A Visual Comparison Study of Ocean Wave Effect Using Real-Time Engine

Jiani Zhou
Film and Visual effects (VFX) International College, Dongseo University, Busan, South Korea
Email: moses472530@gmail.com

Abstract**—With the enhancement Computer Graphics (CG) processing capabilities, the richness of digital content creation has been significantly improved. In particular, the improvement of computer performance has considerably promoted technological innovation in the visual effects field. The practical significance of Visual effects (VFX) for digital content has gradually transformed into an essential form of expression from the beginning of auxiliary embellishment. This means that the VFX team needs to spend more time and manpower to make changes in response to the feedback, which leads to delays in the project schedule. In this paper we propose a workflow to reduce the rendering time of ocean wave effects at certain camera distances. Token two non-dynamically driven ocean effects, the image similarity of the camera views at different distances from the sea surface under the two software is compared and the time is recorded. Found image similarity in the 80%+ range and dramatically reducing rendering time has helped the VFX industry solve the long-standing problem of excessive rendering time consumption.**

Keywords**—ocean wave effect, real-time rendering, visual comparison, reduce rendering time**

I. Introduction

Traditional Digital Content Creation (DCC) software, such as Houdini and Maya, has undergone a series of functional updates for the Visual effects (VFX) sector. Notably, Game Engines (GEs) have also started to enter the VFX production field. Compared to the traditional offline rendering methods of DCC software, GEs have inherent advantages in efficiency due to real-time rendering characteristics.

In this paper, we will focus on the challenging ocean effect in the realm of special effects. We aim to compare the outputs rendered by offline rendering and real-time engines, using the same ocean wave model, standardized lighting, shading, and other variables. We'll conduct image comparisons at various camera distances, aiming for a similarity rate above 80%. This pursuit intends to reduce rendering time in special effects production by substituting GEs for DCC in real-time rendering, ultimately enhancing efficiency in special effects production.

II. Literature Review

This section will be divided into three parts: ocean waves on visual contents, image quality assessment, and pre-testing overview.

A. Ocean Waves on Visual Contents

Real-life ocean waves are difficult to define because latitudes and longitudes influence the distance between the Earth and Moon as well as tidal forces and topography influences the length and height of waves, and there are too many variables that make a real ocean or river (large fluids) uncontrollable and untraceable [1]. Extracting the core variables from the disordered, unstable and non-periodic behaviour and visualising formulae to simulate realistic water bodies has been one of the major challenges in the field of CG and game development. The most central part in water rendering is the waveform simulation technique, i.e., how to simulate realistic wave flow changes on the water surface. Mao [2] summarised the mainstream technical development of water waveform rendering in the past 50 years, in which there were several major wave implementation methods for games, animations and movies that are most closely related to our visual content. The wave implementation methods are mainly based on linear waveform superposition (Gerstner wave) for games and statistical models (Fast Fourier Transform: FFT) for movies, primarily as a spectrum and as a basis for the Houdini Ocean; meanwhile, physical-based methods (Eulerian and Lagrangian methods) are commonly used in modern times to solve the wave breaking effects. In recent years, in addition to physics-based simulations, machine learning and deep learning have also been focused on, Mario [3] has extensively explored the application of deep learning in fluid dynamics and categorized the common deep learning into physics- and data-driven methods, but also demonstrated very many limitations, such as data requirements, computational resource requirements, and lack of generalizability.

VFX delivered through the screen are often delivered without regard to real-time, and just require a lot of time to render, a lot of time is consumed in the feedback-rendering-feedback process, and often this is the reason for the inefficiencies faced by the VFX industry.

Manuscript received November 7, 2023; revised December 18, 2023; accepted January 2, 2024; published May 8, 2024.

