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Unreal Engine Meets Computer Vision : Technological Evolution and Trends

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Abstract

This study examines the integration of Unreal Engine with computer vision technologies and emphasizes its evolution from a game engine into a platform that supports synthetic data generation and real-time simulation. Tools such as UnrealCV, CARLA, and OmniSCV have advanced the automation and efficiency of high-quality synthetic data generation, which has been applied to areas such as autonomous driving, robotic vision, and smart city planning. This study provides a structured analysis of the technological progression of Unreal Engine and emphasizes its applicability in diverse research and industrial contexts. Unreal Engine's customizable environments and advanced rendering capabilities help to overcome challenges in real-world data collection while they enable cost-effective and scalable solutions. This study can expand to make a comparison with other game engines and performance evaluations between synthetic and real-world data.

Keyword : Unreal Engine, Computer Vision, Game Engine, Synthetic Data, Real-Time Simulation

1. Introduction

Unreal Engine has established itself as a versatile platform widely used in the gaming industry and research fields such as computer vision, artificial intelligence, and simulation. It offers advanced capabilities and includes real-time rendering, high-quality physically based rendering (PBR), and advanced synthetic data generation. Tools such as UnrealCV, CARLA, and other domain-specific frameworks have demonstrated its potential in autonomous driving, robotic vision, and related domains. However, most studies focus on specific applications, with limited exploration of Unreal Engine's full integration into computer vision research. A detailed review can guide researchers in using Unreal Engine to tackle emerging challenges in this field.

This study addresses this gap through a systematic analysis of the chronological progression of Unreal

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Engine's integration into computer vision. By examining this progression, it offers an in-depth exploration of Unreal Engine's transformation from a gaming tool into a versatile platform for computer vision research. This analysis highlights the importance of understanding the engine's historical and technological trajectory to better utilize its capabilities for solving complex real-world problems.

2. Theoretical Background

Unreal Engine, along with Unity, is one of the most widely used game development engines. It offers tools like Lumen for lighting, Blueprint for visual scripting, Niagara for particle effects, and Chaos Physics for collisions [1]. These tools help developers create high-quality graphics and optimized gameplay, while visual programming and real-time previews enhance modeling efficiency. Its interactivity and compatibility with 3D models make it a versatile platform for various applications [2][3].

Unreal Engine first contributed to computer vision research in 2016 with UnrealCV, a plugin that used game environments to create synthetic images and ground truth data for training and testing computer vision algorithms [4]. UnrealGT, introduced in 2019, added the ability to generate training data for object detection and V-SLAM [5]. In 2023, ReplicAnt further improved model training for object detection and tracking, which contributed to advancements in autonomous driving and robotic vision [6].

BMW utilized Unreal Engine 5 for Digital Twin modeling to optimize factory design, while Disney Plus's 'The Mandalorian' employed Virtual Production technology with LED wall projections to improve both filming efficiency and quality [7][8]. These advancements highlight the evolution of Unreal Engine from a basic rendering tool into an integrated platform for real-time computer vision applications.

Computer vision uses human perception as a model to extract meaningful insights from digital images. This process supports decision-making in areas such as urban analysis, IoT integration, extended reality, and behavioral analysis for accessibility improvements [9-13].

Synthetic data is created in virtual environments to supplement or replace real-world data. Unreal Engine generates labeled datasets such as RGB images, depth maps, and segmentation masks. This process reduces costs and removes barriers in real-world data collection. Synthetic data is crucial for applications like autonomous driving, robotic vision, behavior analysis, and reinforcement learning [14].

3. Methodology

This study reviewed research papers to analyze how Unreal Engine and computer vision technologies were used together. To examine trends before 2016, when their combined use became widespread, the study searched Google Scholar with the keyword “Unreal Engine” and included papers published between 2010 and 2015. From this process, 24 papers were selected based on their focus on the characteristics and usage trends of Unreal Engine.

After 2016, the study focused on cases where Unreal Engine and computer vision technologies were integrated. Papers containing both “Unreal Engine” and “Computer Vision” as keywords were collected. Among these, 45 papers were selected for final analysis based on abstracts that described Unreal Engine's applications and the role of computer vision technologies. Priority was given to papers with detailed descriptions and clear examples of how these technologies contributed.

The selected papers were analyzed to identify the main applications of Unreal Engine and the roles of computer vision technologies. The findings were arranged chronologically to highlight trends in technological development and application domains. This study examines the evolution of research that combines Unreal Engine and computer vision and explores how Unreal Engine has transitioned from a game engine to a versatile platform for research and development. The selection criteria are outlined in [Table 1].

