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Developing of the Digital-Twin-Technology-Based Performance Simulator

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Abstract: Contents using immersive experience technology are growing worldwide, but they are underutilized in the performing arts industry. Virtual reality is still in the experimentation and development stage, and it is rather difficult to fully define its potential and cost value. This study aims to apply and use virtual reality and related technology in the performing arts sector. We analyzed the trends and sources of technology development related to virtual performance, and the essential components of digital-twin-based performance production to derive the general directions for the development and methodology of research on performance that applies digital twin technology. Through this analysis, we elicited four components for developing a digital-twin-based performance simulation model. The proposed model can be modified as per the applied circumstance. However, an empirical study must be conducted to prove the validity of the theory by applying digital twin technology to theatrical performances such as plays and musicals and by investigating audiences' response to the performance.

1. INTRODUCTION

The importance of developing and utilizing digital twin technologies emerged in the face of the accelerated and advanced metaverse era of social, cultural, and economic changes and digital transformation due to unprecedented pandemic situations around the world. There are cases of development and application of digital twin technologies based on urban environment such as Virtual Singapore, Busan, and Sejong Smart City, which are representative examples of overseas, and performance content using existing virtual reality platforms, but research on performance content based on digital twin is insufficient.

A digital twin is a digital replication of physical objects that can be defined as a hypothetical model that maintains the properties and states of target object elements throughout the life cycle and describes the dynamic properties of how they operate. Here, physical objects refer to tangible assets, processes, systems, etc., and there is a growing demand to improve productivity, economy, safety, etc. in various industrial sites to which these physical objects are applied.

Currently used in the field of performing arts, digital twins follow simulations, the fundamental meaning of digital twins. Representative software includes Light Converse, Disguise, Capture, etc., and although there are differences in functions from software to software, a virtual concert hall environment is established, and based on this, it shows the arrangement and operation of stage and stage devices in the concert hall, and pre-visualization of the performance of actors on the stage. Since digital twin-based performance production simulation makes it easier to check in advance the problems that may arise in the physical operation of stage sets and stage devices, performance directors and stage designers can improve the accuracy of stage space and stage production, and efficiently verify and implement planning intentions. In addition, actors and staff can check the operation status of the stage device according to the timeline in advance, so it is possible to increase the understanding of the intention to plan the work.

However, in this study, I would like to look at digital twin technology with a slightly different meaning and perspective. To this end, first of all, what are 'performance' and 'stage' to humans? consideration is needed for consideration of Since COVID-19, the performance industry has attempted to videoize the performance itself in offline performance venues and transmit it in a live streaming manner, which can be interpreted as creating contacts online and distributing secondary works. Simply moving to digital has created meaningful numbers that make tens of thousands or more watch the performance, which is the maximum per episode, but it is not enough to satisfy the traditional audience who misses the sense of realism immersed by the actors who dominate the stage. This makes us think about what will be the next stage in an era when the stage is disappearing. Among them, some artists who did not stop creating rushed to conduct digital experiments as new tools and media, and directed not at the audience on the scene, but

at the audience connected live, the audience existing in the comments, and the audience remaining as digital data. There have also been teams that perform live on YouTube and Twitter, hold workshops by zoom, try performing in games, and use clubhouses to perform live. At this time, the trial and error of organizations and artists who faced many difficulties may have become another new art experiment and expanded the spectrum of art. While the definitions and questions of "stage" and "performance" create a variety of interpretations and discussions, another experiment has been added. The fact that the end of the technology called Digital Twin and the classic play during the classic itself leave a lot of implications. Based on this need, this paper analyzes the factors for developing a digital twin-based performance production simulation system and derives the overall development task of future research.

2. RELEVANT RESEARCH

2.1 DIGITAL TWINS

Digital twin technology and simulation technology share a symbiotic relationship, with aerospace industry at the forefront of this association. Essentially, simulation predicts how the aircraft works based on bank of experimental data because there are several risks involved in actual aviation using a real airplane or spaceship. In the past, simulation was only partial due to the limited-function early computers, which could only predict the aircraft maneuverability or flight safety. Currently, however, digital twins aim to observe all possible scenarios pertaining to aircraft operations by conducting various tests in advance by entering all aircraft components into the computer's virtual memory [1].