B. *Image Quality Assessment*

In image science, a perceptually adequate measure is an old and fundamental quest. Such a measure would play a vital role in numerous image processing algorithms and applications, e.g., error criterion-based algorithmic design, such as denoising, restoration, classification and super-resolution. However, deriving such a measure is a non-trivial task [4]. The Structural Similarity Index Measure (SSIM) is a measure of how similar two digital images are. When two images are taken, one without distortion and the other with distortion, the structural similarity of the two images can be seen as a measure of the image quality of the distorted image [5]. The SSIM is a better image quality metric than the human eye can judge when compared to traditional image quality metrics, such as Peak Signal-to-Noise Ratio (PSNR) [6].

C. *Pre-testing Overview*

This section collates and summarises the content published by Zhou between 2019 and 2021. Zhou [7] employed the Vertex Animation Textures (VAT) node in Houdini to generate ocean wave effects, subsequently utilizing game development tools to import the fluid simulation as a mesh into the game engine. Although the points of the wave effect created in Houdini were 300,000, the derived positional texture was 4K and it was necessary to collate these points in a new form to import the full animation into the GE. The tests aimed at a maximum polycount limit of 45,000 for the waves created in Houdini to be imported into the GE. However, the simulation is based on the entire volume and unnecessarily wastes some values at the sides and bottom, so the VAT method is suitable for simulating water in a cup or a fountain type of fluid.

In Ref. [8], when comparing the renderings of Houdini and GEs, it was common to see that the VFX in UE4 was generally bright and lacked the appearance of shadows. After testing UE4's material and lighting properties, it was found that UE4 itself would simulate realistic lighting. After adjusting the angle and intensity of the light sources in UE4, the VFX was 80% similar to that of Houdini. Fig. 1 shows the additional SSIM comparison with different light type presented by Zhou [8] in the Future of Information and Communication Conference (FICC) oral presentation.

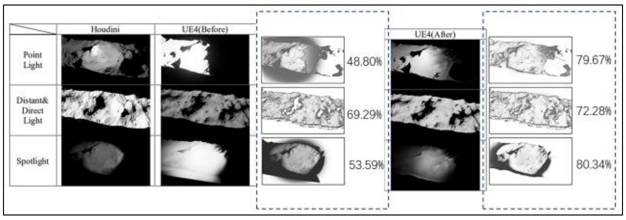


Fig. 1. Additional SSIM comparison graphs with different light type.

Subsequently, Zhou [9] tested the camera distances while the wave grid exported to UE4 was altered. The ocean effects simulated in Houdini were imported into the engine in the Alembic file format using the SSIM system to test the camera distances and compare the effects imported from Houdini by UE4. During the comparison, it was found that the Houdini and UE4 rendering differed significantly in brightness, mainly due to the different brightness of the default High Dynamic Range Image (HDRI), which further led to the lower similarity of the renders. The lower similarity of the renders was effectively improved after unilaterally increasing the light brightness of UE4. The HDRI data in the engine was adjusted to different values, but the supposed improvement was very limited (see Fig. 2), with the highest similarity reaching around 80% at a camera distance of 20 m.

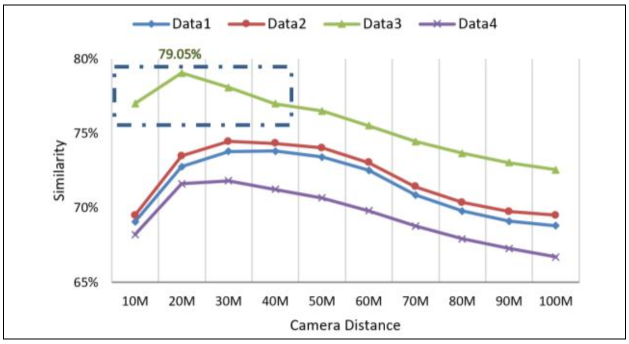


Fig. 2. Change in similarity due to HDRI brightness adjustment.

The discussion of ocean effects that started in 2019 focused on ocean waves, lighting and camera distance, with a single sample for comparison and a test environment that was not fully unified, making the comparison of each paper related but not connected. However, based on previous tests, we can summarise and make some trade-offs.

