledge, there is no simulation environment supporting a simulation of our security function. Consequently, we decided to implement a proprietary simulation environment, which is schematically illustrated in Figure 1.

A. Parking Constellations

The number of parking constellations is infinite since the driver's route can be manifoldly modeled and vehicles can be positioned in different ways. Nevertheless, we demand both, to freely position vehicles and to model driver's route. Further, a lot of possibilities exist how a vehicle is equipped. Consequently, we will have to pick out wisely "typical" constellations to be simulated and evaluated. Actual equipment rates of advanced lighting systems can be used to determine penetration rates for the simulation. Additionally, we think

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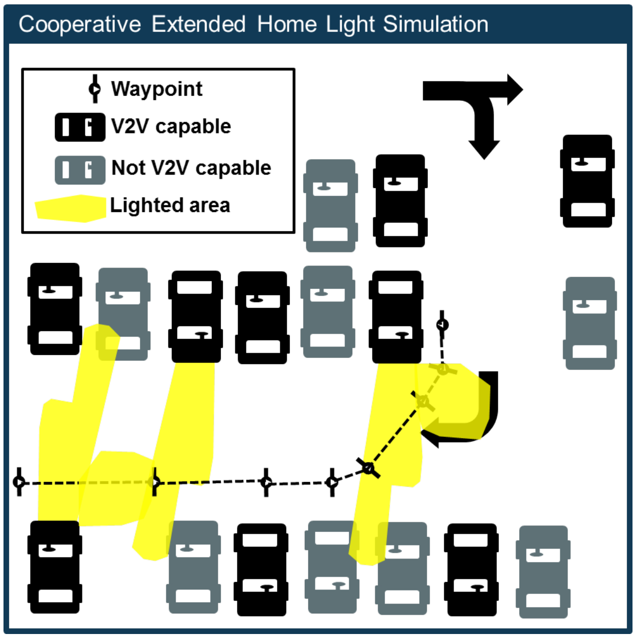

Fig. 1. Simplified schematic and dimensionless illustration of the simulation environment

that regarding an area of 100m around the host vehicle is a good approach since typical remote keys and low beams work nearly up to this distance.

B. Vehicles

Each vehicle has a set of light sources which can be used to light the environment. Light sources are not limited to low and high beams. We also consider fog beams, rear lights, license plate illumination and lighting elements integrated into exterior mirrors. Each vehicle is configured separately, so that vehicles with different equipment levels can be simulated. For reasons of simplification, we limit the lighted area of each light source in the first approach to one specific area. This way, we would not consider different light technologies, which consequently implies different lighted areas, especially regarding low beams. But, we keep the opportunity to model different lighted areas for each vehicle, as will be seen in section V-A. Furthermore, in reality, there is a fluent transition from a lighted to a non-lighted area due to effects of scattered light. However, we will approximate lighted areas by polygons so that lighted areas end abruptly. Vehicles supporting dynamic low beams, have also an adjustable yaw and pitch angle. Additionally, each light source has a predefined energy consumption parameter so that consumed energy is calculated within the simulation.

C. Driver's Route

Driver's route is modeled via linear interpolation of a chain of points, hereafter referred to as waypoints. A polynomial interpolation was discarded due the tendency for oscillation [11]. Furthermore, the driver's walking speed is adjustable so that the covered distance is calculated dependent on the discrete simulation steps.

D. Communication

The propagation of electromagnetic waves highly varies affected by many influencing factors. For example, Kwoczek et al. [12] investigated the influence of roof curvature, roof racks and panorama glass roofs on the antenna gain in the reserved V2V communication frequency band and found inter alia a high loss of gain caused by glass roof. Hence, it is highly challenging to consider and simulate all influencing factors.

We choose the Friis propagation model [13], which models a deterministic path loss over the distance from sender to receiver, in order to simulate propagation aspects of wireless communication. Since we don't have moving vehicles in our environment, we discard fading models accounting for non-deterministic effects of moving objects. When making our decision, we took into consideration available models benchmarked by [14] and implemented in the most widely used network simulator NS-3 [15]. However, we keep the propagation model exchangeable in our simulation to have the opportunity to use another loss model.

V. Implementation

A. Coordinate Systems

Our parking environment is represented by a coordinate system called environmental frame (e-frame), which could be mapped when needed to the World Geodetic System 1984 (WGS84) or a system related to a parking facility. Further, each vehicle has a coordinate system (v-frame), which is attached to the center of the vehicle. Each lighted area, which is generated by light sources, is represented by a polygon whose points refer to a coordinate system called a-frame. Consequently, several a-frames are attached to a vehicle depending on the vehicle's configuration. To represent the driver, we also decided to use a Cartesian coordinate system (d-frame) instead of a point in order to have the opportunity to model driver's orientation. Since we have two-dimensional (2D) right-handed Cartesian coordinate systems, rotations happen in the plane around the z-axis, which is directed out of the plane. All aforementioned frames are illustrated in Figure 2.