Modeling creates the mode for representing the structure and e behavior of the physical entity. The structure can be represented either in 2D (two-dimensional) or 3D (three-dimensional), and behaviors are represented as mathematical formulae, procedural steps, selective options, and algorithmic rules, so that the computer can process the data. Complex motions can be modeled based on actual data using artificial intelligence. Modeling of a physical entity or system depends on the purpose, and it is not necessary to invest unnecessary time and money to model everything. Modeling must be done as required, and it is ideal to define the objective before the structure and behavior are developed.

Physical entities' behavior can be analyzed from multiple perspectives such as time, cost, performance, sustainability, and safety, and depends on the purpose and objective. Therefore, the dimension of data modeling is structuring the data model to determine the axis and the data property. In digital twins, data modeling dimensions are used based on 3D, time, roles, and properties. First, the dimension of 3D data, which is represented in points, sides, shapes, and spaces, has already been widely used, and physical entities for digital twins must be made in 3D models. Thus, 3D is an essential modeling dimension for analysis, design, or the data model structure.

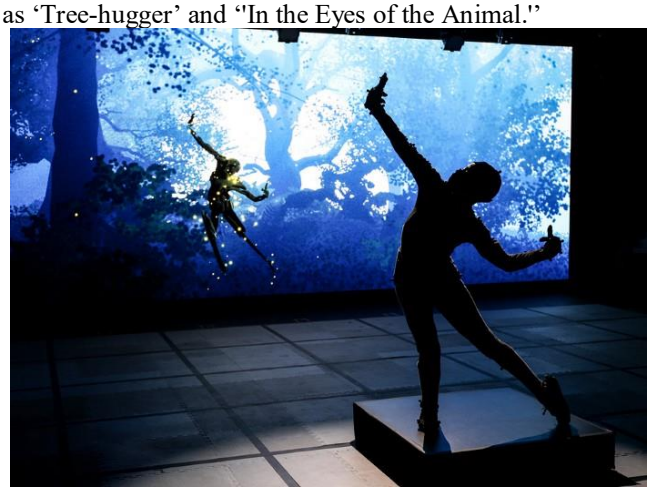
Time is another essential and clear dimension of data, as the past and future can be distinguished and the stored data can be used for root cause analysis through simulation.

Role refers to the movement, action, or behavior of a physical entity that must be implemented. A role comprises a series of behaviors that are linked to performing a certain function. Consistent with the goal, a physical entity may have multiple roles within a working domain. The same physical entity with a defined role in one domain can play a different role in another domain.

Property refers to a factor that affects the behavior of a physical entity. When a greater number of properties are identified and modeled, the more precisely the digital twin's behavior will conform with those of the physical entity [2].

2.2 CASES OF PERFORMANCE APPLYING DIGITAL TWIN TECHNOLOGY

William Shakespeare's "A Midsummer Night's Dream" is a transformational drama where humans are touched by the power of supernatural beings that rule the forest, and magical creatures learn about humans. Figure 1 shows a scene from 'DREAM', which is a novel interpretation of Shakespeare's "A Midsummer Night's Dream." This is a case where digital twins are portrayed as actors. This culmination of cutting-edge research and development (R&D) was collaboratively produced by the Royal Shakespeare Company (RSC), Manchester International Festival (MIF), the Philharmonia Orchestra of London, and Marshmallow Laser Feast (MLF), which is well known for virtual-reality-based performance using nature as topic such as 'Tree-hugger' and ''In the Eyes of the Animal.''



<Figure 1: DREAM>

The project was funded by the United Kingdom (UK) government, and it also received Epic Mega Grant, which is given by Epic Games to promote a new use of game engines in the performing arts sector. The actors wore Lycra motion-capture suits outfitted with sensors and performed live in a 7m x 7m studio specially built in Portsmouth, South England. A total of 47 cameras were used, and when a character in the play ran or moved in the forest that had been created using computer software called Unreal Engine from Epic Games, which are commonly used in movies, games, and VR, the character's movement was digitally transformed through live streaming and projected as if a fairy was being playful. Considering that the kinetic property of the physical entity in the real world was portrayed and controlled in the virtual world, this can be considered as partial application of the digital twin technology.