III. Materials and Methods

We propose to shorten the rendering time workflow, i.e., the ocean wave effects produced by DCC software Houdini are imported into GEs UE4 in the form of vertex animation and replacing the time-consuming offline rendering process at a certain camera distance. The proposed workflow is shown in Fig. 3.

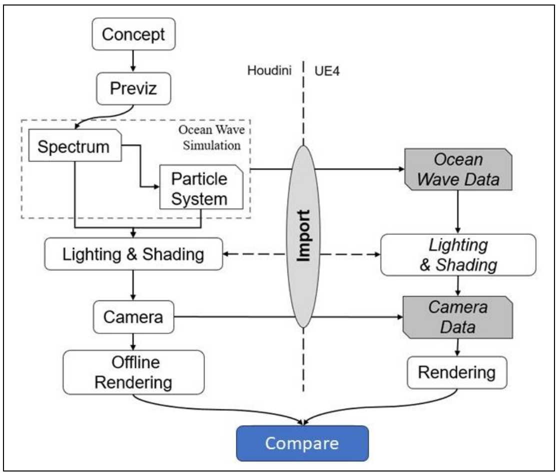


Fig. 3. Proposed ocean wave effect production workflow.

A. Ocean Wave Simulation

In Houdini, conventionally, ocean effects can be categorized into four types based on their implementation and visuals: non-dynamic, dynamic, non-conflict, and conflict. Non-dynamic ocean refers to simulating the undulation of the sea surface using a frequency spectrum. Dynamic ocean refers to using a frequency spectrum to drive particles and simulate wave effects through particle interactions. Non-conflict ocean implies no objects on the sea surface interacting with waves, while conflict ocean involves objects on the sea surface interacting with waves. Table I displays four types of ocean wave effects. These categories encompass all types of ocean wave effects. This paper will compare two ocean wave effects on different platforms, using non-dynamics as the benchmark.

TABLE I. THE FOUR OCEAN TYPES USED FOR TESTING

Ocean Type	Non-conflict	Conflict
Non-dynamics	Spectrum	Simulate the motion of a collision by projecting to find a point on the spectrum (with initial velocity)
Dynamics	Spectrum driven particles	Spectrum driven particles create realistic wave effects with moving colliders (with velocity, boats)

The ocean system we chose here comes with the Houdini menu bar- wavetank, so such tests have a certain universality and can be widely used. Sampling is set to 100×30×100 (x, y, z), subdivided into 500×500, and tested the 30fps 150frame ocean wave effect as a model. Particles driven by the spectrum can be adjusted more through the particle system, except that there is a Particle Separation setting of 0.15 involved. Table II shows the ocean simulation parameters.

TABLE II. OCEAN SIMULATION PARAMETERS

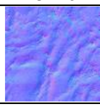
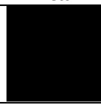
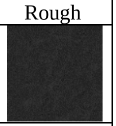
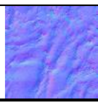
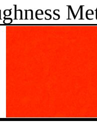
Items	Description	
Time	30fps/ 150frame	
Spectrum	Size	100×30×100
	Rows × Columns	500×500
	Speed	45
Particle System	Resolution Exponent	9
	Particle Separation	0.15

B. Lighting & Shading

In order to unify the material effects of the ocean, this thesis uses a water shader with Physical Based Rendering properties, which comes from the opensource share in Substance Share, and we exported the water shader in Substance painter according to the corresponding Houdini and UE4. We exported the water shader in the Substance Painter to the corresponding Output format for Houdini and UE4, resulting in two separate sets of maps. The maps used for the Houdini test were Base colour map, Normal map, Metal map and Rough map, while the maps used for the UE4 test were Base color map, Normal map, Occlusion Roughness Metallic. Table III shows the texture maps exported through Substance Painter.

In order to keep the test environment uniform, this thesis uses the same daytime HDRI to provide global lighting, with a specific HDRI resolution of 4K. Fig. 4 shows the HDRI source we used. The reason for choosing this HDRI is that the HDRI is shot in an environment without too much shading, the light source is from a single daylight source, and the ground material is the most common sandy material. The location is close to the sea, which is also relevant to the scenario we will be discussing for the ocean effects.

