Building a Metaverse for Transportation Systems: A Brief Review and Demonstration

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***Abstract*—The prospective applications of extended reality and the digital twin have previously been reviewed for transportation systems. With the current interest in the metaverse, it is necessary to examine ways in which it can help improve transportation systems. Thus, this study provides a brief review of these previous reviews and discusses the potential impact of the metaverse on transportation systems. This study also examines three prospective solutions including; parking spot detection, parking assistance, and lane detection. It also examines two current case studies that employ the metaverse and its technologies for transportation systems, including Hyundai Motorstudio and WayRay's Holograktor**

***Index Terms*—metaverse, transportation, digital twin, augmented reality, virtual reality**

I. Introduction

Transportation systems are a key part of any community, country, and even the world as a whole. This is why a lot of research is currently being conducted to create more intelligent, reliable, and optimal transportation systems, such as autonomous vehicles and self-driving cars [1]. Despite all the groundbreaking research and industrial experiments on autonomous vehicles and the like, there has yet to be a tangible breakthrough, especially with the rise in the development of more advanced artificial intelligence algorithms, which keeps opening up more potential [2]. As a result, there is still a critical need to keep up with research and development of new elements that can be used to improve existing transportation systems.

One of the key technologies that is now gradually being employed in developing transportation systems is extended reality (XR), which is a technology that combines the real world with the digital world, encompassing virtual reality (VR), augmented reality (AR), and mixed reality (MR) technologies [3], [4]. XR has been employed to improve the existing driving training systems by offering immersive virtual training to drivers, and enabling them to learn to navigate even the most complex of terrains [5]. This is just one of the few ways XR can be applied to the transportation industry. With the rising interest in XR came the hype about the Metaverse, mostly influenced by the related announcement by *Meta*, formerly known as *Facebook* [6]. The word "metaverse" refers to an artificial world that exists in a digital space that was simulated as a replica of a physical space [6]. In essence, this digital space coexists with the corresponding physical space.

The main objective of this paper is to give a review of the application of metaverse to transportation systems. As a result, these are the contributions:

1) To give a brief review of previous works that have studied the interaction between XR, digital twins, metaverse, and transportation systems.
2) To discuss the effect of the metaverse on the transportation industry,
3) To demonstrate some prospective solutions that metaverse can proffer to transportation systems, and
4) To discuss some of the existing applications that are already underway.

II. Background and Related Works

In this section, the various surveys and selected articles that have explored XR, the digital twin, and even the metaverse for the transportation industry will be discussed. In [2], a systematic review of AR for automated driving applications was conducted, providing insight into the employment of this technology at various levels of autonomous vehicles. [3] also conducted a similar review, and even went further to analyze the challenges of applying AR in the automotive field. AR was explored in [5], where a simulated system was developed for military training. This system can be used to develop soldiers' skills for combats. AR for future mobility and its realities was reviewed in [7], and the concept was termed "augmented vehicular reality". This concept basically refers to the ability of AR to provide enhanced visibility and safety to vehicles. The application of VR for the interaction between pedestrians and autonomous vehicles was reviewed in [8], showing great potentials. VR and AR were concurrently reviewed for the development of simulators tailored for driving in [1].

Digital twin has been extensively explored and reviewed for the transportation industry. One way in which digital twin has been explored is in the development of better battery and energy management systems. For instance, in [10], the authors focused on reviewing and developing alternative means of energy storage systems for electric vehicles using digital twins. A similar review was conducted in [11], [12], where the advancements in battery management systems that employ digital twin amongst other technologies for electric vehicles were discussed. [9] and [13] go further to review the requirements of autonomous maintenance systems that employ digital twin. Some other authors went on to not only review these systems, but also discuss the potential challenges and recommendations [14].

There have been very few reviews of the applications of the metaverse to transportation systems. [6] and [15] conduct very detailed review on these applications and the corresponding

TABLE I
SUMMARY OF REVIEWS ON XR, DIGITAL TWIN, AND METAVERSE FOR TRANSPORTATION SYSTEMS.

