Lighting utilization as a tool for interaction of small autonomous urban vehicles in mixed traffic environment

Manoeva Devina
FDIBA Postgraduate school
Technical University of Sofia
Sofia, Bulgaria
devina@tu-sofia.bg

Draganov Sasho
Faculty of Mechanical engineering
Technical University of Sofia
Sofia, Bulgaria
sasho.draganov@tu-sofia.bg

***Abstract*— The paper presents results from a study regarding the lack of regulations for the safe interaction via signaling systems between high automated vehicles and pedestrians. The traffic safety today is a function of computer vision and computer warning and non-verbal signaling subsystems for all uncontrolled intersections on the road. Investigated are interaction systems for small urban e-vehicles and e-bikes. The goal of a new design is to find a small and energy efficient signaling device for e-bicyclist for safe urban riding ability to display vehicle intentions like "Turn L/R", "Stop", "Speeding up", "Constant speed", "Slowing down". The conducted analysis is based on a future application of Communication Display/ LED wearable indicator system as a proposal for the project "AuRa Autonomous Bicycles". The research is based on the software and hardware application set designed for mobile computers and smartphones including MEMS and video/photo sensors.**

Keywords*— *autonomous vehicles, signs for safety signaling, interaction, E-Bike, AuRa, wearable displays, activity recognition, haptic feedback modality.

I. Introduction

The following paper examines innovations and tendencies regarding the light signaling of urban autonomous vehicles in the context of the rising need for new interaction and communication rules between the autonomous vehicle and everyone else on the road. This paper analyses the practicality and effectiveness of current models of nonverbal communication in a new traffic environment, which includes vehicles on different automation levels. It showcases the latest research of the existing regulatory norms and exemplary solutions and as a result, this paper offers the benefits of such a system for the scientific project "AuRa Autonomous Bicycles", developed by the Otto-von-Guericke-University Magdeburg [1].

II. The Road to Autonomous Mobility

The automation of road vehicles quickly transforms all aspects concerning mobility. The technological revolution and the efforts to reduce the amount of road accidents are the driving force behind the evolution of this new form of mobility. Many questions have arisen in scientific and public fields on how to safely integrate them into the current traffic system, what knowledge and what acts we need for this transition. The question about how these new vehicles will interact with all other components of the urban traffic system is gaining traction. The new traffic medium will include partially autonomous and fully autonomous vehicles as well as other traffic participants. The stages leading up to fully autonomous vehicles are formalized in Fig.1.

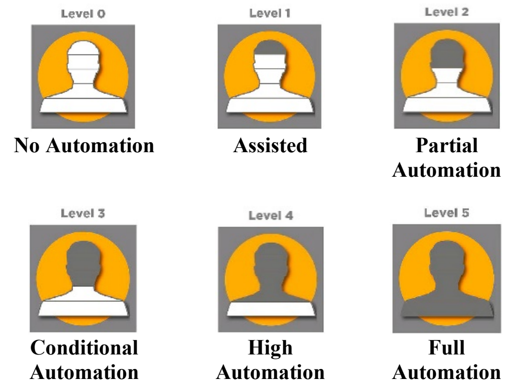
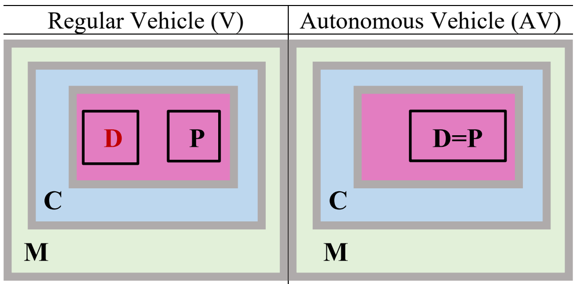


Fig.1. The levels of vehicle automation, according to the Society of Automotive Engineers (SAE, 2016)

III. Pending Regulations for a New Interaction System

As shown in Fig.1 the human factor in the vehicle driving process will be completely reduced by level 5. But, how the human factor is going to be replaced in a new interaction concept for mixed traffic environment is still unknown. The transition to a new interaction system is demonstrated in Fig.2.