TABLE III. TEXTURE MAPS EXPORTED THROUGH SUBSTANCE PAINTER

Platform	Output Texture			
	Base color	Normal	Metal	Rough
For Houdini				
	Base color	Normal	Occlusion Roughness Metallic	
For UE4				

HDRI used 4K HDRI of <HDRI Heaven>, a free HDRI library site [10]. HDRI does not have a standard computer graphics model. <HDRI Heaven> was the most frequently used HDRI library in interviews with 3D artists at VFX Studio in Korea [11].

Fig. 4. Outdoor HDRI used in the experiment.

C. Camera

The camera replaces the camera in the real physical world in 3D software and becomes the window through which the viewer watches the film or TV production. As an important part of the production, the distance of the camera from the main object, directly affects the visual senses. For the study of the restoration of the ocean wave effect at different distances, several cameras at different distances need to be set up as tests. To further improve the accuracy of our tests, we added cameras at different distances to test the impact of camera distance on the image similarity.

A red grid is created above the sea level as a reference target, and the specification of the reference is a 1 m×1 m red grid. The distance from the camera to the sea surface is defined by adjusting the focus distance between the camera and the reference target. The number of cameras at an angle of 60° the sea level is ten, and the distance between adjacent cameras is 10 m (see Fig. 5). The focus lens of the camera is kept constant at 50 mm.

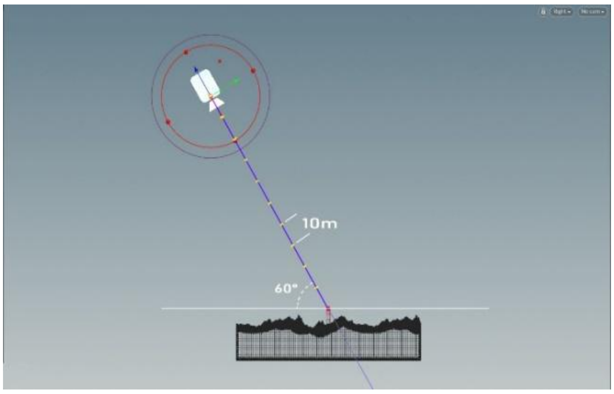


Fig. 5. Cameras, target, and sea surface's position relationship diagram.

IV. Result and Discussion

In this part, we present two scenarios, one without object and one with object, using Houdini and UE4 renders as comparison samples for Frame 30, Frame 60, Frame 90, Frame 120, and Frame 150 of the five images. In addition to this the rendering times in Houdini for the 150 frames of data. We mainly show the change curve of the similarity of the rendering graph and specific experimental data in the form of graphs, as well as the time spent in tabular form.

A. Verify the Similarity of Non-dynamic and without Object Ocean Wave Effect

Table IV shows the rendering of Frame 90 at camera distance between 10 and 100 and compares the similarity by SSIM, which shows that from 10m the similarity is as high as 90%, but as the distance increases the overall similarity tends to decline, with the furthest camera distance tested showing a 5% decrease in similarity compared to the closest camera distance. However, at frame 90, the similarity is above 84% for all the camera distances tested.

In Fig. 6, a comparison of the similarity of the five images, Frame 30, Frame 60, Frame 90, Frame 120 and Frame 150 of the 150-frame sequence shows that Frame 120 becomes a watershed. Before Frame 120, the similarity is around 85% for all cameras, but after that, there is a clear trend of decrease until Frame 150. At 150 frames, the similarity of images at different distances is mostly in the range of 78%–84%, but at camera distance of 50, the similarity is below 75%. In addition to the relatively low similarity of individual data, there is also a similarity of more than 90% at Frame 120 at camera distance of 10, reaching 91.37%.

Table V records the rendering time for 150 frames at different camera distances, non-dynamics and without object ocean wave effect. UE4's time includes the export time in Houdini and the import time to UE4.