Paper	Year	Remarks
		XR and Transportation
[1]	2019	Reviewed the development of driving simulators using AR and VR.
[2]	2019	Reviewed the application of AR in autonomous vehicles.
[3]	2020	Reviewed the challenges of applying AR in the automotive field
[7]	2017	Reviewed the application of AR for future mobility
[8]	2021	Reviewed the application of VR for the pedestrian and autonomous vehicle interaction
		Digital Twin and Transportation
[9]	2020	Reviewed the requirements of autonomous maintenance systems using digital twin
[10]	2021	Reviewed digital twin for alternative energy storage for electric vehicles
[11]	2021	Reviewed digital twin for BMS
[12]	2021	Reviewed digital twin for BMS and electric vehicles
[13]	2022	Reviewed digital twin for autonomous vehicles
[14]	2022	Reviewed the potential challenges and recommendation of digital twin for BMS
		Metaverse and Transportation
[6]	2023	Reviewed the prospects and challenges of metaverse for transportation
[15]	2022	Reviewed the technologies required and the applications of metaverse for vehicles

technologies required, including the potential challenges and recommendations. A summary of these studies is given in Table I.

III. REVIEW METHODOLOGY

This review followed the preferred reporting items for "systematic reviews and meta-analyses" (PRISMA) approach for the methodology. The following keywords were employed while searching for related studies on the subject; "metaverse", "vehicles", "transportation", "augmented reality", "virtual reality", "extended reality" and "digital twin". The following databases were consulted for article research; *IEEE Xplore*, *Wiley*, *MDPI* and some other sources. The scope of inclusion covered only article written in English language. As illustrated in Fig. 1 and itemized in Table II, a total of 85 documents were obtained after the preliminary search. Afterwards 34 documents were excluded due to duplication, 16 of the remaining documents were excluded for lack of relevance, another 13 documents were excluded due based on eligibility, while the remaining 22 documents were categorized based on qualitative and quantitative analysis.

TABLE II
STATISTICS OF DOCUMENTS REVIEWED

Database Source	No. of documents
MDPI	3
Elsevier ScienceDirect	1
IEEE	3
Wiley	3
arXiv	1
Other sources	11

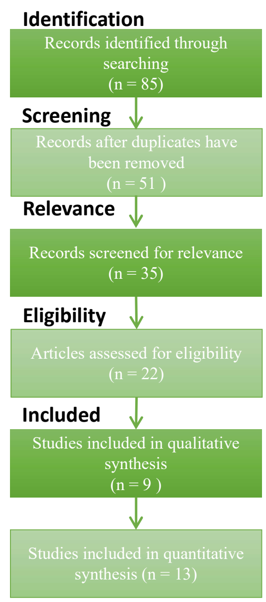


Fig. 1. The adopted PRISMA flowchart

IV. IMPACT OF METAVERSE ON THE TRANSPORTATION INDUSTRY

With the level of interest and research in the application of XR, digital twins, and metaverse to transportation systems. It is pertinent to evaluate how the introduction of these technologies will impact transportation systems and the vision for mobility in the future.

A. Delivery of Immersive Services

One key goal of the metaverse is to improve real-life experiences, not completely replace them. This is what will be realized when the metaverse is introduced to the transportation industry, as boundaries between the virtual and physical worlds will be blurred to allow for more immersive experiences [6]. This has been illustrated by *Acura Honda*, which launched the first ever virtual showroom [16], and by *Sonata*, which created a metaverse experience that allows users to test drive vehicles in a virtual space [17]. Moreover, by creating a digital network of roadways, *Nvidia* is on its way to solving numerous problems in the transportation system, such as difficulties in parking, real time travel path planning or recommendation by maps, and traffic congestion [18].

B. Design of Healthier Transportation Systems

With the metaverse, there are boundless possibilities in planning and decision-making, which can enable the optimal resolution of issues that persist in transportation systems [6]. Metaverse platforms can be used to create a healthier transportation system that enables users to get the best experience and suffer minimal road hazards, accidents, and even congestion. Inefficient routes and plans can be promptly replaced upon discovery by employing the metaverse. Transportation systems can become more connected, enabling the traversal across multiple transportation systems within the metaverse. Companies like Hong Kong's MTR Corporation are already starting to develop a virtual railway system that can ease congestion in cities and enable communication with the younger generation [19].