[Table 1] Summary of Collected Papers and Criteria by Period

Publication Period	2010 - 2015	2016 - Present
Search Keywords	Unreal Engine	Unreal Engine, Computer Vision (both keywords explicitly included)
Selection Criteria	Papers that focus on the characteristics and usage trends of Unreal Engine	Papers with abstracts clearly describing Unreal Engine's use and computer vision contributions
Number of Papers	24	45

4. The Development of Unreal Engine's Integration with Computer Vision

4.1 General Use of Unreal Engine (~2015)

Game engines are high-performance software packages that utilize rendering pipelines, specialized data structures, and optimized technologies to visualize textured 3D objects, scenes, and entire 3D worlds in real time [15]. Unreal Engine, developed by Epic Games, is one of the most prominent game engines and has been widely licensed to accelerate game development. It features a script-based visual programming environment that enables intuitive and efficient control of virtual objects [16][17]. Continuous advancements in its physics and rendering engines, enhanced graphics capabilities, and support for particle systems have made it instrumental in developing iconic games such as Gears of

War, Mass Effect, BioShock, Deus Ex, and Rainbow Six: Vegas [18].

Beyond its use in gaming, Unreal Engine has been applied to various simulations such as virtual mining systems, emergency response in nuclear power plants, GIS-based 3D terrain visualization and robotic modeling [19-23]. These applications have utilized its advanced material systems, accurate lighting effects, and real-time rendering features. Its free availability and support for visual scripting have further contributed to its widespread adoption by researchers [19-23].

4.2 Early Stages of Utilizing Unreal Engine for Synthetic Data (2014~2016)

Following the release of Unreal Engine 4 in 2014, attempts to generate realistic datasets using synthetic data began. Unreal Engine provided high-quality Physically Based Rendering (PBR), which allowed researchers to generate realistic synthetic images. However, the process lacked automation, requiring researchers to manually adjust the data [24]. Although efforts were made to generate large-scale annotated data using commercial game data, these endeavors required complex techniques like Detouring and debugging tools such as RenderDoc, which made data extraction and processing cumbersome [25]. The research from this period clearly highlighted the need for greater efficiency and automation in synthetic data generation.

4.3 Period of Expansion - Emergence of UnrealCV (2016)

Efforts to improve automation and efficiency in synthetic data generation gained momentum in 2016, with UnrealCV emerging as a key tool. UnrealCV, the first open-source tool connecting Unreal Engine with computer vision research, automated the creation of object bounding boxes, depth maps, and segmentation masks. Researchers used UnrealCV to generate images in virtual environments, control cameras, and test various lighting and rendering settings [26]. The tool also provided an intuitive environment creation feature, which allowed researchers to design new environments or use pre-built binaries for quick setup [27]. These features simplified the data generation process and created an experimental environment for various vision tasks. Moreover, UnrealCV supported integration with major AI frameworks, such as Caffe and TensorFlow, which enabled seamless use of synthetic data in model training workflows [28]. This streamlined the entire process, from data generation to model training and evaluation, which improved research efficiency.

Synthetic data has been critical in robotic vision, where simulations demonstrated its importance in evaluating vision systems and its broad applicability in computer vision research [29]. Tools like

UnrealCV automated data generation, which allowed synthetic data to replace or supplement real data in various tasks [27][28]. This foundation paved the way for CARLA, an autonomous driving simulator that expanded UnrealCV's capabilities and advanced autonomous driving research.

4.4. Period of Growth: Development of AI Applications and Synthetic Data Tools (2017~2019)

After 2017, simulation environments for drones and autonomous vehicles advanced quickly, which established synthetic data as a core foundation for AI and machine learning research. Unreal Engine, which supports high-quality Physically Based Rendering (PBR) and interaction, became a key tool for training and validating vision-based algorithms. One study demonstrated its effectiveness in supporting autonomous UAV-based moving object tracking and map learning in urban and suburban environments [30]. Another study emphasized its use in extending real datasets through realistic synthetic data [31].

During this period, research in virtual environments addressed key vision problems, such as object detection, depth estimation, and action analysis. Some simulation frameworks supported drone and multi-robot simulations, which allowed researchers to evaluate the performance of computer vision algorithms in realistic environments. These frameworks also simulated complex human behaviors in both indoor and outdoor settings for tasks like behavior recognition and event detection [32][33].