TABLE IV. Comparison of Non-dynamics and without at Different Camera Distances in FR90

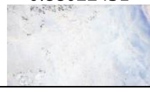
Camera Dis (m)	Houdini	UE4	SSIM
10			0.89442435 
20			0.88022451 
30			0.87654241 
40			0.87258700 
50			0.86528455 
60			0.86042887 
70			0.85813784 
80			0.85348290 
90			0.85028440 
100			0.84509301 

TABLE V. Rendering Time Comparison of Non-dynamics and without Object Ocean Wave Effect

Rendering time (sec.) / Camera Distance(m)	Non-dynamics and without object		
	Houdini	UE4	
10	4497 s	Ocean Export time: 35 s	3 s
20	4476 s		4 s
30	4521 s		4 s
40	4399 s		3 s
50	4445 s		4 s
60	4415 s	Ocean Import time: 480 s	4 s
70	4444 s		3 s
80	4467 s		3 s
90	4422 s		4 s
100	4374 s		4 s
Avg	4446 s	519 s	

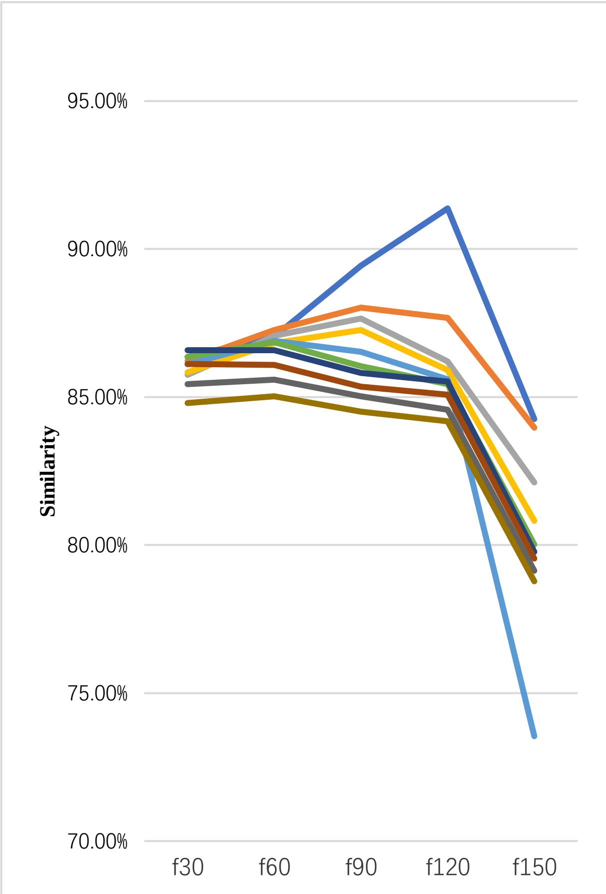


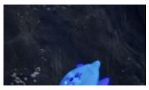
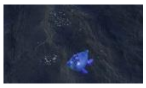
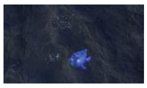
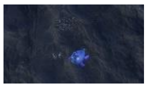
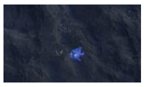
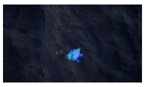
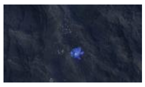
Fig. 6. Comparison of non-dynamics and without object at different camera distances.

B. *Verify the Similarity of Non-dynamic and with Object Ocean Wave Effect*

The non-dynamic nature of the simulation means that the ocean does not interact with the objects and therefore the movement of the ocean does not change due to the presence of the objects. However, the addition of new objects will have an effect on the similarity, as the lighting and material systems in Houdini and UE4 are not the same, resulting in some differences in the final visual effect of the ocean surface objects. In order to investigate the effect of this difference on the similarity of the images rendered by Houdini and UE4, we have used the same comparison method as in the previous section, extracting and using the ocean effects images at Frames 30, 60, 90, 120 and 150 as samples.