WHO? **D** - user, driver /h/ **P** – user, passengers /h/ **C** - other users of analog products in the medium = all other non-motor users /h/ *WHAT?* **V** = vehicle /exterior + interior/ *WHERE?* **M** = medium / field of use	*WHO?* **D = P** - users /h/ **C** - other users of analog products in the medium = all other non-motor users /h/ *WHAT?* **AV**= autonomous vehicle/ re-design, adds /digital driver= machine/ *WHERE?* **M** – medium/ re-design, adds /mixed/

Fig.2. Comparison, which illustrates the participants in a traffic medium with regular vehicles and traffic medium with autonomous vehicles /*h – human/

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In this study the interaction design in a regular traffic medium is categorized as:

I1. **D - V**: creates by itself an interaction couple product-user and in the context of a formally regulated system for road mobility /medium/ they are both in a process of perpetual interaction;

I2. **D - (V + M)** (static interaction): the medium transmits information to the Driver (D) - (V) /as well as all the other traffic participants/;

I3. **D - (V + C)** (dynamic interaction): this is a two-way exchange, which has three main functions: showing recognition, intent and confirmation.

The integration of autonomous vehicles in the traffic medium will be very complicated due to the always present non-autonomous participants in the urban traffic medium that preserve the human factor and will inevitably cause accidents and road violation. Nowadays the *I3* interaction is using:

- the light-acoustic signaling system of the vehicle;
- non-verbal communication /body gestures/.

Nonverbal communication is defined by behavioral signals such as eye contact, nodding and hand gestures. These signals are used when, for example, the official rule of the law is ambiguous or if the specific case requires it. In the current road medium, behavioral signals are especially useful and often used for the interaction with pedestrians and bicycle riders, thanks to their ubiquitous meaning [2]. These facts prove the need for recreation of non-verbal communication via other tools as new lighting utilization. The National Highway Traffic Safety Administration (USA) is the leader in light and acoustic signaling research. NHTSA is actively searching for public commentary to identify and remove the barriers in the existing safety standards concerning autonomous vehicles (ADS) [3].

In Bulgaria the Association of the Bulgarian Insurers, the Institute for Road Safety are also active in this field [4]. The topic of perception of autonomous road vehicles was activated by them at the launch of a popular individual mobility service in the capital city Sofia - rental of two-wheeled so-called e-scooters. The emergence of e-scooters causes confusion among pedestrians and motorists, especially among mothers with young children. The fact is particularly relevant to the thesis of this report, linking the psychology, perception, human factor and the technogenic origin of the problem very clearly. The worrying perception comes from 30 km/h-moving pedestrians fixed in upright positions. 150 years later, the same reaction is repeated, as by the meeting of pedestrians with 40 km/h-moving chariot without horses in the front. The adaptation from our brain to such big changes is a slow process and the transition from adopting the New as 'dangerous' to adopting it as 'safe' takes time. The task in front of us is to link the impact and perception of an autonomous road vehicle with road safety, taking reference to the infrastructure and the intonation environment of information transport systems.

The status quo of regulations is at an alarmingly low level. For example, the Bulgarian National Agency for Road Traffic Safety offers hypothetical and unjustified regulations for the traffic of vehicles from the example above [5]. In 14 categories (from L1 to L7E) lightweight vehicles are allocated according only to the following indicators - mass (kg), power (kW), number of wheels, without any requirements for the signaling subsystems, and in some categories they are not even structurally foreseen. Moreover, the regulator in Art. 100 prohibits the use of an acoustic signal in settlements other than to prevent a road accident and penalizes the use of a "light horn".

In the regulations [6], [7], of the Ministry of Justice in Germany, the requirements for light and acoustic signaling are clearly defined and are a good starting point for their future improvement in terms of design.

After a research the following current examples or concepts of new methods for light interaction design for autonomous urban vehicles was found:

Fig.3. „Duke-Display“ USA - Duke University Field study with Communication Display; [8]

Fig.4. Screenshots of investigating display emotional concept; [9]

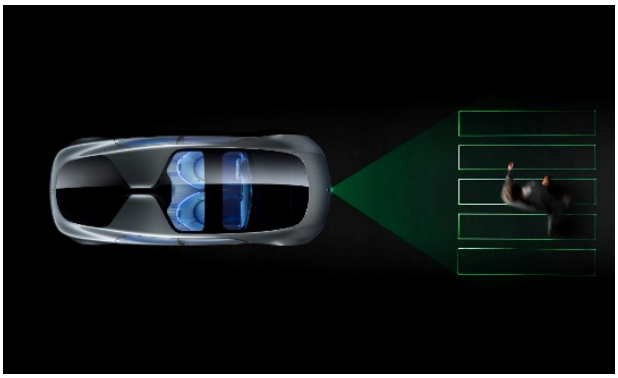

Fig.5. Daimler digital lighting zebra crossing concept; [10]