Since 2018, advancements in automating synthetic data generation have allowed for the creation of large-scale datasets for neural network training and evaluation [5]. Research in activity analysis generated detailed attribute data and explored the transition to real data, while improvements in crowd behavior simulation made it easier to handle crowd dynamics and collision avoidance [34][35]. Additionally, studies in autonomous systems used virtual environments to validate autonomous vehicle algorithms and estimate optical flow-based trajectories. Some generated synthetic data to detect power cable faults and used MATLAB for computer vision experiments [36][37]. Other studies tested motion detection algorithms for vision-based mobile robots in various real-world scenarios at low cost [38].

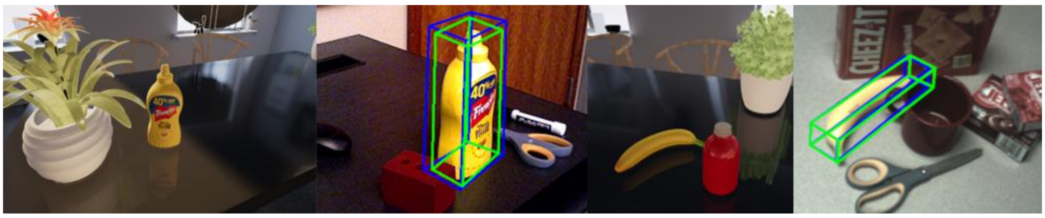
4.5. Unreal Engine in the 2020s: Expanding Beyond Game Development (2020s)

Unreal Engine has expanded its applications beyond game development and has become a valuable tool in non-gaming industries during the 2020s. In agriculture, it has been used to simulate crop growth and environmental conditions, which allows the generation of synthetic data for tasks like crop identification, health assessment, and yield prediction [39]. A precision agriculture robot simulator developed with Unreal Engine 5 further demonstrated its potential by producing photorealistic data that enhanced efficiency through 3D point cloud reconstruction [40].

In transportation, Unreal Engine played a key role in Driver-in-the-Loop simulations and enabled the testing of ADAS features such as object detection and collision prevention under diverse conditions. It also contributed to automated traffic systems by improving flow optimization and accident response in virtual urban environments [41][42]. Similarly, in aviation, Unreal Engine supported UAV research by providing data for AI improvement and enabling critical tasks like object detection, route planning, and urban mapping [43][44].

The construction sector has also benefited from Unreal Engine, where it was used to simulate architectural environments. This application supported object detection training and promoted advancements in automation. Additionally, its ability to model hazardous scenarios has proven effective in enhancing worker safety [45][46]. For crisis response, Unreal Engine facilitated rescue missions through realistic earthquake simulations and contributed to security planning by modeling terrorism scenarios in sensitive areas [47][49].

In space exploration, Unreal Engine supported the simulation of lunar environments for autonomous robots and generated photorealistic spacecraft images to improve component recognition. IIts Physically Based Rendering technology also addressed the challenges of domain adaptation by reducing the gap between synthetic and real data, which enhanced AI performance and transparency [50-55].



[Fig. 1] Training Synthetic Data with Two Objects Generated by UnrealROX+

Tools such as OmniSCV and UnrealROX+ have expanded functionality for applications in SLAM, object detection, and depth estimation [14][56], while AI Playground has enhanced AI performance by analyzing lighting and resolution variations [57], and NOVA has improved the quality and diversity of synthetic data [58]. [Fig. 1] shows synthetic data training with two distinct objects generated using UnrealROX+. Unreal Engine's versatility also extended to UAV research and dynamic simulations, which facilitated advancements in object tracking and action recognition [59][60]. In the entertainment industry, it has shown its potential by improving automated testing, soft body simulation accuracy, and real-time rendering. Technologies like Metahuman creation and reinforcement learning pipelines have further highlighted Unreal Engine's transformative impact on game development and simulation-based learning [61-65]. These topics are summarized in [Table 2].

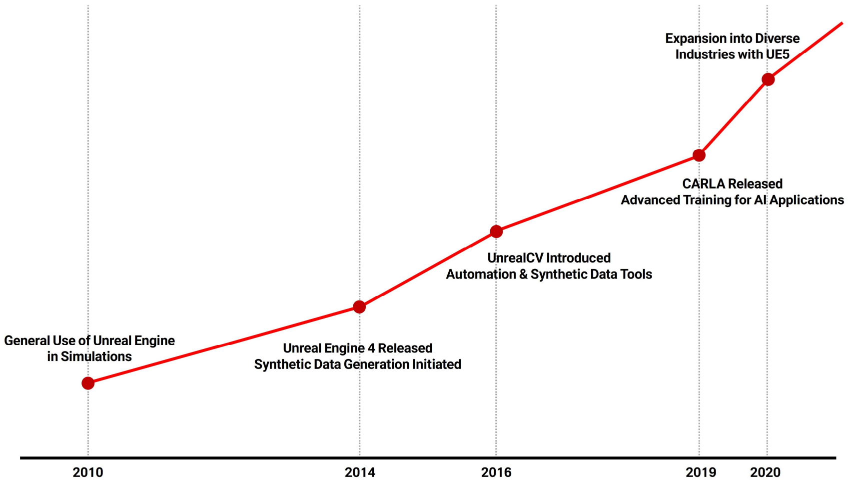
[Table 2] Unreal Engine and Computer Vision Uses in the 2020s