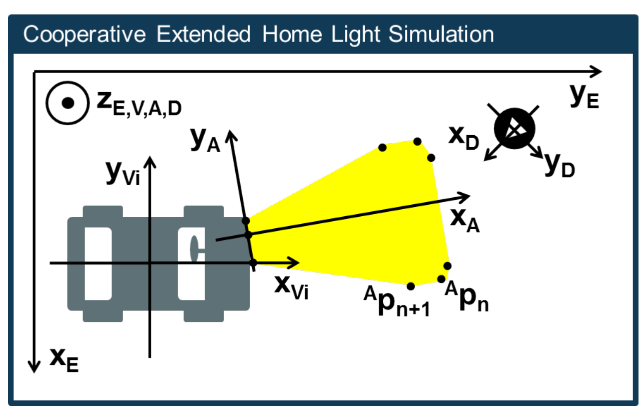

Fig. 2. Schematic illustration of frames involved in the simulation

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B. Coordinate System Transformations

We use homogeneous coordinates [16] to calculate transformations between as well as within our frames. Since we have different frames of reference, we precede vectors with a superscript to show the related system. Transformation matrices are followed by a subscript to show the source frame and preceded by a superscript to show the target frame. For example, to calculate a point ${}^{V}\mathbf{p} = \left({}^{V}x, {}^{V}y, 1\right)$, which refers to a v-frame, i.e., a vehicle, into coordinates related to the e-frame, i.e., the environment, we use the following equation

$$ {}^{E}\mathbf{p} = \begin{pmatrix} {}^{E}x_p \\ {}^{E}y_p \\ 1 \end{pmatrix} = {}^{E}\mathbf{H}_V * {}^{V}\mathbf{p} = {}^{E}\mathbf{H}_V * \begin{pmatrix} {}^{V}x_p \\ {}^{V}y_p \\ 1 \end{pmatrix} \quad (1) $$

with the transformation matrix

$$ {}^{E}\mathbf{H}_V = \begin{pmatrix} \cos\left({}^{E}\alpha_V\right) & -\sin\left({}^{E}\alpha_V\right) & {}^{E}a_V \\ \sin\left({}^{E}\alpha_V\right) & \cos\left({}^{E}\alpha_V\right) & {}^{E}b_V \\ 0 & 0 & 1 \end{pmatrix} $$

where ${}^{E}\left(a, b\right)_V$ is the position of the v-frame related to the e-frame and ${}^{E}\alpha_V$ the according orientation, respectively.

Due to the use of homogeneous coordinates, a combination of transformations is achieved by multiplying according matrices as shown in (2) where a point is transformed from the a-frame via a v-frame into the e-frame.

$$ {}^{E}\mathbf{p} = {}^{E}\mathbf{H}_V * {}^{V}\mathbf{H}_A * {}^{A}\mathbf{p} \quad (2) $$

C. Beam Movement

To simulate a low beam's horizontal rotation, the according a-frame is rotated with reference to its v-frame. To simulate a low beam's vertical movement, we directionally scale the lighted area on the x-axis of its according a-frame. Hence, a movement downwards will shrink and a movement upwards will enlarge the lighted area [17]. So, each point of the polygon representing the lighted area has to be multiplied with the scaling matrix $\mathbf{S}$ as shown in (3) where s_x is the scaling factor. A scaling factor $s_x < 1$ means a beam movement down and $s_x > 1$ up, respectively. The interested reader can find further information regarding the installation of lighting and light-signalling devices in the vehicle regulations [18] provided by the United Nations Economic Commission for Europe (UNECE).

$$ {}^{A}\tilde{\mathbf{p}} = \begin{pmatrix} {}^{A}\tilde{x} \\ {}^{A}\tilde{y} \\ 1 \end{pmatrix} = \mathbf{S} * {}^{A}\mathbf{p} = \begin{pmatrix} s_x & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} * \begin{pmatrix} {}^{A}x \\ {}^{A}y \\ 1 \end{pmatrix} \quad (3) $$

D. Message Propagation

We estimate whether a vehicle takes part in communication or not using the Friis propagation model shown in (4). R is the distance between the transmitting and the receiving vehicle and λ the wavelength, which is calculated from the frequency used for V2V communication. Further, each vehicle has a transmission power (P_t), a threshold for receiving power (P_r) as well as antenna gain (G_t and G_r).

$$ \frac{P_r}{P_t} = G_t G_r \left(\frac{\lambda}{4\pi R}\right)^2 \quad (4) $$

VI. Conclusion and Future Work

The main goal of this work was to present an idea for a security function making use of new lighting opportunities as well as V2X communication and to show our approach to verify the effectiveness of our function.

In our future work, we will focus on finishing the implementation of the simulation environment and evaluating different parking scenarios. Besides, we will continuously extend our simulation environment by slipping in new ideas and improvements. Furthermore, we will elaborate on a more detailed realization of the V2X communication and an according protocol based on the latest standardization provided by the European Telecommunications Standards Institute (ETSI).

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