Intelligent Lighting Angle Dynamics for Enhanced Cinematic Shadows in VR-based Serious Games

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ABSTRACT

This study addresses the challenge of achieving optimal cinematic lighting in virtual cinematography education, particularly under the constraints of physical infrastructure. The relationship between light intensity and angle in virtual cinematography is examined using an Unreal Engine-based serious game-based learning platform. Cinematic outcomes are enhanced by fuzzifying intensity and angle lighting, with moderate intensity and medium angle improving the shadow quality. The Fuzzy Inference System (FIS) classifies shadows as cinematic, harsh, and dark. Validation using Ordinal Logistic Regression (OLR) and t-test revealed significant effects of intensity ($p=0.031$) and angle ($p<0.001$) on the lighting results. This serious game improved learning, with the experimental group's post-test scores being 42% higher than those of the control group. This technology provides scalable and immersive cinematography training without the need for expensive infrastructure. Future applications involve AI-based adaptive lighting systems for cinematography learning and pre-production. The findings show that fuzzy-based classification significantly improves the cinematic quality of shadows, contributing to scalable VR-based cinematography learning and adaptive lighting design in educational contexts.

Keywords-light intensity; angle dynamics; virtual cinematography; serious game

I. INTRODUCTION

Cinematography uses virtual technologies in the digital age and requires lighting to create atmosphere, narrative, and emotion. This transition is becoming more essential as VR technology is employed in learning and cinematography production. Cinematography lighting requires a deep understanding of light intensity, angle, and dynamics. Resource constraints, such as the high cost of technology and soundstages, make learning about lighting challenging [1]. Lighting design involves significant practice in a real context to understand optimal lighting configurations [2]. This problem is compounded by the insufficient professional facilities in many educational institutions. VR allows immersive and cost-effective lighting simulations, allowing students to explore various situations without the need for expensive infrastructure [1].

The novelty of this study lies in the integration of a serious game approach with the exploration of intensity and lighting angles in virtual cinematography. Although previous studies have discussed the use of VR for cinematography learning [1, 3, 4], very few have specifically explored how light intensity and angle affect visual narratives in the context of serious games. This approach is relevant to the industry's need to develop interactive and immersive learning methods for cinematography students, particularly in virtual environments. Furthermore, this study contributes to the development of lighting evaluation techniques by utilizing quantitative parameters, such as luminance and light distribution at specific angles, which can be measured in real time in a virtual environment [5, 6]. Research in the field of virtual cinematography has made significant progress. For example, the use of game engine technology, such as the Unreal Engine, allows realistic lighting simulations for training and production [1, 3]. In the context of learning, VR can simulate lighting setups on a virtual soundstage and is capable of replacing some functions of a physical one [1].

Although many studies have discussed the use of VR for lighting simulation [7-10], very few have focused on the aspects of light intensity and angle. This research fills this gap by providing an in-depth analysis of how these parameters affect visual outcomes in a virtual cinematography environment. This study also expands the scope of VR technology by integrating serious game-based learning elements. As proposed in previous studies, serious games enable students to explore lighting configurations safely and flexibly, enhancing engagement and creativity [11-13]. VR-based simulations allow users to engage directly and in real time with the virtual world, helping to visualize building details accurately and effectively before field installation [14]. Additionally, VR supports cinematography by allowing lighting tests before production, thereby reducing time and costs [15]. Most of these studies, however, focus on general VR lighting simulations without investigating how fuzzified light intensity and angle interactively affect the cinematic shadow perception in educational games.

This study examines light intensity, angles, and effects of virtual cinematography and develops a serious game-based cinematographic lighting curriculum. Last, it evaluates how effectively serious games provide cinematographic lighting. First, it explores light intensity, lighting angle, and virtual cinematography visuals. As in [3, 16], the Unreal Engine was used to simulate a virtual cinematography scene with customizable lighting conditions. Ordinal Logistic Regression (OLR) statistical analysis was used to determine lighting configurations and characteristics that affect shadow results in initial trials with participants [17]. Following statistical analysis, this study presents a fuzzy system approach to cinematic shadow classification to improve flexibility and precision. The fuzzy system can express continuous lighting factors, including intensity, angle, and light distribution, which are difficult to represent discretely [18, 19]. This integration provides a more accurate shadow categorization into harsh, dark, and cinematic shadows, extending the possibilities of serious game-based learning in virtual cinematography simulation. The second stage involved creating a serious game based on that exploration that explains lighting configurations through interactive scenarios [1]. Content relevance and usability are examined in the game prototype. The final evaluation of the serious game's effectiveness used the quasi-experimental method to compare the experimental group using the game with the control group using traditional methods. A t-test measures knowledge improvement using pre- and post-test results. [20].