IV. Proposal for a Lighting System for a Autonomous Urban Cargo E-Bike “Aura”

After the conducted research, a demo E-Bike – wearable LED indicator system was developed with the following design considerations:

1. Possible use-case scenarios for the wearable indicator system in everyday traffic;

2. Fit and comfort of the indicator system;

3. Form factor, size and weight of the indicator system;

4. User feedback from the indicator system to the client;

5. Visibility of the indicator system by the other participants in traffic such as vehicles and pedestrians.

Fig.6. Autonomous urban cargo E-Bike prototype – project by Otto-von-Guericke-university Magdeburg; Photo: Jana Dünnhaupt/ OVGU

As a satisfactory solution to the above design considerations, we'll accept the WAYV [11] design for bicycles. For the hardware controller and powering of the E-Bike - wearable LED indicator system we'll develop a display system centered around a smartphone with the power to control the independent functions of the indicator system such as displaying the scenarios of "stopping", "turning left/right", "falling from the E-Bike/Emergency/Danger", "Losing the E-Bike" etc. For these purposes, we'll use the algorithms, programs and sensors described by Kachamackov, Manoev in [12].

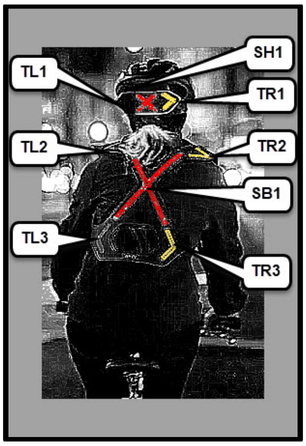

Fig.7. E-Bike- wearable LED indicator system

Finding/Decoding illuminated pedestrian walkways by spectrum characteristics and modulation [13], [14], [15], of light is planned to be realized using "Infrastructure/ Smart City" smartphone's module. "Pedestrian crossing Detection", "Brake" as well as "Forward Collision Warning (LDW)" conditions activate acoustic/haptic vibrations in the front of the bicycle helmet to create "Slow-Down!" feedback loop to gain bicyclist attention and to give preparation time for taking the appropriate position of the body to overcome the moment of inertia.

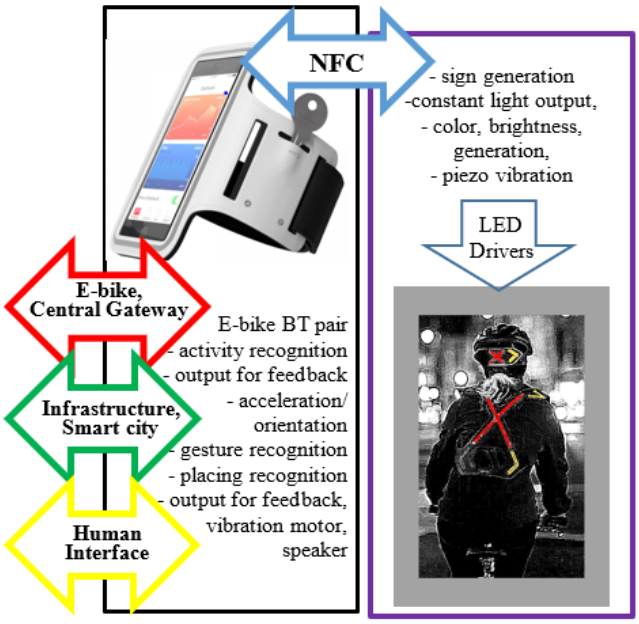

Fig.8. E-Bike – control diagram

The other task for the smartphone controller is generating images/signals using the LED segment displays TR1…TR3, TL1…TL3, SH1, SB1, by controlling their brightness, color and power. The challenge of generating images onto LED segment displays is their low resolution to display text. Pictograms are the main carriers of light transmitted information and messages to the other participants in the medium. The smartphone controller is connected to the drivers of the LED segment displays by NFC, contactless interface, compatible with ISO / IEC 18000-3 mode 1 (ISO / IEC 15963), which is a standard for wearable electronic circuits.