Industry	Applications	Key Applications and Tools
Agriculture and Environment	▪ Simulating crop growth and conditions ▪ Supporting crop identification, health assessment, and yield prediction ▪ Developing precision agriculture robots	▪ Photorealistic data generation ▪ 3D point cloud reconstruction
Roads and Traffic	▪ Testing ADAS under diverse road conditions ▪ Simulating smart traffic management systems	▪ Driver-in-the-Loop simulation ▪ Computer vision-based traffic control systems
Aviation	▪ UAV data collection and flight simulation ▪ Object detection, route planning, and mapping ▪ Improving AI algorithm performance	▪ Urban environment simulation ▪ AI-driven aerospace advancements
Construction	▪ BIM-integrated architectural and urban simulations ▪ Simulating hazardous scenarios for risk assessment and worker safety improvement	▪ BIM-integrated AI systems ▪ Synthetic data generation for hazard prediction
Crisis Response	▪ Simulating earthquake and disaster scenarios ▪ Supporting rescue missions and environmental recovery ▪ Simulating security scenarios in sensitive areas	▪ RESenv for rescue planning ▪ Virtual environments for security planning
Space Exploration	▪ Simulating lunar environments for autonomous systems ▪ Generating photorealistic spacecraft component images	▪ Synthetic data generation for lunar research ▪ Spacecraft component recognition models
AI and Data Tools	▪ Advancing domain adaptation for bridging synthetic and real-world data ▪ Enhancing AI data analysis and quality control	▪ Tools for automated data generation (UnrealCV, CARLA) ▪ OmniSCV and UnrealROX+ for SLAM and semantic segmentation
Entertainment and Media	▪ Behavioral analysis and automated testing ▪ Creating 3D scenes with NeRF technology ▪ Improving real-time rendering with Gaussian Splatting	▪ Soft-body simulation research ▪ Real-time rendering improvements

5. Discussion

[Fig. 2] summarizes the development history of Unreal Engine and computer vision. Synthetic data is a crucial resource in computer vision and various industries. In AI model training, it supplements or replaces real-world data, which helps overcome challenges in data collection and annotation while enabling efficient scenario simulation [66].

Recent studies show a shift from large dataset production to reducing domain gaps between synthetic and real data and improving model generalization. Datasets like Cloth-Changing Unreal Person (CCUP) highlight the potential of scenario-specific synthetic data and the need for innovative pipelines [67].



[Fig. 2] Timeline of Unreal Engine's Integration with Computer Vision

Unreal Engine and similar tools are expected to expand beyond gaming into sectors like agriculture, healthcare, autonomous driving, and entertainment and the arts [11][68][69]. This approach has proven effective in Driver-in-the-Loop simulations, UAV research, and urban modeling [30][38][40].

In conclusion, the integration of synthetic data and Unreal Engine is expected to grow in non-gaming vision applications. As new technologies emerge, they will offer researchers and professionals unprecedented opportunities for innovation and progress.

6. Conclusion

The integration of Unreal Engine and computer vision has driven significant advancements in synthetic data generation and real-time simulation. Tools like UnrealCV, CARLA, and OmniSCV have enhanced synthetic data generation by automating processes and improving data quality. Unreal Engine's influence extends beyond gaming into industries such as agriculture, construction, crisis response, and aviation.

The combination of Unreal Engine and synthetic data has promoted key developments in computer vision and industrial applications. Future research must focus on narrowing the gap between synthetic and real data and developing tools to enhance AI applicability in various sectors. This study analyzed Unreal Engine's role in synthetic data generation and its integration with computer vision. It emphasizes its transformation into a platform for research and development, particularly in domain adaptation and model generalization. However, this study is limited by its exclusive focus on Unreal Engine, without comparisons to other engines like Unity or detailed analyses of synthetic versus real data performance. Future research can address these gaps and contribute to a deeper understanding of the industrial and research impact of synthetic data technologies.

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