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A Study on Visualization of Digital Twin Electric Vehicles Based on Gamification: A Simulation Using Game Engines

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Abstract: This study investigated a methodology for implementing and simulating a digital twin (metaverse) electric vehicle visualization with gamification using a game engine (Unity 3D). This paper is important because it is the first study to visually represent an electric vehicle using a game engine. The core of this study is to analyze the differences between internal combustion and electric vehicles by implementing them in a digital twin, and the KONA model of Hyundai Motor Company, which has two types of engines, was selected. To create the driving roads to compare the performance of the two cars, the terrain was created with Unity Component Terrain. After creating the terrain, configuring the digital twin assets, creating a fuel economy system, setting up object placement and collision settings, and animating, the team created a simple comparison drive that yielded meaningful results. Several gamification elements were applied to motivate players to use the implemented digital twin electric vehicle simulation, increasing curiosity and engagement. Further research will be conducted to add more gamification elements and augment the digital twin experience to make it more engaging and visualize the electric vehicle to increase driver engagement and understanding.

Keywords: digital twin; electronic car; gamification; game engine; visualization

1 INTRODUCTION

The purpose of this research is to develop a methodology to simulate the driving environment scenario of an electric vehicle on a digital twin by visualizing it with a gamification interface using the game engine Unity 3D. The results of this study are expected to quickly and effectively convey information necessary for the manufacture and operation of electric vehicles, and will be very useful for the design of electric vehicle designs, and in particular, gamification elements applied to vehicles in virtual space will contribute to providing a positive driving experience for drivers.

To implement both internal combustion and electric vehicles in the digital twin, products with two different engine types were selected. The KONA model of Hyundai Motor Company, which has both internal combustion and electric models, was selected to be implemented with the game engine Unity 3D. This study was conducted with the following three goals:

1) Differentiating from existing electric vehicle research, a digital twin driving environment based on the Unity 3D game engine was implemented to visualize and compare the differences between electric vehicles and internal combustion vehicles intuitively.
2) By utilizing digital twin technology to create a simulation similar to the actual driving environment of electric vehicles, gamification elements were applied to make the features of electric vehicles more vivid and fun to experience.
3) A visualization methodology is proposed to increase drivers' interest, interest, engagement, and understanding of EVs by applying gamification elements (points, levels, progressive bars, competitions, challenges, etc.).

2 RELATED WORKS

In recent years, many manufacturers have been conducting research and development on electric vehicles. In addition, as the parts and software of vehicles become more complex and diverse as autonomous driving functions become more advanced, it is time-consuming and costly to manually evaluate and verify them in the real world [1]. With the development of gamification and digital twin technologies, it has become possible to efficiently visualize electric vehicles using them. In this paper, an electric vehicle visualization was studied by combining gamification and digital twin technology through Unity 3D.

In this study, Unity3D, a game engine, was mainly utilized to create a digital twin environment. Unity3D game engine is one of the general-purpose engines utilized by most game production companies and game developers around the world. Unity Engine was developed by David Helgason, Joachim Ante, Nicholas Francis, and others. They founded Unity and developed the Unity Engine to help small game developers create games [2]. Unity3D can work on MS Windows and Mac OS X. Unity3D is available for Windows and Mac. Programs created in Unity3D run on windows, Mac OS, Xbox, PlayStation, Wii, IOS, and android [3].

Digital twin is a technology that implements a 3D model of a twin that identically reflects the physical features of a real object in the virtual world (Digital), simulates it in real-time synchronization with the real object, and uses it for real-world decision-making such as control, analysis, and prediction [4].

The twin of a digital twin, as used in the current concept of a digital twin, first appeared in NASA's Apollo program. In this program, the environments of two or more space vehicles were simulated under the same conditions to enable accurate flight condition prediction and real-time simulation [5]. Digital twin was first introduced in Grieves' work in 2003 and have continued to evolve to the present day [6].

By adopting a real-time ‘digital twin’ framework that bridges the virtual and physical worlds, projects can take full advantage of digital twin technology's ability to avoid technical defects or unexpected performance anomalies that arise later in the process. To improve the validation of any finished product, using simulation from the earliest stages of prototype development to real-world testing can prevent costly design changes later in product development. Utilizing Digital twin for this simulation approach can save money and increase efficiency.