Virtual cinematography shadow classification methods that adjust to light intensity and angle are unsolved. To fill this gap, this study provides a fuzzy logic-based intelligent system to adaptively classify cinematic shadow quality based on light intensity and angle. This research proposes an interactive, adaptive, and precise VR-based serious game-based virtual cinematography learning approach. The main contributions of this study are: (i) the development of a fuzzy logic-based classification system for cinematic shadows in a serious game VR environment, (ii) the integration of fuzzy inference with real-time simulation using Unreal Engine 5, and (iii) the validation of the model's impact on user learning through ordinal logistic regression and T-test analysis. This study's novelty lies in its integration of fuzzy logic-based adaptive lighting with real-time VR serious game learning, a combination not previously implemented in previous works focusing either solely on VR simulation or traditional cinematography instruction.

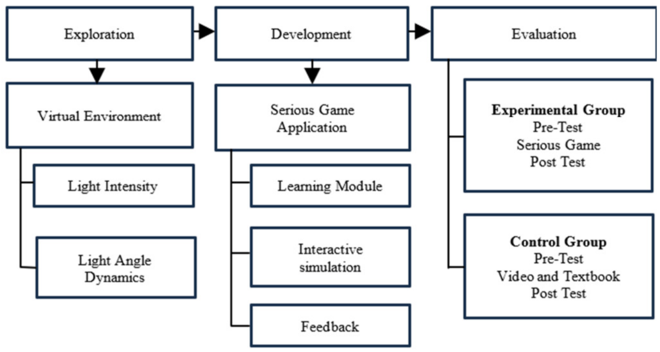

Fig. 1. Experimental scheme of this study.

II. RESEARCH METHODOLOGY

This research uses an experimental approach with three main stages: exploration, development, and evaluation. This approach aimed to provide an in-depth understanding of the relationship between light intensity and lighting angles in virtual cinematography and to develop and test the effectiveness of serious games-based learning. Quantitative and qualitative methods were used to collect comprehensive data regarding a mixed-method research for educational technology studies [21]. Figure 1 shows the research cycle. The initial exploration stage involved constructing a virtual world simulation. The Unreal Engine was used to create the virtual environment with a changeable lighting intensity and angle. Key, Fill, and Backlight were modeled and tested in the daytime (adequate ambient light) and nighttime (limited ambient light). After constructing the virtual environment, experiments were performed to examine how lighting conditions affect the visual narrative. The virtual environment was developed using Unreal Engine version 5.3, running on a system with an Intel Core i7-12700K, 64 GB RAM, and NVIDIA RTX 4080 GPU. Ray-tracing and Lumen global illumination settings enabled us to simulate realistic shadow behavior. These settings were critical to achieve photorealistic lighting effects that respond dynamically to the intensity and angle variables.

The participants were 125 design students, who had taken cinematography courses, and 8 Indonesian cinematography professionals, who were asked to evaluate daytime and nighttime lighting scenarios in a virtual environment with Non-Playable Characters (NPCs) as cinematic objects in bright settings. All participants were asked to assess aesthetic perception and visual narrative using the Likert scale. The design student participants ranged in age from 19 to 24, with a mean of 21.6 years, all had completed at least one semester of cinematography coursework, and approximately 80% had prior experience with 3D software tools. Participants were given guided instructions through a video tutorial and brief text before entering the simulation. They were asked to adjust the lighting parameters to match a reference cinematic style shown in sample images and then asked to rate their perceived visual quality using a 5-point Likert scale. Each session lasted approximately 15-20 minutes. Observing the participants' simulated interactions was the next assessment strategy. Data were analyzed using both assessment techniques. OLR determined how lighting variables affect visual outputs [22], chosen due to its ability to model the relationship between predicted and dependent variables. OLR can also capture the nonlinear effects of predictor variables on the probability of each category of the simulation results [23]. In this case, the predicted variable is the shadow of the character resulting from the lighting simulation. The dependent variable in this analysis is the shadow category, which consists of three ordinal levels: (i) Dark, (ii) Harsh, and (iii) Cinematic. These categories represent the increasing levels of visual quality in cinematic lighting outcomes.