C. Development of More Intelligent Transport Systems

According to predictive reports, the value of investment in the manufacture of metaverse-supported vehicles will amount to about $16.5 billion [20]. As a result, there will be more than sufficient support for the development of more intelligent vehicles. The company *WayRay*, took the world by storm when it introduced its metaverse vehicle, called *Holograktor* [21]. This vehicle employs a novel deep reality display technology that enables a totally different kind of windshield powered entirely by XR. By the time the complete version of the vehicle is completed, users of the vehicle can experience a borderless link between the digital and real worlds.

D. Optimal and Flexible Transportation Systems

The potential of the metaverse to provide a more optimal and flexible transporation system has already been discussed in the preceding subsections. One of the most prevalent challenges in the transportation system in most parts of the world is the identification and prompt response to traffic congestion, travel path planning, issues with fleet management, and even traffic hazards, especially those that occur in remote locations. With the metaverse, simulated vehicular environments and scenarios can be used to conduct trial-and-error experiments and make the transportation decision-making process easy and simple. The road management authorities will be able to access remote locations to determine the situation before deploying the necessary response teams.

E. Summary

This section evaluated the current and future potential effects of metaverse on the transportation industry, including; (i) delivery of immersive services, (ii) design of healthier transportation systems, (iii) development of many more intelligent transport systems, and (iv) development of optimal and flexible transportation systems.

V. Demonstration of Metaverse for Transportation Systems

Metaverse has the potential to revolutionize transportation industries. This section presents three of such potentials including: (A) parking spot detection, (B) parking assistance and automated valet system, and (C) lane marker detection. The realization of these potential applications requires a mixture of computer vision techniques, perception technologies, augmented reality interfaces, and autonomous vehicle technologies. All these will be combined to help create immersive and efficient virtual environments for vehicle parking, and driver assistance.

The demonstration and results presented in this section were generated using MATLAB and Unreal Engine software and were based on a 3D simulation environment rendered in Unreal Engine and represented in Fig. 2.

Fig. 3 illustrates the different workflows of the parking spot detection system.

Fig. 2. Map of the environment (the specific name of the environment might be helpful

A. Metaverse-based Parking Spot detection

Parking spot detection can be realized in the metaverse by exploring perception technologies like LiDAR sensors, cameras, and sensor fusion algorithms. These tools can help with detecting and recognizing parking spaces in real-time, using virtual environments, enabling more accurate and efficient parking spot detection. To automatically park an autonomous vehicle, the sensors need to visually sense the environment and find available parking spots. The basic workflow is to:

- Drive through the parking lot to build a map of the environment, by exploring the data which has been segmented from the camera sensor.

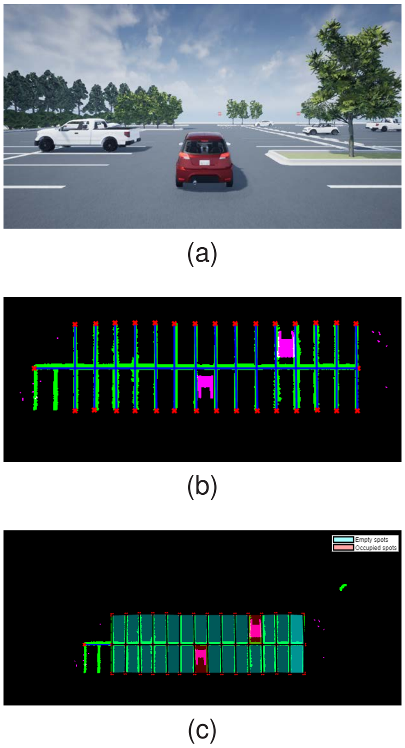


Fig. 3. Illustration of Metaverse-based Parking spot detection system showing the (a) initial position of the vehicle, (b) The identified parking lines, and (c) identified empty spaces.

- Detect the parking lines illustrated on the map using hough transform.
- Analyze the map and identify the empty parking spaces using
- Maneuver the vehicle to park in an identified spot.