The core of digital twin is to integrate the real world and the virtual world in real time by implementing a model that reflects reality in the virtual world, and the process of "create → send → aggregate → analyze → understand → execute" of data [7].

Based on these benefits and procedures, this study aims to visualize an electric vehicle in a digital twin using Unity 3D. The process of visualizing an electric vehicle in a digital twin environment consisted of five steps.

① Set (create) goals - Set and create the goals you want to achieve with Digital twin in research. In this case, the project visualizes an electric vehicle and a conventional vehicle in the same virtual environment and compares various performance and post-driving status factors such as fuel efficiency, speed, and durability.

② Vehicle selection and data collection (transmission) - After selecting the vehicle model that best meets the project goals for visualization, all elements of the transmission, such as driving-related specifications, exterior shape, and functions of the model selected in this paper, are analyzed and information is collected for later production.

③ Digital twin driving environment planning (aggregation) - Based on the data collected and aggregated, the system, content, and user interface to be implemented in the Unity 3D space were planned.

④ Implementation (analysis and understanding) - Collect the same data as in real-world driving within the digital twin, analyze it to implement the 3D environment, and create a Unity environment that players can understand on the digital twin.

⑤ Driving test and drawing conclusions (execution) - Collect various data through driving test of electric vehicles in the implemented 3D digital twin driving environment, simulate the situation in the real environment based on this data, and draw conclusions.

Gamification is a new word made up of the words game +ification (a Latin noun –ification suffix) and refers to the application of game elements to non-video game contexts. Gamification is the recognition of problems in everyday political, economic, social, cultural, and industrial situations and relationships between people (users, consumers, receptors, etc.) that seem unrelated to games and the application of "game elements" as solutions [8]. Gamification can be used to make the driving experience of an electric vehicle more fun and enjoyable in a visualized space, and increase the driver's sense of engagement and understanding.

Examples of electric vehicle visualization implementations using gamification and Digital twin include Hyundai Motor Group's trial of Digital twin technology for managing electric vehicle battery performance [9] and BMW Group's use of NVIDIA's Omniverse artificial intelligence (AI) to create a virtual car production environment to virtually build cars [10]. The system adds a gaming element to engage the driver. Digital twin technology can not only monitor the status of electric vehicles in real time, but also synchronize information and functions from the manufacturing site to derive various analytical results to evaluate, analyze, optimize, and predict the situation on site [11].

3 RESEARCH METHODOLOGY

The methodology of this research is to create and implement a digital twin virtual space similar to the real driving environment, and to conduct simulation experiments in which the user selects a vehicle and controls and manipulates variables while driving.

First of all, to realize the digital twin driving environment of goal 1) presented in the introduction, three scenes were set up in Unity 3D: lobby, options, and driving. The digital twin environment was then built as a PC application (deliverable) for users to play. The application allows the user to select the options, driving, and exit scenes via three buttons, and provides a comparable and testable 3D driving environment for further research.

For Objective 2), the application was gamified to provide the driver with a fun and enjoyable experience of driving an electric vehicle, either an EV or a conventional car. Gamification technology can increase the player's engagement and understanding in the virtual space of the digital twin. Therefore, this research project was implemented by providing appropriate gamification elements to provide the driver with the experience of driving a car video game.

To implement Objective 3), the gamification was realistic enough to allow the driver to select a 'damage option' from the vehicle's options during the driving test, just like in a car video game. This damage option implements an event that dents the body of the vehicle when the vehicle collides with another object, to visualize the impact of damage to the body in an accident during real-world driving and provide the driver with a realistic sense of immersion.

Physical phenomena and basic vehicle dynamics that occur in real-world driving situations were also applied. A system was created to independently drive all four wheels of the car to check the status of all wheels, and the wheel drive system was reinforced and tested. The durability of the car body was implemented so that it can be adjusted through the mass variable of RigidBody.