Table VI shows the rendering of Frame 90 at camera distances between 10 and 100, and the similarity is compared by SSIM, which shows that the overall similarity remains between 80% and 86%. Although the similarity decreases at all distances for this frame compared to the no-object ocean, the percentage decrease remains at 5% for the farthest camera distance tested compared to the closest camera distance. In the case of frame 90, the similarity of the images at all camera distances tested is above 80%.

TABLE VI. COMPARISON OF NON-DYNAMICS AND WITH AT DIFFERENT CAMERA DISTANCES IN FR90

Camera Dis (m)	Houdini	UE4	SSIM
10			0.85833548 
20			0.84500806 
30			0.84473846 
40			0.84059249 
50			0.83240388 
60			0.82535134 
70			0.82005225 
80			0.81403471 
90			0.81085913 
100			0.80724730 

In Fig. 7, a comparison of the similarity of the five images, Frame 30, Frame 60, Frame 90, Frame 120 and Frame 150 of the 150-frame sequence shows the increasing and decreasing trend of similarity.

Between Frame 30 and Frame 90, the deviation of similarity is less than 1% for cameras at all distances except camera distance of 60. Between 90 and 120 frames, there is a significant increase in image similarity between camera distance of 10 and 50 intervals, especially in the case of camera distance of 10, where the similarity increases by 4.82%. After 120 frames, the similarity of all camera distances shows a decreasing trend, with the highest similarity value occurring at Frame 120 in the camera distance of 10 case, with a similarity of 90.65%, and the lowest value at Frame 150 in the camera distance of 50 case, with a similarity of 73.54%. Excluding the highest and lowest values, the average of similarity is above 80%.

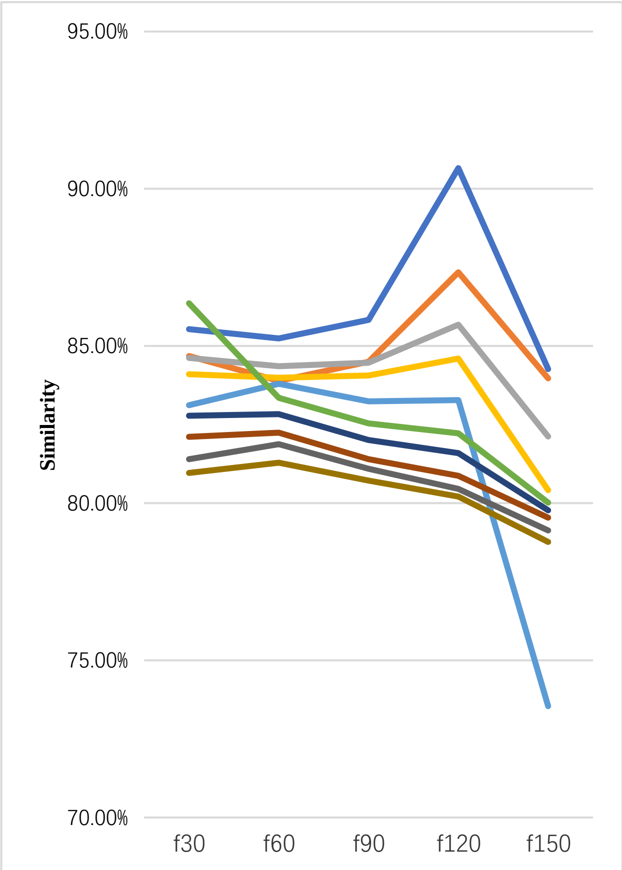


Fig. 7. Comparison of non-dynamics and with object at different camera distances.

Table VII records the rendering time for 150 frames at different camera distances, non-dynamics and with object ocean wave effect. UE4's time includes the export time in Houdini and the import time to UE4.