The dynamic light angle is processed using light intensity data to adjust for day and night variables that affect cinematic shadows during the virtual environment experimentation phase. To improve the serious game's performance, the Fuzzy Inference System (FIS) classifies the shadow types based on the simulation lighting parameters and reacts dynamically when the light intensity changes from day to night. Development began with serious game design after experimentation. According to the exploration results, the serious game was built for interactive learning [24], having three main components. The learning module begins with the basics of lighting, where integration and playback precede the simulation. Second, the interactive simulation allows for variable illumination intensity and angle, recording situations with three light objects and a virtual camera. Third, real-time feedback assesses lighting settings immediately after adjustment and review.

Figure 2 illustrates the serious game framework. The serious game in this experiment was developed as a virtual reality application for the Oculus Quest 2 headset. It includes interactive simulation capabilities for educational module features and feedback or evaluation functionalities. The game starts with the user situated in a virtual setting at the Borobudur Temple cultural monument in Indonesia [25]. Game users can place the tripod lights in the ideal location, modify their intensity, and move the virtual recording camera. After setting the lights and camera location, the user can press the review button to receive a review of the lighting simulation results, which includes a text description and a score value between 1 and 5. The score is given to motivate the user to find the best lighting layout.

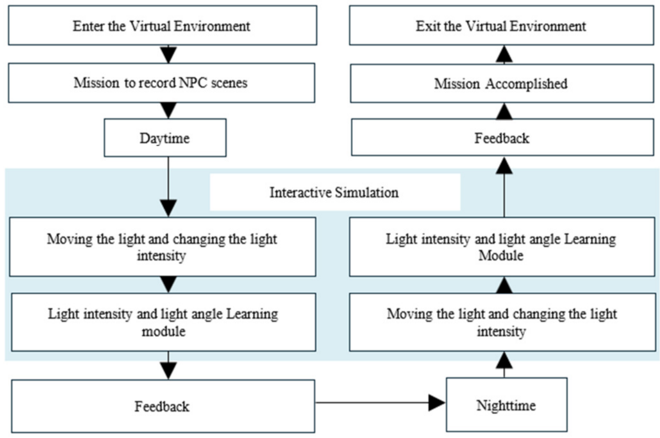

Fig. 2. Serious game scheme.

The prototype validation followed serious game design. This serious game was validated by 8 cinematography specialists after 125 student trials. This qualitative validation evaluated the usability and relevance of the content [26]. The prototype validation was followed by a research evaluation. Two groups were tested: the experimental group, involving 35 students who learned through serious games, and the control group of 35 students. The 70 students in these groups were different from the 125 participants in the experimental stage of evaluating the day and night light narrative scenario in the serious game development stage, to avoid subjectivity in the evaluation stage. All evaluation participants were distinct from the early experimental exploration phase participants in constructing the virtual world simulation. The control group viewed tutorial videos and read textbooks.

The evaluation procedure was carried out in three stages. The pre-test stage was conducted before the intervention to measure the initial understanding. In the intervention stage, the experimental group used games for 3 sessions, while the control group learned using traditional methods. The next stage was the post-test conducted to measure the improvement in understanding after the intervention [27]. The evaluation instrument used a Likert scale to measure learning experiences, followed by a comprehension test instrument. The next instrument was a semi-structured interview to explore in-depth experiences from the experimental group [27]. From the evaluation results, two types of data were obtained: quantitative and qualitative. A t-test was used to compare the pre- and post-tests in the experimental group [28]. Meanwhile, for qualitative data, interview data were used and analyzed to identify themes related to the effectiveness of the game. This research followed ethical research guidelines, including informed consent for participants, data confidentiality, and the use of data solely for scientific research purposes.

III. RESULTS AND DISCUSSION

Figure 3 shows an interactive simulation of the Unreal Engine learning module. To explain the lighting principles, the interface displays the light intensity, angles, and key light, fill light, and back light setups. The Unreal Engine creates a realistic virtual environment for direct lighting simulations to demonstrate how lighting factors affect images. Figure 4 shows the real-time feedback serious game from this study. The technology behind this feature allows students to rapidly check their lighting settings. Light intensity and angle simulations were evaluated with OLR and improved with fuzzy logic. The assessment ratings were 1-5. Figure 3 shows the best cinematic lighting with low light diffusion and harsh or dark shadows. The Unreal Engine automatically compares the user settings with Figures 5(a,b). In the exploration phase test, the first simulations determined the lighting position and intensity.