B. Parking Assistance and Automated Valet System

Metaverse can also help with parking assistance, by providing real-time guidance to drivers for parking maneuvers. This can be realized through AR interfaces and virtual markings on those interfaces. Technologies like this will enable vehicles to be parked with minimal human input.

This idea was explored in MATLAB and Unreal Engine simulation environments, and the results are illustrated in Fig. 4. Automated parking is a very complex problem, as the system of the vehicle is expected to assume control and steer the vehicle to an available parking spot. This involves planning a feasible path through the environment. Just like the previous example, the vehicle first explores the environment, while visually sensing the environment and building a 3D map. The difference is that, while the user controls the vehicle in the first example, here the vehicle is expected to automate the driving and parking. To achieve this, path planning and dynamic obstacle avoidance algorithms are implemented. With a goal in mind, the vehicle control system assumes control of the steering and speed of the vehicle.

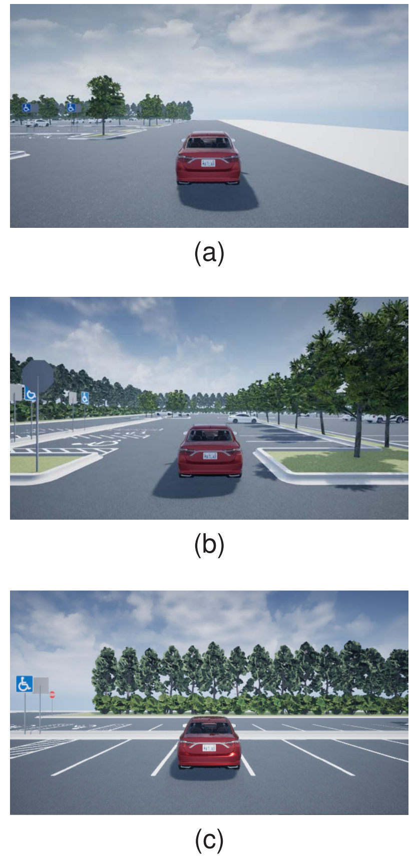


Fig. 4. Illustration of Metaverse-based Parking assistance system showing the (a) initial position of the vehicle, (b) vehicle turning left, and (c) vehicle parking.

C. Lane Marker detection

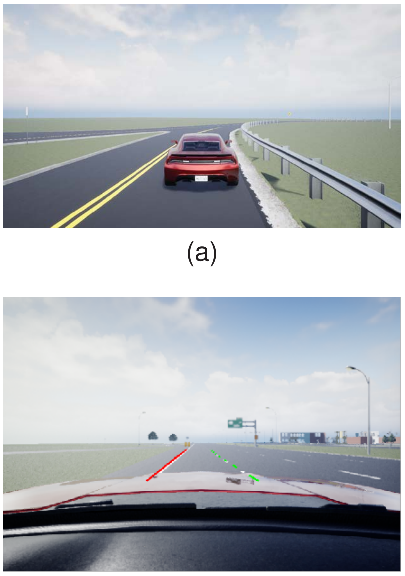
By employing computer vision and image processing algorithms, metaverse can provide drivers with real-time visual guidance and cues to enable them to stay within the designated driving lanes. Figs. 5 and 6 illustrates this example. In this lane marker detection system, multiple solutions are combined, including vehicle detection, lane marker detection and distance estimation.

D. Summary

This section presented three prospective applications of metaverse for transportation systems. Essentially, the metaverse provides us with a simulation environment for testing all these algorithms before deployment to the autonomous vehicle, since it is expensive to do this in real-time and on a real vehicle.