This case shows that digital twin technology is a tool that can expand the scope of performing arts. Essentially, the concept of a digital twin is to synchronize the changes in twins by transforming a real world physical entity such as a person, vehicle, and manufacturing equipment into a real-time virtual counterpart in the digital world, and to re-create the motion and the behavior of the real world entity in the virtual world. A certain change in a twin leads to the same change in the other twin. Depending on the width and the depth of the change, the appearance will also change by human imagination.

2.3 PERFORMANCE AND TELEPRESENCE

Since the emergence of media, the discussion on immersion and distance between reality and virtual reality has been ongoing. Long before the term, "presence" was defined, researchers across various fields of study discussed to objectify the "sensation of being there" in the process of experiencing a particular virtual reality. Presence can be also referred to as an immersive virtual environment that generates feelings of social presence depending on the field. It can be considered as "feeling as though one exists in a particular media away from the reality"[3].

In 1980, Marvin Minsky coined the term "telepresence." It highlights the possibility of manipulating a human operator to experience the feeling of being physically transported to a distant work space through a tele-operating system. It was predicted that using telepresence, it will be possible to carry out dangerous tasks in a safe and cost-effective manner, design a new healthcare and operation technology, and empower people to experience the freedom of working from home as the level of simulation technology and sense feedback technology are advanced and refined [4]. Thereafter, the term, 'telepresence' was used to refer to the "sense of being transported to the space created by technology." In other fields of study, telepresence refers to the phenomenon of a physical entity leaving its reality and living in a different space that is similar to dreams, hypnosis, and daydreams. Such spaces can be either too remote for a physical body to reach, a very dangerous place, or an imaginary space created by oneself or others.

A psychologist from Yale University wondered about the psychological state of the audience watching Shakespeare's tragedy "Othello." Why does the audience feel distressed for the protagonist in a dangerous situation even though they have read the book and know the entire story before entering the theater? He discovered that the audience's orientation of judgment has already shifted from the real world to the imaginary world called "Othello." When the audience's judgment is oriented toward the real world, the stage is simply a raised platform above the audience's seats and actors are people who perform roles based on the given dialogues. On the other hand, when the orientation of judgment is transferred to the play or when the audience become immersed in the play, the audience perceives the stage as a world and the actors as people leading the world, and their behaviors as a series of events occurring before their eyes, and not as a famous Shakespearean tragedy [5]. To create a dominating world such as dreams and hypnosis, there are several prerequisites. However, the fact that people, objects, and the events that happen between them in the virtual world can be manipulated implies the possibility that using the medium, the sender of messages can freely manipulate the thoughts and feelings of the receiver of the message.

The concept of telepresence, created by the medium, was recently specified and introduced in science fiction (sci-fi) movies such as Matrix, which is being remade into a new version of virtual reality. In computer imaging engineering, the technology that creates virtual 3D space through simulation is being deployed in medicine, mechanical engineering, and space engineering. Due to the advancement of medium technology, particularly with the emergence of virtual reality devices, the concept of telepresence has drawn the attention of many researchers and the general public. Nevertheless, the concept has long been recognized in the academic domain [6].

According to the media model proposed by Heilig in 1955, the basic function of media is to create telepresence through the extension of five senses. Does the medium that allows telepresence, enabling the recipient to dream as the sender intends, must be a bizarre helmet from a sci-fi movie?

Therefore, there is a need to re-evaluate the conditions for establishing the dreaming state.

Habit theory proposes that people's perception becomes dull when there is no change in content. When a viewer is focusing on a television screen, it is difficult for the real world objects near the TV screen to pass the information processing stage from sensory input to cognitive awareness as time passes due to no changes in content. Habit theory suggests that people create a neural model, similar to a filter, to reduce the use of brain resources for efficient information processing when detecting changeless or repetitive sensory information [6]. Once a neural model is created for a specific stimulus, then a stimulus with the same structural model is hardly detected. This ability allows people to encounter telepresence by experience and effort through multi-media such as television screens, which cannot completely block the visual and auditory senses as the virtual reality headgear, which blocks the visual and the auditory sense from the real world. The audience's reaction to media such as feeling startled, laughing, or crying with the TV characters can be considered psychological responses accompanied by telepresence based on their immersion in the media [7].