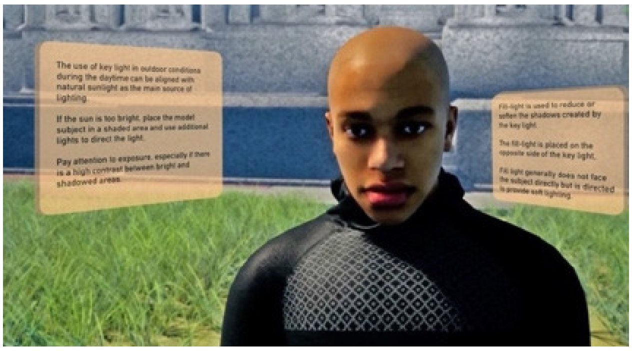

Fig. 3. Integration of the learning modules showing user-adjustable key, fill, and backlight intensities at various angle presets (30-90°).

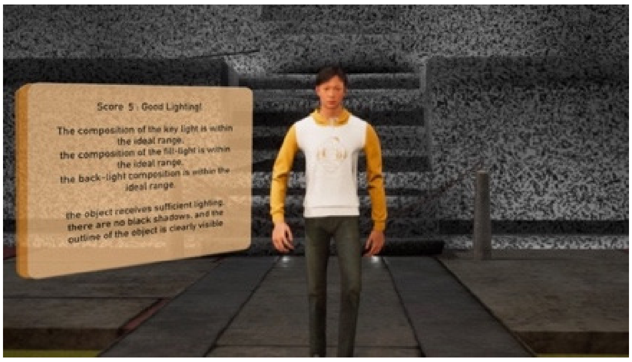

Fig. 4. Feedback interface presenting real-time evaluation of the simulated lighting angle (preset 45°) and intensity (3.5) applied to the virtual scene.

Fuzzification converts numerical data into fuzzy representations for system variable interrelationship analysis. Light intensity and angle were separated into three fuzzy value ranges for this study. Low values were 0-2.5, medium values were 2.5-4.5, and high values were 3.5-the measured maximum. Low light angle values were 0-30°, medium 20-70°, and high 60° to the highest measured value. Fuzzification analyses the intensity levels and light angles using the triangle membership functions to determine the fuzzy category membership. The fuzzification results suggest that an intensity value of 3.25 dominated the medium category with a modest contribution to the high category. Its membership degree was 0.00 in the low category, 0.75 in the medium category, and 0.25 in the high category. The light angle of 44.01° dominated the medium category, with a membership degree of 0.00 in the low, 0.88 in the medium, and 0.12 in the high. Table II shows the fuzzified data, displaying membership degrees by intensity and light angle. These investigations demonstrate that the degrees of fuzzy category membership fluctuate based on the numerical values. A membership degree of 0.34 and an intensity value of 2.66 substantially influenced the low category and prevailed over the medium category with a value of 0.66. This value was not classified as high. The angle was 17.74°, indicating a predominance in the low group with a membership degree of 0.75, 0.25 in medium, and no contribution in high. The fuzzy membership functions were defined using triangular distributions based on expert tuning from the simulation outputs. The system used a Mamdani-type inference mechanism with three inputs: light intensity, angle, and time of day, producing shadow categories as output. Algorithm 1 shows the pseudo-code of the fuzzy classification system.

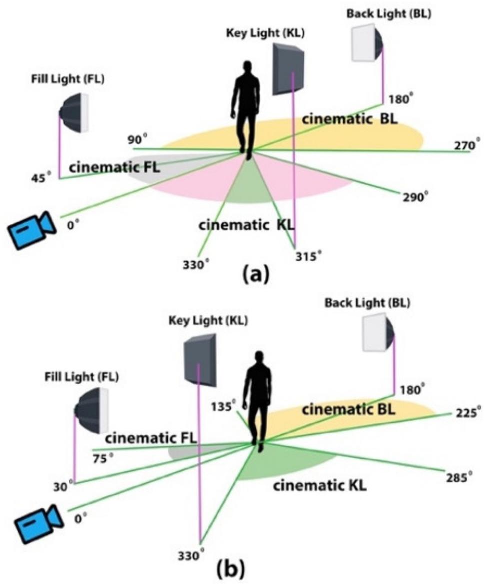

Fig. 5. (a): Lighting layout results in the daytime simulation with cinematic position of KL 330-315°, FL 45°, BL 90-270°. (b): Lighting layout results in the night simulation with cinematic position of KL 285-330°, FL 30-75°, BL 135-225°.