In addition, unique performance indicators of electric vehicles (e.g., fuel economy, speed change, Regenerative Braking) were implemented on the Digital twin. The fuel system of each vehicle was implemented in the form of a progressive bar in gamification so that the performance of electric and conventional vehicles could be compared. In addition, gamification systems were implemented to change the details to differentiate between electric and internal combustion vehicles, such as the ABS system.

In conclusion, this paper presented a simulation experiment of gamification-based digital twin electric vehicle visualization, implementing a real driving environment on a digital twin and allowing users to select an electric vehicle and an internal combustion vehicle to compare and analyze the differences in participation and interest levels, creating a basic environment for further research.

4 ELECTRIC VEHICLE DIGITAL TWIN VISUALIZATION RESEARCH PROJECT DETAILS

This research is a project that combines the Unity3D game engine, Digital twin, and gamification technology to visualize the driving environment of an electric vehicle and allow users to conduct simulation experiments. The purpose of the research is to develop a methodology for realizing gamification-based electric vehicles and their virtual driving environments in Unity 3D. In particular, the UI design was created with feedback from electric vehicle experts.

The results of this study will be very useful in providing information for the design, manufacturing, and operation of electric vehicles. Furthermore, the driving environment in the digital twin and the gamification techniques applied to the electric vehicle will provide users with an interesting driving experience and make a meaningful contribution to the electric vehicle industry.

There are many possible methods and tools for building a digital twin environment. In this study, the general-purpose game engine Unity3D (21.3.15f1 and 21.3.33f1) was mainly used, and the accompanying graphics tools (3D Max Studio, Zbrush, Photoshop, etc.) and programming language C# were applied. The recommended hardware specs for the build are CPU: AMD Ryzen 5-5 7600 (Raphael), Memory: SEC DDR5-4800 (16 GB), Graphic: Geforce RTX 3070 Miracle II D6 8GB, and the app should run fine on these specs.

The following five steps were used to guide the research. The research content for each of the five stages of the EV visualization process covered in the previous literature review is as follows.

4.1 Goal Setting

There are five main goals for this study:

- Visualize and communicate the differences between electric vehicles and internal combustion vehicles in an easy-to-understand way so that they can be intuitively understood and compared.
- Increase the attractiveness of the visualization by adding gamification elements by actively utilizing the features of electric vehicles.
- Increase drivers' interest and engagement with EVs through EV visualization to improve understanding.
- By utilizing digital twin technology to create a simulation that is similar to the actual driving environment of an electric vehicle, it is possible to more vividly experience the characteristics of an electric vehicle in a real driving environment.
- It is set to strengthen competitiveness in the field by producing technical results that are differentiated from existing electric vehicle visualization research.

4.2 Vehicle Selection and Data Collection

Since the main focus of the study is to implement an internal combustion and electric vehicle in a digital twin to analyze the differences between the two, it was necessary to select a product with two different engine types within the same vehicle. Therefore, the KONA model from Hyundai was chosen, which has both internal combustion and electric models.

The image below is of the 2021 Hyundai KONA model, which is very detailed in terms of exterior appearance and interior implementation (Fig. 1).

A car is divided into two parts: the body and the sash, and since the body is the most important part for driving, a detailed model of the body was selected. For the interior of the car, the project did not implement additional models, prioritizing the reproduction of the system through code. The interior model will be added in future years through enhancements. In addition to these parts, there are many other parts in the car, so the project was conducted by collecting as much data as possible.

Figure 1 2021 Hyundai Kona Electric 3D model (up), 2021 Hyundai Kona N-Line model (down)

4.3 Planning and Organizing the Unity3D Environment

For this study, in the game engine Unity 3D, three scenes were set up for this study: Lobby, Options, and Driving. The options scene was set up to be scalable, utilizing Unity's Additive Scene feature to open multiple scenes on top of a specific scene.

To apply the basic physics system to the vehicle, this paper introduces Unity's RigidBody. Also introduced at this stage is the MeshCollider, which implements collision events with external objects. There are many options for Colliders, but are chose Mesh Collider to accurately fit the shape of the model. For the Rigidbody, it is added to the highest parent object, while for the Collider, it is added to the Body child object because it needs to follow the shape of the model (Fig. 2).