The NFC interface uses Pulse Width Modulation (PWM) at 25kHz to control the brightness of the LEDs with and accuracy of +/-0.1%.

This is the first time that LED drivers, which can store the "working hours" for every LED in their internal memory, are used for such a project. This information is used for the automatic CLO system for compensating the bright LEDs which degraded over time. On the right pane of Fig.10 there is a graph showing the long-term stable brightness of a CLO corrected LED – a feature we believe will lead to improved safety characteristics during a long period of exploitation.

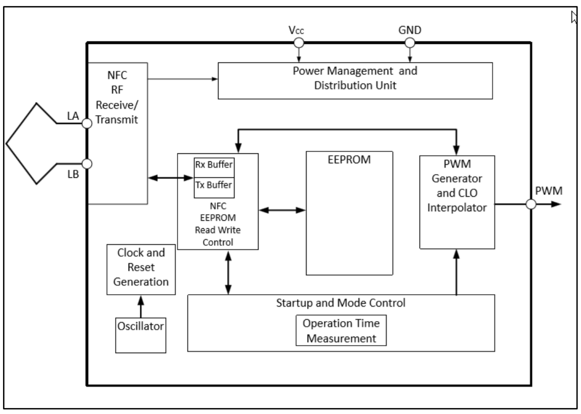

Fig.9. E-Bike- NFC contactless interface

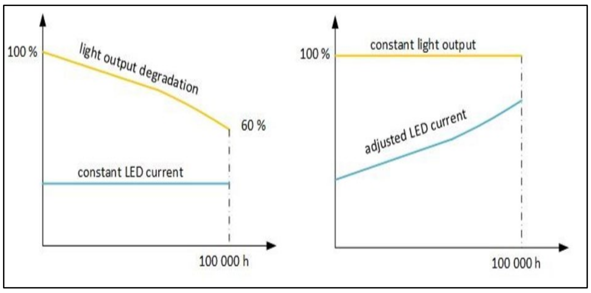

Fig.10. E-Bike- Constant light output (CLO) with 8 configurable points

The LED AAAF5051 we use are designed and manufactured specifically for wearable devices and are used in outside conditions [16]. They have excellent capabilities of creating bright images which are visible from a wide viewing angle Fig.11. The chosen hardware for good visibility and prolonged life of the wearable system as well as the controller are a good foundation for experimenting in the field of subsystems for a new and adequate light and acoustic signaling system for autonomous vehicles.

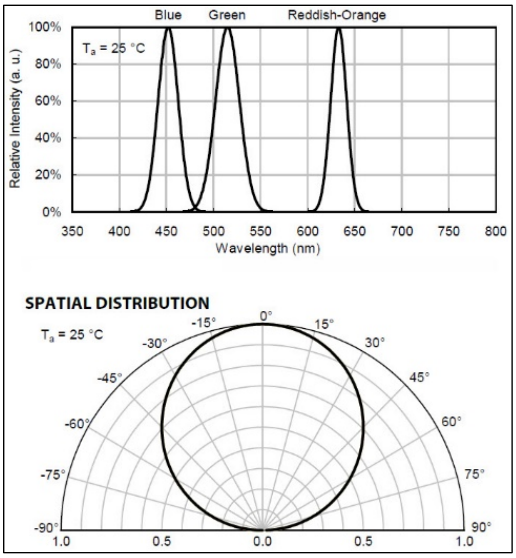

Fig.11. E-Bike-LED AAAF5051- main colors and spatial distribution

V. Analysys

The new communication technologies for interacting in a medium containing autonomous vehicles are entirely dependent on the light and acoustic interaction systems to transmit/ receive information in the traffic medium. New uses for light, color, semantics and acoustics, unbeknownst until now in the context of the exterior design of vehicles, are being applied, tested and improved.

VI. Conclusion

Light and sound, which are taking 50% on the dynamic interaction in a regular traffic system, will evidently take 100% in the dynamic interaction in the future urban traffic system with autonomous vehicles, because the new applications of light, color, semantics and acoustics are what's have to replace the role of the driver in that urban traffic interaction system. A long process of research and analysis will decide which new methods will be most effective for the new urban traffic medium, whereby in the future they will be included in the universally defined package for required elements in the exterior design of autonomous vehicles.

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