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Algorithm 1: Fuzzy Classification System
INPUT: intensity, angle
FUZZIFY: Apply membership functions to
input variables
RULE EVALUATION:
  IF intensity is High AND angle is Low
  THEN shadow is Harsh
  IF intensity is Medium AND angle is
  Medium THEN shadow is Cinematic
  ...
AGGREGATE: Combine fuzzy output sets
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DEFUZZIFY: Compute crisp output using the
centroid method
OUTPUT: shadow category
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TABLE I. FUZZY INFERENCE RULE BASE

Intensity	Angle	Output shadow category
Low	Low	Dark
Low	Medium	Cinematic
Low	High	Cinematic
Medium	Low	Harsh
Medium	Medium	Cinematic
Medium	High	Cinematic
High	Low	Harsh
High	Medium	Harsh
High	High	Dark

Table I presents the complete fuzzy rule base used for shadow classification and defines how combinations of light intensity (Low, Medium, High) and angle (Low, Medium, High) produce specific shadow outputs: Dark, Harsh, or Cinematic. This structured rule set is essential for the fuzzy inference engine to consistently determine shadow quality based on dynamic input parameters. The rules reflect expert knowledge derived from exploratory simulations and were implemented using a Mamdani-type fuzzy system. This table enables readers to understand the logic behind the system's classification decisions and supports reproducibility in similar educational cinematography systems.

TABLE II. MEMBERSHIP DEGREES BY INTENSITY AND LIGHT ANGLE

Parameter	Numerical value	Low membership	Medium membership	High membership
Intensity	3.25	0.00	0.75	0.25
Intensity	2.66	0.34	0.66	0.00
Angle	44.01	0.00	0.88	0.12
Angle	17.74	0.75	0.25	0.00

Figure 6 shows that the Low group dominates at low light intensity, peaking at 0 and falling to 2.5. Medium runs from 2.5 to 3.5. The High category dominates intensity values above 3.5. Figure 7 shows a similar light angle pattern: low 0-30°, medium 20-70°, and high above 60°. The fuzzy system can use numerical data to create fuzzy representations that accurately represent the input values and their proportional contributions to the fuzzy categories. Fuzzy inference requires this approach when light intensity, angle, and shadow classifications are associated. The Mamdani fuzzy rules relate the input variables to the output in the fuzzy inference. Fuzzy principles describe temporal conditions, light intensity, light angle, and shadow classifications. Low angle, strong intensity, and daylight cast cinematic shadows. Nighttime, low intensity, and high-angle cast dismal shadows. The fuzzy inference results from different beginning inputs are shown in Table III, which displays the fuzzy-rule-based output shadow category membership. These data reveal that certain intensity and angle combinations dominate certain shadow categories. For example, an intensity of 3.25 and an angle of 44.01° dominate the Harsh category with a membership degree of 0.75, whereas an intensity of 1.75 and an angle of 65.00° dominate the Dark group with a very high membership degree of 0.90.

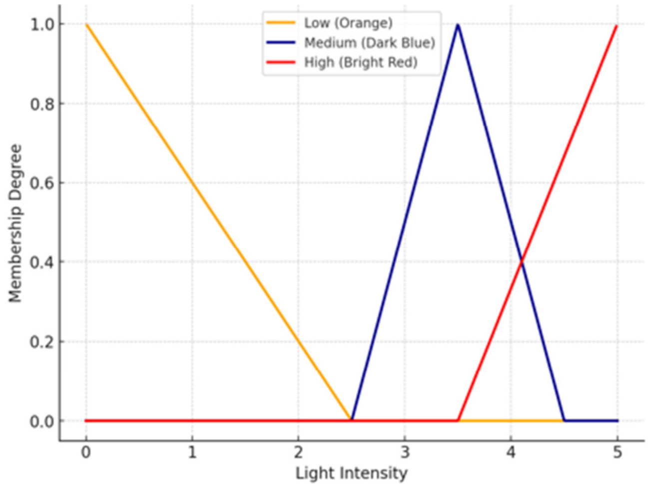

Fig. 6. Membership function for the light intensity variable.

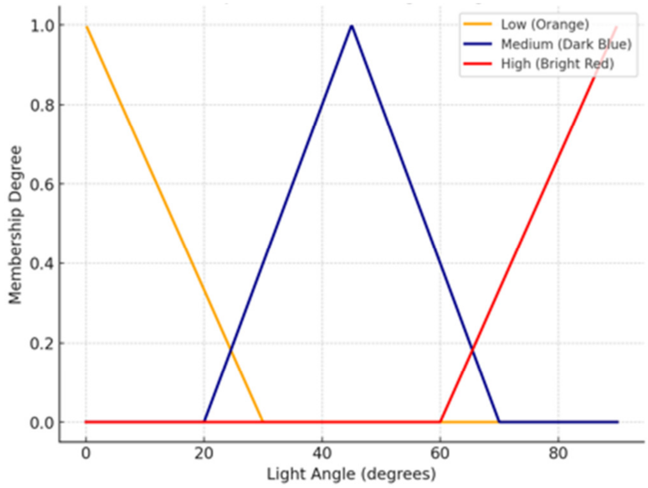

Fig. 7. Membership function for the light angle variable.