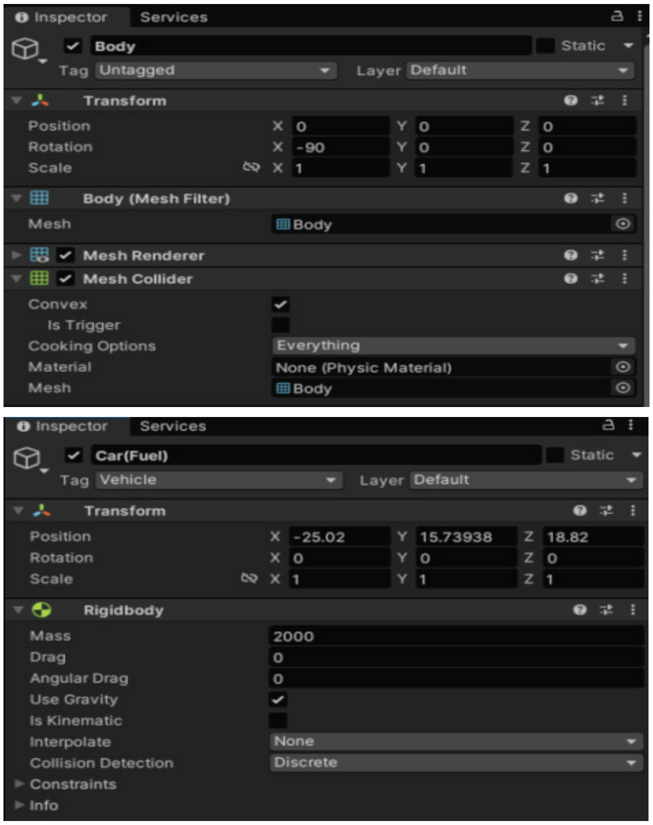

Figure 2 RigidBody and mesh collider. The game engine can be manipulated to adjust the physical behavior of the vehicle and adjust the values of collision event variables.

Figure 3 Lobby scene. When the driver launches the application, they are greeted with a video game-style lobby window.

When players launch the Digital twin program, they'll see three buttons to start, options, and exit. In addition, a 3D background has been created and placed in the background to show the title of the project and a preview of the car player will be driving (Fig. 3).

In order for the player to press the 'Start' button to make the car move, Unity Engine needs to receive input from the player. To do this, the variables that need to be input are summarized below (Tab. 1).

Table 1 Player input data

Steering-related	
Throttle	Float variables for accelerator inputs
Brakes	Bool variables for break input
Steering	Float variables for direction (negative 'left', 'center' for 0, positive 'right')
Clutch	Float variables for clutches
Handbrake	Bool variables for handbrake
ShiftUp	Bool variables that correspond to a gear up.
ShiftDown	Bool variables that correspond to downshifting
EngineStartStop	Bool variables corresponding to engine start
Light-related	
LeftBlinker	Bool variables for left turn signal
RightBlinker	Bool variables for right turn signal
LowBeamLights	Bool variables for high beams
HighBeamLights	Bool variables for high beams
HazardLights	Bool variables for emergency lights
ExtraLights	Bool variables related to additional indicator lights needed for other vehicles
Others	
Horn	Bool variables corresponding to klaxon
CruiseControl	Bool variables for cruise control

4.4 Create a Digital Twin

4.4.1 Implementing the EV Digital Twin Terrain and Basic UI

To create a driving surface for comparing the performance of internal combustion and electric vehicles, you can use Unity Component Terrain to create the underlying terrain. For example, mountains, hills, and holes for lakes are created using this feature (Fig. 4). The dirt road model is then overlaid with the driving road model, which is further modified and textured for added realism.