3. RESEARCH RESULT

It can be seen that efforts to understand and utilize the factors of telepresence are necessary to direct performances applying digital twins. Related studies show that the factors that cause presence can be largely classified into technical factors (objective quality of technology), user factors (individual differences), and social factors (social characteristics of technology) [8]. Due to the nature of performances targeting an unspecified number of people, excluding user factors and social factors, and classifying presence around technical factors is divided into the fidelity of sensory information, environmental-related sensory control, and ability to modify the environment [9]. 'Fidelity of sensory information' means the total amount of valid information delivered to the user. 'Environmental-related sensory control' refers to the ability of a user to adjust or control the surrounding environment by using five senses such as sight, hearing, and touch by his or her will in a virtual space. The 'ability to modify the environment' refers to the ability of a user to change the relationship with an object or others in a virtual space. Sheridan (1992) argues that when these three factors are harmonized, users can experience complete presence.

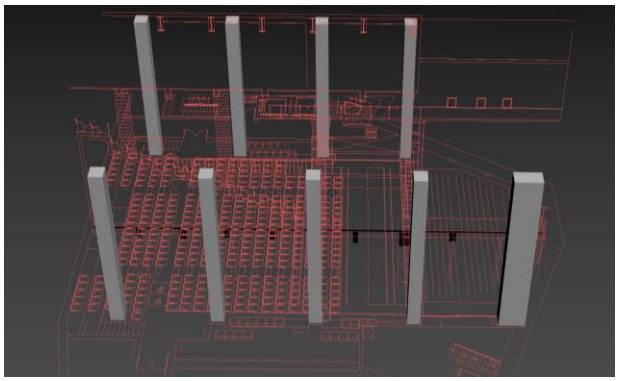
Steuer (1992) argues that the factors that determine the presence in the relationship between human experience and technology are vibrancy and interaction. Vibrant feeling is again divided into breadth and depth, which means the number of simultaneously activated sensory channels, and depth means the resolution within each sensory channel. Interactionality is divided into speed, range, and mapping. Speed means the time required for the response of the input environment, and the range represents the number of environments that can be successfully manipulated and the amount of change that can be selected within each property. Mapping means how similar actions within a virtual environment reproduce natural actions in a real environment [10]. When previous studies analyzing such factors of presence are combined, it can be seen that the technical factors of presence are mainly through improving the level of information related to the user's sensory organs or improving interactions in virtual spaces.

Recently, many cases of producing metaverse-based performance content have been announced. However, although these metaverse-based contents are being released as contents in the form of performances in a virtual reality environment, there is a limit in that only the virtual environment was considered. Digital twin technology, which is closely synchronized by matching reality and virtual, has not yet been applied in earnest in the field of cultural and performance content. Workers and experts in related fields are expected to see an era in which content that experiences telepresence by interacting with reality rather than content that simply targets virtualization will be in the spotlight. Therefore, developing digital twin-based performance content simulators requires virtual performance halls, stage sets, stage devices, and digital actors, and a real-time integrated control environment is required to closely link the functional parameters of each of these elements with reality and improve telepresence. Based on this research analysis, the development guidelines presented in this paper can be implied as four elements: first, the establishment of a digital model for performance, the middleware system for synchronization between reality and digital twin performance halls, the pre-visualization and authoring tool for planning intention, and the integrated management control system based on the concert hall.

3.1 ESTABLISHING A DIGITAL PERFORMING ARTS CENTER MODEL

To build a digital model of a performing arts center, the target of implementation must be analyzed. It is essential to derive the scope of digital twin implementation in the performing arts center, cases of implementation, service scenario, and various physical elements and circumstantial information about the performing arts center. To control, operate, and simulate the performing arts center, it is necessary to analyze the parameters of both space and stage.