TABLE III. FUZZY INFERENCE RESULTS FOR SHADOW CATEGORIES

Intensity	Angle	Cinematic	Dark	Harsh
3.25	44.01	0.00	0.00	0.75
2.66	43.42	0.34	0.00	0.66
1.75	65.00	0.00	0.90	0.10

These membership functions indicate how the intensity and angle values are fuzzified. For instance, a light intensity of 2.66 contributes 66% to the Medium category and 34% to the Low category. Practically, this helps to determine whether lighting configurations produce cinematic or harsh shadows, which is crucial for training optimal lighting setups.

This study determines the crisp value from the weighted average of membership degrees using the centroid fuzzification method. Crisp values classify shadows as Cinematic up to 33.3, Dark between 33.3 and 66.6, and Harsh above 66.6. The fuzzification data results are shown in Table IV. The crisp-value distribution fits the fuzzy criteria. Harsh is always high intensity and low angles, while Cinematic is low intensity and high angles. Crisp values were derived using the centroid method due to its ability to provide more accurate and smooth transition results in real-time simulations, especially for continuous lighting variables. This simulation illustrates that the fuzzy system can capture complex input-output relationships and produce cinematography and lighting effects. The results of the lighting layout tests carried out under simulated day and night conditions produced two outcomes with quite different lighting styles. Figure 5(a) displays the intensity and angle of lighting in daytime conditions, where if the camera is at a 0° angle from the object, the ideal area of the Key Light (KL) is 290° to 0° with the cinematic key light angle of 315° to 330°, the ideal area of the Fill Light (FL) is 0° to 90° with the cinematic fill light at 45°, and the cinematic Backlight (BL) area in daylight conditions is 90° to 270°. Figure 5(b) shows the intensity and angle of light under nighttime conditions, indicating that the cinematic key light area is 285-330°, the fill light area is 30-75°, and the backlight area is 135-225°.

TABLE IV. DEFUZZIFICATION RESULTS AND SHADOW CATEGORIES

Intensity	Angle	Crisp value	Shadow category
3.25	44.01	74.99	Harsh
2.66	43.42	74.99	Harsh
1.75	65.00	31.20	Cinematic
2.88	30.00	62.81	Dark

As shown in Figure 8, the cinematic shadows have clean edges, excellent gradation, and adequate contrast, producing an artistically attractive visual depth while preserving the object features, including the shadows on the eyes, forehead, and frontal face of the NPC character. Harsh shadows possess defined edges and significant contrast and are often deemed less visually appealing, as they obscure details in darker regions, such as shadows on the NPC's chin. Dark shadows contain areas of absolute darkness devoid of visible detail, as exemplified by shadows on the NPC's shoulders and abdomen.

In Table V, the OLR results illustrate how intensity, angle, elements (key light=1, fill light=2, backlight=3), and conditions (day=1, normal=2) affect cinematography in an Unreal Engine-designed virtual world. OLR was used to examine cinematography quality, which comprises three hierarchical categories: Dark Shadow (code=1), Harsh Shadow (code=2), and Cinematic Shadow (code=3). A significance of 0.031 was discovered for the intensity variable analysis. This score is below 0.05, showing that light intensity influences the virtual cinematography. The intensity coefficient is -0.934, which can be interpreted as exp(-0.934)=2.5. The reduction in light intensity by one unit reduces the quality of the cinematography by 2.5. The significance of the angle variable is 0.000. Based on this value, the light angle substantially affects cinematography. The light angle ordinal regression is -0.093, exp(-0.093)=1.09. The film quality is reduced by 1.09 times as the light angle variable decreases. Analysis of the element variable code =1 (key light) shows a significance value of 0.000 and a coefficient of -12.03. This value is less than 0.05, indicating that it is an essential element that significantly affects cinematography. The key light coefficient is -12.03, with exp(12.03)=16711. This score indicates that the key light reduces the cinematography quality compared to the backlight.