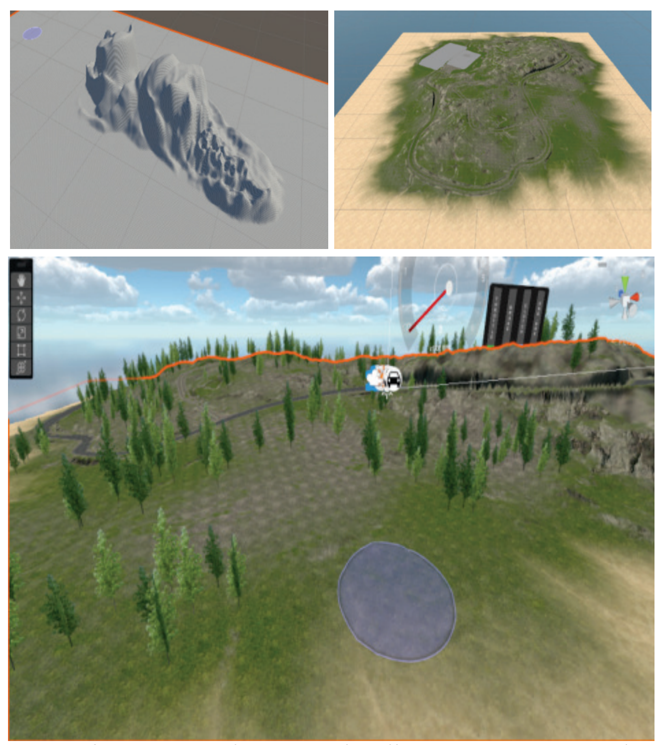

Figure 4 Creating and modifying a terrain (up left), viewing the created terrain (up right), and modifying the terrain texture (down)

Textures such as stone textures for hills, grass textures for grass, and sand textures for sandy ground are applied using the brush function of the terrain so that they can blend in naturally. After that, trees, bushes, and various structures are installed to create a sense of three-dimensionality.

To create the digital twin electric car, the UI for the driving screen was synthesized by using the player input data as the corresponding variables. On the left side of the driving UI, there is an analog instrument panel to check the current RPM and gear of the car, and on the bottom right, a slider gauge shows the values of Throttle, Brake, Clutch, Hand Brake, and Handle that the user inputs when driving (Fig. 5).

On the right side of the driving UI, there is an analog instrument panel that displays the current speed, turn signal, high beam, low beam, etc. and the current Torque, Lat Slip, Lng Slip, and Load values through the input data, a horizontal slider that shows the accumulated damage of the car, and a button to enable/disable damage and a button to repair. The integration with the UI was finalized by referencing the variables managed by the Scriptable Object to reference the material while driving. In future research, more road types, weather conditions, slopes, ground conditions, etc. will be implemented.

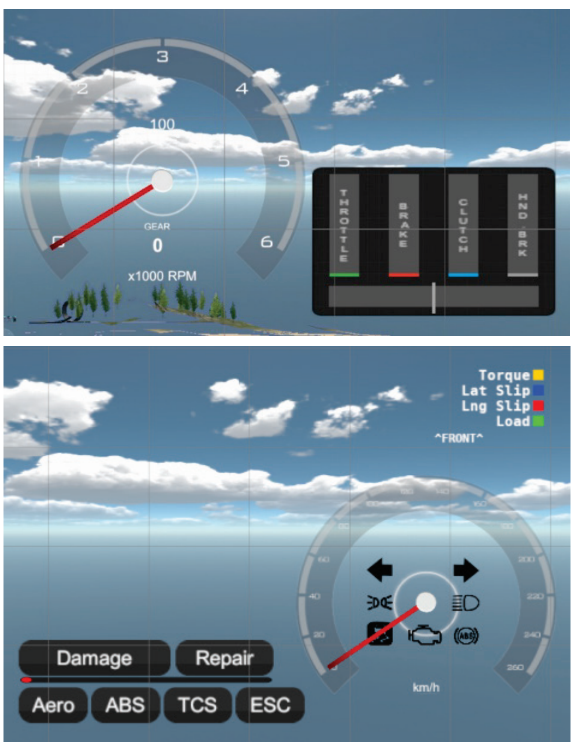

Figure 5 Driving UI left (up) and right (down). It is implemented so that the user can check the driving status and conditions by looking at the HUD in the front of the car.

The energy display for the car was implemented by creating a ScriptableObject that stores fuel based on data from the car based on user input, so that the maximum amount of energy that can be stored and the amount of energy currently remaining can be linked to the UI (Fig. 6).