TABLE VI. RENDERING TIME COMPARISON OF NON-DYNAMICS AND WITH OBJECT OCEAN WAVE EFFECT

Rendering time (sec.) / Camera Distance(m)	Non-dynamics and with object		
	Houdini	**UE4**	
10	4891 s	Ocean Export	4 s
20	5092 s	time: 35 s	3 s
30	5114 s		4 s
40	5062 s	Test Object	4 s
50	5029 s	Export time:180 s	4 s
60	5038 s	Ocean Import	4 s
70	5065 s	time: 480 s	4 s
80	4854 s		3 s
90	4811 s	Test Object	4 s
100	4886 s	Import time:120 s	3 s
Avg	4984 s	819 s	

In terms of time, the engine takes much less time than offline rendering, not taking into account the proficiency of the maker, but just the time consumed. In terms of visual representation, the comparison of the similarity between different camera distances at frame 90 shows that the length of the camera distance is inversely proportional to the image similarity, i.e., the farther the camera is from the sea, the less similar the rendered image is. Camera distance should not exceed 70m, the similarity of the images under both software will be higher than 80%, is more ideal, can be replaced under certain circumstances.

V. CONCLUSION

As a leader in game engines, Unreal Engine is no longer confined to game content development but has expanded into the film and television industry. This technology now allows for the creation of film and television-quality visuals using real-time rendering.

This paper categorizes non-dynamic wave effects into two types: oceans with and without objects. The effects, using the same wave model, consistent lighting, shadows, and other variables but rendered at varying camera distances, are produced through both offline rendering and real-time engine processing. The resulting images are compared to identify intervals with over 80% similarity. Additionally, the time taken is recorded and compared. The camera distance should not exceed 70 meters, the similarity of the images under the two software will be higher than 80%, and the time required by the engine is much less than the time required for offline rendering, which can be replaced in some cases. For instance, in special effects production for sub-scenes, ultimate details are not sought, yet a natural and smooth overall visual perception is essential. Subsequently, future studies will include supplementing the remaining two dynamic-based ocean effects and providing supportive cases.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

FUNDING

This work was supported by the Dongseo University Research Fund of 2022. (DSU-20220017).

REFERENCES

[1] Cause and Effect: Tides. [Online]. Available: https://education.nationalgeographic.org/resource/cause-effect-tides/
[2] X. Y. Mao. Summary of realistic water rendering techniques. [Online]. Available: https://blog.csdn.net/poem_qianmo/article/details/103447558
[3] M. Lino, S. Fotiadis, A. A. Bharath, and C. D. Cantwell, "Current and emerging deep-learning methods for the simulation of fluid dynamics," in *Proc. R. Soc. A.*, vol 479, issue 2275, 2023. doi: https://doi.org/10.1098/rspa.2023.0058
[4] W. Zhou and A. C. Bovik, "A universal image quality index," *IEEE Transactions on Signal Processing*, vol. 9, no. 3, pp. 91–94, 2002.
[5] SSIM. [Online]. Available: https://en.wikipedia.org/wiki/Structural_similarity
[6] Image quality assessment metrics: SSIM/PSNR/MSE. [Online]. Available: https://sherlock.blog.csdn.net/article/details/78756680
[7] J. N. Zhou and T. S. Yun, "Visual restoration of ocean wave effects produced by Houdini in the engine," *Journal of Image and Graphics*, vol. 9, no. 3, pp. 109–113, 2021. doi: 10.18178/joig.9.3.109-113
[8] J. N. Zhou, K. H. Beak, B. C. Lee, and T. S. Yun, "Visual quality comparison of ocean wave effects produced by Houdini in the

engine," in *Proc. Advances in Information and Communication, FICC 2021*, Springer, Cham, 2021, vol. 1364, pp. 378–387.
[9] J. N. Zhou, K. H. Beak, and T. S Yun, "Visual quality comparison of ocean wave effects at different camera distances, smart trends in computing and communications," in *Proc. SmartCom 2021*, 2021, pp. 219–228. doi: 10.1007/978-981-16-4016-2_21
[10] HDRI HAVEN. (2021). [Online]. Available: https://hdrihaven.com/
[11] K. H. Beak, "Workflow for utilizing game engines to reduce drama VFX production time," Doctoral dissertation, Graduate School of General Studies at Dongseo University, Korea, 2021.