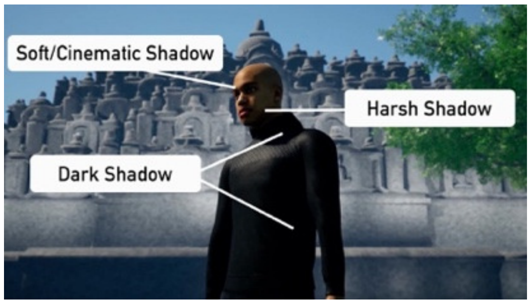

Fig. 8. Shadow criteria from the lighting composition.

Analysis of the variable element code =2 (fill light) showed a significance value of 0.000 and a coefficient of -12.871. This number is less than 0.05, indicating that fill light affects the cinematography quality. The fill light coefficient is -12.871, with exp(12.871)=3888. This indicates that fill light reduces the cinematography quality compared to backlight. The condition variable analysis yielded 0.001 significance, which is less than 0.05, indicating that the day conditions affect cinematography quality. The day condition coefficient is -3.27, with exp(-3.27)=26. Daytime cinematography is inferior to that at night. This is possible during the day as sunlight, directed light, skylight, and sky environment greatly affect Unreal Engine cinematic scene lighting, making fill light essential. Fill light consistently casts cinematic shadows. The OLR results demonstrate that even a small change in lighting intensity or angle significantly impacts perceived shadow quality.

TABLE V. ORDINAL LOGISTIC REGRESSION RESULT

Parameter estimates								
		Estimate	Std. error	Wald	df	Sig.	95% Confidence interval	
							Lower bound	Upper bound
Threshold	[Shadow = 1.00]	-23.261	4.195	30.751	1	.000	-31.482	-15.039
	[Shadow = 2.00]	-20.719	4.066	25.968	1	.000	-28.688	-12.750
Location	Intensity	-.934	.432	4.673	1	.031	-1.781	-.087
	Angle	-.093	.019	23.654	1	.000	-.130	-.055
	[Element=1.00]	-12.030	2.803	18.425	1	.000	-17.524	-6.537
	[Element=2.00]	-12.871	2.443	27.746	1	.000	-17.659	-8.082
	[Element=3.00]	0^a	.	.	0	.	.	.
	[Condition=1,00]	-3.270	.956	11.703	1	.001	-5.144	-1.397
	[Condition=2,00]	0^a	.	.	0	.	.	.
Link function: Logit								

A decrease in intensity of one unit reduces the probability of cinematic shadow by a factor of 2.5. This implies that learners must be trained to finely calibrate light variables to achieve the desired visual outcomes. Additionally, the strong significance of the fill and key light elements emphasizes their dominant influence, providing key teaching insights for lighting configuration training. The fill light enhances object features and adds dimension. The study shows that nighttime cinematic shadows are the best. Since ambient light is rare in virtual filming, additional lighting is essential. Nightlight is brighter than daylight, producing depth and clarity. In serious game creation and VR training, nighttime illumination modeling is essential. Movie shadows and narratives suffer from bright lighting. As in movie lighting, intensity must be controlled to maintain contrast without overexposure [25]. Cinematic shadows are reduced using extremely wide lighting angles. Focal lighting angles improve the images. Changes in lighting angles improve soft lighting and cinematic shadows. These findings confirm that virtual environments and cinematography require lighting dynamics [29].

TABLE VI. T-TEST RESULTS

Group	Pre-test mean	Post-test mean	SD pre-test	SD post-test	N
Experimental	60	85	5	7	35
Control	58	70	6	8	35