To differentiate between electric vehicles and internal combustion vehicles, the UI for checking the fuel level was differentiated by using a battery-shaped UI to emphasize the fact that electricity is used for energy, and for internal combustion vehicles, the analog instrument panel that usually displays the remaining fuel in internal combustion vehicles was replaced with a vertical slider.

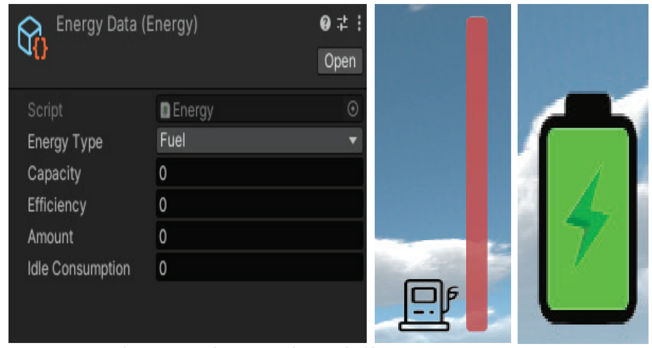

Figure 6 Car energy ScriptableObject (left), car energy display UI internal combustion (center) / electric (right)

Finally, regenerative braking, which is a unique characteristic of electric vehicles, is an electric braking technology that recovers kinetic energy (brake and acceleration) and stores it in the battery [11]. In this study, a visualization UI (Fig.7) that simulates the regenerative braking of an electric vehicle on a digital twin was implemented and the driving characteristics were compared with those of an internal combustion vehicle.

Figure 7 First Person View - Regenerative Braking UI Visualization (up) Third Person View - Regenerative Braking UI Visualization (down)

4.4.2 Animating an Electric Car Digital Twin

When the car is moving, turning the steering wheel causes the front wheels to rotate the steering shaft connected to them according to the amount of rotation of the steering wheel. The pinion gear at the end rotates and finally engages with the rack gear connected to it to finally turn the wheel to change the direction of the car. Fig. 8 shows the animation of the wheels using this principle.

Figure 8 Wheel rotation animation. The driver can adjust the strength of the rotation animation by adjusting the value of a variable in Unity.

A car is a device that allows the left and right wheels of a car to change the number of revolutions through a differential gear to make it rotate smoothly without effort on bumpy roads and when turning. When a car runs on a flat road, the two wheels have the same rotational resistance, so they show the same number of revolutions, but when passing through bumpy roads such as mountain roads and hills, the left and right wheels have different rotational speeds (Fig. 9).

To realize this phenomenon, the coefficient of rolling resistance of the car's wheels was calculated and reflected in real time, and the wheel animation was applied to emphasize the realistic feeling.

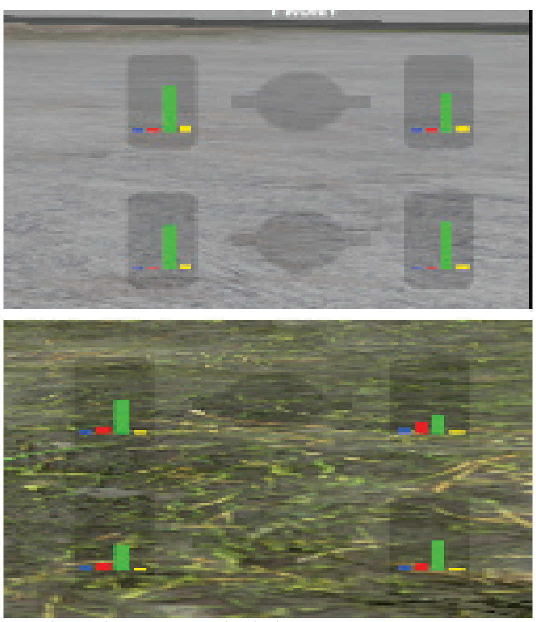

Figure 9 State of the wheels UI flat (up). Wheel state UI on a mountain road (down).

While the basic movement of a digital twin vehicle has been implemented so far, there are still some gaps in the vehicle's movement that need to be filled. In real-world driving, the suspension and inertia of a car cause the body to sway when the car hits a bump or curves. In this project, linear interpolation was used to realize these animations. In the case of a traditional car body, the model's position is fixed immediately after a collision, while interpolation allows it to move to the next position more naturally.