Next, it is necessary to decide the Internet-of-things (IoT) sensing method and the data input/output structure of the actual performing arts center and stage props. It is also necessary to design a data management structure for analysis, management, and storage of sensed data. To create a realistic virtual environment from the virtual performing arts center, point cloud data must be created using 3D laser scan or modeled based on the actual drawings of the design (Figure 2). Props in the virtual performing arts center (lights, projectors, lasers, fog.) must be reproduced based on simulation data.



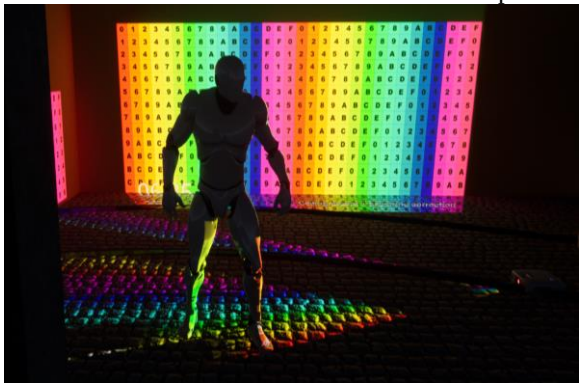
<**Figure 2:** Example of a drawing-based performing arts center>

3.2 MIDDLEWARE SYSTEM FOR SYNCHRONIZING THE REALITY AND DIGITAL TWIN PERFORMING ARTS CENTER

To synchronize the real performing arts center with the digital twin performing arts center, the functional parameters of stage props and contents control systems must be mapped on the digital platform while integrating the input/output signals and data modules. For this, an interoperable module must be implemented based on Open API, and the types of IoT sensing data and control signals must be classified.

3.3 PRODUCTION TOOLS AND VISUALIZATION OF THE PERFORMING ARTS CENTER'S DIGITAL-TWIN-BASED PERFORMANCE CONTENTS REFLECTING INTENDED PLANNING

As shown in the case of Figure 3, the performance content pre-visualization module should implement multi-projection, edge-blending, warping, and hologram image transmission result simulation of projection mapping, and illuminance simulation according to light intensity, projection angle, and color temperature of lighting. In addition, prediction simulation of special effects (laser, fog) according to the physical structure of the concert hall should be implemented.



<**Figure 3:** Example of visualizing projection mapping>

3.4 A DIGITAL-TWIN-PLATFORM-BASED COMPREHENSIVE CONTROL SYSTEM AT THE PERFORMING ARTS CENTER

As for a comprehensive control system, the following suggestions are made. To understand the configuration plan and to construct the system to control the performing arts center as well as the stage props in the performing arts center, various signal input/output interfaces such as multiple image contents, lighting control signal, sound data, and interaction data between multiple modules must be first integrated. To efficiently operate the performance contents, it is necessary to implement both the queue table function with a timeline control and multiple content management functions with automation editing. In addition, the system requires a function to visually monitor the various operating conditions about stage props, contents, systems, and use of resources. Based on this, it can perform the function of scheduling and controlling each media server.

4. CONCLUSION AND FUTURE RESEARCH

When the study's development guideline is faithfully implemented, it can provide a solution with all necessary functions for producing a performance applying the digital twin technology. Thus, it is expected that various attempts will be made with no cost burden for maximizing the vividness of performance. This can dramatically reduce trial and error in the production process, with the effect of curtailing both cost and time for production, thus enabling producers to create vivid performance contents through synchronized digital twin platform environments and a new profit model. In addition, it is expected that the guideline can be applied to diverse fields through technology modularization of concrete elements. However, this study's guideline was established based on prior studies and the fragmentary experiment; therefore, it must be revised consistent with the situation where each element is applied. It is also imperative to prove the validity of the theory through an empirical study by applying the digital twin technology in plays and musicals and investigating the responses of both performers and audiences.

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AUTHORS' CONTRIBUTIONS

Both authors contributed toward data analysis, drafting and revising the paper and agreed to be responsible for all the aspects of this work.

DECLARATION OF CONFLICTS OF INTERESTS

Authors declare that they have no conflict of interest.

DECLARATIONS

Author(s) declare that all works are original and this manuscript has not been published in any other journal.

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