The t-test results in Table VI show that the participants found the game useful, easy, and instructive. Real-time feedback and interactive learning modules blended well with the best interactive experience score and lighting simulations and real-time feedback improved instruction. Most of the participants noted that real-time feedback made it easier to understand the effect of lighting changes. Several respondents also highlighted that the cinematic shadow classification improved their decision-making during lighting setups, especially under low-light conditions. Although the sample size per group (N=35) is moderately small, the central limit theorem justifies the use of the t-test due to the approximately normal distribution of test scores. Learning-based games engage users and teach complicated concepts [30]. Its high content relevance grade means that its lighting conditions are useful for cinematography production. The game-playing (experimental) group scored higher post-test values, outperforming those of the control group. Serious games develop cinematographic lighting foundations better than classroom education. Post-test ratings from the experimental group imply that serious games encourage learning. VR-based learning involves interaction and real-time simulation [31]. Comparing that approach with the control group indicates its advantage over traditional learning. This research explains how to optimize virtual lighting intensity and angle for the narrative. Nighttime high-intensity and optimal angles add visual richness to important games and training simulations. Table VII compares this study with others to show their unique contributions, methods, and applications. In [3,4], VR lighting students were engaged using Metashadow. These findings are expanded by this investigation. The FIS classifies cinematic shadows by light intensity, angle, and time, unlike earlier investigations. This is the first significant game-based learning study to classify dark, rough, and cinematic shadows using a fuzzy framework. However, in [5], virtual lighting was analyzed in real time without fuzzy rule-based learning. Interactive VR visualization requires processing efficiency, as shown in real-time volumetric illumination visualization with spherical harmonics [29]. This method allows real-time view and light source switching, although the pre-render computation time might be long, especially at high resolutions. This study's fuzzy method classifies direct lighting without pre-rendering computation and is sensitive and flexible. This research used the Unreal Engine as an interactive simulation platform with a fuzzy system to assess illumination settings in real time for more accurate and adaptive feedback than threshold-based methods. The VR-based serious game improved learning efficacy and is consistent with previous research showing that VR improves user comprehension and technical skills through interactive simulations that replicate real-life situations [14]. The dataset used consisted of 125 lighting configuration logs from student experiments and eight expert evaluations of lighting quality, including intensity, angle, and shadow classification annotations. All datasets were recorded through Unreal Engine's gameplay logging and exported in CSV format.

TABLE VII. COMPARISON WITH PREVIOUS RESEARCH RESULTS

Study	Main approach	Main contribution	Advantages	Limitations	Quantitative result
[4] (2024)	VR simulation for cinematography lighting and "Metashadow"	Enhancing the learning experience through VR	Enhances immersion, creativity, and learning compared to traditional methods	Not focused on shadow classification, evaluation limited to 24 students and 6 experts	Significant improvement in immersion and creativity vs. PowerPoint (qualitative)
[1] (2023)	Virtual soundstage simulation	Provided a virtual lighting stage for VR cinematography learning	Reduces cost and risk, enables personalized learning	Does not involve fuzzy rule-based analysis, preliminary study	Qualitative potential shown; no numerical data available
[5] (2020)	Real-time lighting evaluation	Design framework and research agenda for VR in education	Comprehensive educational VR analysis across domains	Does not support game-based learning, not focused on lighting; no primary experiment	No specific quantitative results (review-based)
[29] (2024)	Real-time volumetric illumination in VR using Spherical Harmonics (SH)	Interactive volumetric design framework and research agenda for VR in education	High-efficiency interactive visualization for real-time viewpoint and light source adjustments	Scientific visualization focus, not educational lighting	System enhances rendering efficiency, lacks user test metrics
Current	VR + Fuzzy for shadow classification	Fuzzy-based cinematic shadow classification	Combination of fuzzy and VR for the adaptive simulation	The scale of the experiment was relatively small	Crisp values: Cinematic: 31.20, Harsh: 74.99, Dark: 62.81

IV. CONCLUSION

The main contribution of this study is a fuzzy logic-based classification of cinematic shadows implemented in real-time VR simulations, bridging computational lighting models with experiential learning platforms. Unlike previous studies, this integration allows real-time feedback for learners based on expert-informed classification rules. This study effectively used fuzzy logic with serious game-based learning to enhance cinematic lighting in a VR setting using the Unreal Engine. The main novelty of this research lies in the development of an intelligent FIS that adaptively classifies shadow quality into cinematic, dark, or harsh, depending on the intensity and angle of illumination. Empirical fuzzification results indicate that low intensity and high angle yield cinematic shadows (crisp value 31.20), but high intensity and low angle result in sharp shadows (crisp value 74.99). The OLR analysis demonstrated that light intensity ($p=0.031$) and lighting angle ($p<0.001$) greatly affected the quality of cinematic shadows. The originality of this study comes from the integration of fuzzy logic and OLR methods within the framework of VR-based serious games.

However, several shortcomings must be rectified in subsequent research. The proposed enhancements include increasing the experiment's scale by incorporating additional participants to strengthen the generalization of the findings and introducing more variations in temporal settings and lighting scenarios to investigate a wider spectrum of lighting dynamics. Moreover, it is advisable to incorporate Machine Learning (ML) technology to deliver adaptive recommendations for lighting settings, thus enhancing the system's interactivity and precision. This research significantly advances the creation of effective and adaptive interactive learning techniques in virtual cinematography. The Unreal Engine project files, fuzzy logic configuration scripts, and anonymized user evaluation data are available at [32].

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