This allows us to represent the natural sway of the body when it collides or curves above a certain speed. The interpolation value was made a variable so that it could be adjusted to the vehicle's information if it changed in the future.

4.5 Test and Draw Conclusions

If users select the Damage option in the car's options during a drive test and the car collides with another object, they can implement an event that dents the car's body in the area of the collision to visualize the impact of damage to the car in a real-world accident (Fig. 10). The durability of the body can be adjusted through the mass variable of the RigidBody.

Figure 10 Implementing car body damage from collisions. Adjusting the parameter values in the Damage options can change the amount of damage.

In addition, fuel systems for electric and internal combustion vehicles, changes in details to distinguish between electric and internal combustion vehicles, and ABS systems were implemented (Fig. 11). A system that allows all four wheels of the car to drive independently and check the status of all four wheels was created, and the wheel drive system was reinforced and tested.

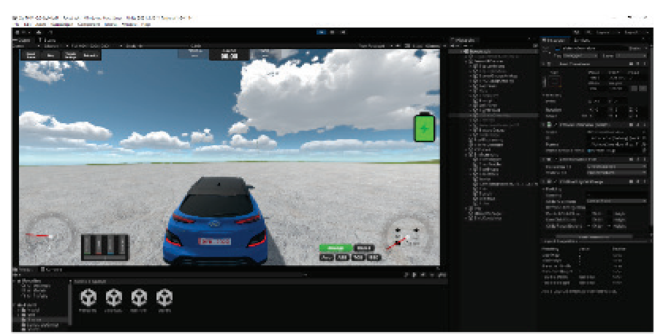

Figure 11 Track scene for electric vehicles. This was implemented to allow simulation experiments by adjusting the values of variables.

5 RESULTS AND DISCUSSION

In this paper, a digital twin environment was implemented based on a game engine (Unity3D) and gamification technology was applied to efficiently visualize electric vehicles. This paper aims to present an efficient visualization method for electric vehicles by implementing a digital twin virtual environment based on the game engine Unity3D and applying gamification elements to the virtual space, virtual vehicles, and objects.

This study was a simulation project to visualize the driving comparison between electric and internal combustion vehicles using a gamification-based digital twin environment with a game engine to make it more visually appealing to drivers and increase their engagement and understanding. Hyundai Kona, which is in line with this research, was developed to implement a physical driving environment so that players can simulate playtesting. In addition to providing the driver with a visually appealing UI (with EV expert feedback) from electric vehicle experts. That is fun and enjoyable like a game, it was also visualized to monitor the status of the electric vehicle in real time. This paper can serve as an overview of how these factors affect driver decision-making and vehicle performance in digital twin.

However, this research project, which applied gamification elements to digital twin environments and vehicles, aims to provide a driving experience for electric vehicles by increasing driver engagement and understanding, but due to the limitations of the research period and budget, it is not possible to increase the driver experience to a sufficient level. Nevertheless, users and subsequent researchers who encounter the results of this project will have a positive perception of EVs and increased interest in the EV industry.

In the future, follow-up studies will be conducted to further analyze the funding and information of other EV models other than the Kona. Findings of this study. It is planned to expand the driving environment and variable conditions of the vehicle to implement more realistic damage conditions, physical conditions of the vehicle, and environmental factors (road type, weather conditions, etc.) to study the impact on vehicle performance. In addition, the follow-up research will provide a HUD that incorporates a gamification-based feedback system on the digital twin to help users learn how to drive more efficiently and highlight the benefits of electric vehicles. This expanded follow-up research will include user experience research by conducting playtesting surveys with actual drivers or potential EV buyers. This will allow for a comparative analysis of engagement between EVs and internal combustion vehicles and evaluate the effectiveness of gamification strategies applied more broadly to each vehicle on users in the EV driving environment.

This study and subsequent studies are expected to contribute to the realization of actual driving, fuel efficiency, and feelings of use by building environments such as factories that produce actual electric vehicles and repair shops that inspect vehicles into digital twin, and making electric vehicles in the digital twin in a suitable form.

Acknowledgement

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