VI. Case Study Applications of Metaverse in the Transportation Industry

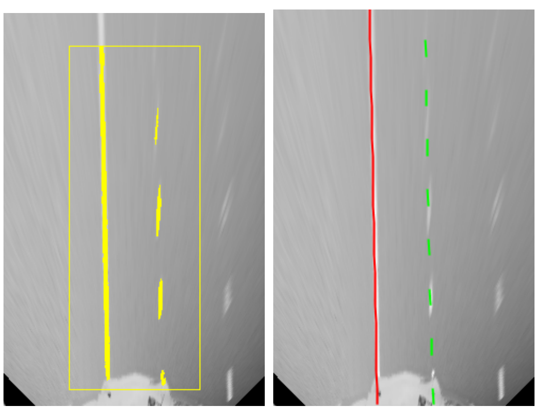
The metaverse has grown beyond the mere concept of the convergence of the real and virtual worlds to become a reality, as it is now being gradually applied in various industries, including the transportation industry. Companies like *BMW* and *Nvidia* have formed a collaboration to develop



(a)

(b)

Fig. 5. Illustration of Metaverse-based lane marker detection showing the (a) vehicle in motion, (b) lane marker detection



(a) (b)

Fig. 6. Illustration of Metaverse-based Parking assistance system showing the (a) raw segmentation (b) lane marker detection

a digital virtual factory that can help reduce the time spent on planning the production process. Digital twins are digital copies of physical assets. With the use of digital twins, they can create digital vehicles and perform all the necessary tests and alterations before making the physical product. In South Korea, *Nvidia* is creating a digital version of roadway networks, which are simulated from the data obtained from a variety of strategically mounted cameras. These and numerous other applications show the potential of the metaverse for transforming transportation systems as a whole.

In this section, two case studies that apply metaverse and its corresponding technologies to transportation systems will be discussed.

A. Hyundai Motorstudio on Zepeto

With the core aim of creating long-term rapport with the younger generation, Hyundai is invested in creating virtual experiences that can enable them get familiar with the brand [17]. One of such experiences is the motorstudio hosted on *ZEPETO*, a South Korean application that features a virtual world that allows users create their own experiences.With this innovation, users;

1) Tour the S-Hub future mobility transit center
2) Explore the three ideas in S-Link purpose built mobility; including party room, clinic and food truck.
3) Ride the S-A1 urban air mobility vehicle

In this studio, the interiors and exteriors replicate the physical motorstudio located in the capital city Seoul.

B. WayRay's Holograktor

The metaverse vehicle developed by *WayRay* termed *Holograkor* and also called *metaverse on wheels* [22] was extensively discussed in [6]. *Holograkor* was built based on the concept of the metaverse and employs related technologies such as XR and digital twin. It employs a display technology which is unique to *WayRay*, called *deep reality display*, which allows user to enjoy an immersive ride.

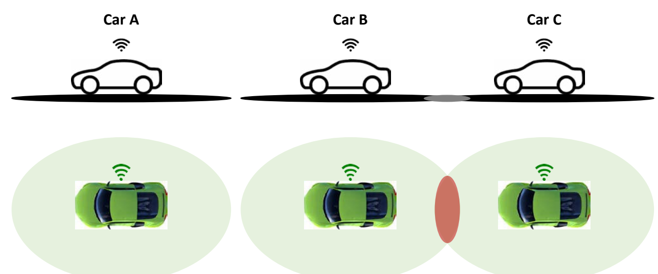


Fig. 7. Driving scenario illustrating the role of AR in ensuring minimum vehicle following distance

Some of the features users can access while using this metaverse vehicle include:

1) Remote control of vehicle using a specific vR remote control, thus enabling users to take part in ride hailing services. This means that road users can get a ride from a remote driver.
2) A smooth link between the virtual and physical world through AR glazing, allowing images to be superimposed smoothly onto the windscreen as if it were really physical.
3) healthy interaction with other passengers through the AirKnife technology that helps to demarcate the airflow of the vehicle users and control air pollution that can occur during conversations or sudden sneezing.

Fig. 7 illustrates how AR glazing technology is employed in the WayRay's Holograktor to ensure that vehicles are driving, while following the specified following distance. This will help to prevent sudden collisions due to short braking distance.

VII. Conclusions and Future Works

In this study, we conducted a brief review of previous studies on the metaverse, its technologies, and their application to the transportation industry. We also reviewed the potential impact of these applications on transport systems. Furthermore, we examined two case studies that employ metaverse for transportation systems; they include Hundai's motorstudio and WayRay's Holograktor. We anticipate that this short study will shed more light on the impact of the metaverse on transportation industries.

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