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IMPROVED RENDERING METHOD OF SKELETAL ANIMATION BASED ON CONTROL POINTS

During the research, analysis and improvement of visualization methods for human skeleton animation in the Blender 3D environment were carried out, particularly based on control points for limb movement control. Current research builds on an investigation of skeletal animation methods, focusing on the use of control points for managing limb movements. It thoroughly considers the relevance and significance of the chosen topic and its impact on creating realistic and effective visual projects in the modern world of digital graphics and reproduction. The research includes an analysis of the impact of sample quantity on the frame transitions smoothness and the rendering time to achieve a balance between quality and efficiency. It also involves refining the method through adaptation for execution on a GPU graphic processor.

Studied Blender 3D engines (EEEVE and Cycles) allowed to analyze rendering performance on different computational architectures – CPU and GPU depending on sample values (60 and 128), frame number (250, 500, and 1000), and also the frame frequency at a rate of 30 frames per second. The goal of the research was an achievement of optimal balance between performance and realism in animation details reproduction. Three experiments were done to reach this goal and make the following conclusion: graphical processor utilization through the Cycles engine demonstrated a rendering acceleration of 43%, ranging from minimal to maximum settings. In the same time, the acceleration of the hybrid system via the EEVEE engine showed an acceleration of 15.2% only.

By combining two important methods - frame-by-frame animation and using different sample counts - it was achieved a significant improvement in the quality and realism of displaying motion and dynamics of skeletal animation. Such an approach allowed a significant reduction in the rendering time of skeletal animation.

Keywords: animation, computer graphics, image, three-dimensional image, acceleration, graphics processor, computing, Blender

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ВДОСКОНАЛЕНИЙ МЕТОД ВІЗУАЛІЗАЦІЇ СКЕЛЕТНОЇ АНІМАЦІЇ НА ОСНОВІ КОНТРОЛЬНИХ ТОЧОК

В ході дослідження було проведено аналіз та вдосконалення методів візуалізації анімації скелету людини в середовищі Blender 3D, зокрема на основі контрольних точок для управління рухом кінцівок. В даній роботі проведено дослідження методів скелетної анімації, базуючись на використанні контрольних точок, для керування рухом кінцівок. Докладно розглядається затребуваність та актуальність обраної теми та її вплив на створення реалістичних та ефективних візуальних проектів у сучасному світі цифрової графіки та відтворення. Робота включає аналіз впливу кількості семплів на плавність переходів між кадрами та час виконання візуалізації для досягнення балансу між якістю та ефективністю, а також вдосконалення методу за рахунок адаптації для виконання на графічному процесорі GPU.

Досліджувані двигуни Blender 3D (EEEVE та Cycles) дали змогу проаналізувати продуктивність рендерингу на різних обчислювальних архітектурах – CPU та GPU у залежності від значеннях семплів, що становили 60 та 128, кількості кадрів, що становили 250, 500 та 1000, а також частота кадрів із позначкою 30 кадрів на секунду. Метою дослідження було досягнення оптимального балансу між швидкодією та реалістичністю у відтворенні деталей анімації. Для досягнення мети було проведено три експерименти, результати яких показали наступне: використання графічного процесора за допомогою двигуна Cycles показало результат прискорення рендерингу на 43%, починаючи з мінімальних показників до максимального, в той час як прискорення гібридної системи за допомогою двигуна EEVEE показало прискорення лише на 15,2%.

Завдяки поєднанню двох важливих методів - покадрової анімації та використання різної кількості вибірок - було досягнуто значного покращення якості та реалістичності відображення руху та динаміки скелетної анімації. Такий підхід дозволив значно скоротити час рендерингу скелетної анімації.

Ключові слова: анімація, компютерна графіка, зображення, тривимірне зображення, прискорення, графічний процесор, обчислення, Blender

Introduction

Skeletal animation is an important and influential sphere within the world of computer graphics and visual effects. It takes a crucial role in creating impressive visual representations, whether it's for video games, animated films, architectural visualization, or scientific research, VR [1-2]. Exactly skeletal animation is responsible for creating realistic movement and expressions in digital objects, making this topic important and relevant for many practical spheres (figure 1).

Current research explores methods of visualizing the skeletal animation process, based on the use of control points to manage limb movements [3]. It examines the importance of this topic and its impact on creating realistic and effective visual projects in the modern world of digital graphics [4-6] and reproduction.

Skeletal animation is a technique in computer animation, where the representation of a character consists of two parts: an external appearance (handled by the polygonal mesh) and a tree of interconnected bones (skeleton) necessary for animating the mesh [6-7]. The skeleton is a hierarchical structure of connected bones, used to control the movement of objects in a 3D environment. One of the differences between image recognition or image analysis systems and 3D skeletal animation systems is that there is no need for deep learning of noise reduction techniques [8]

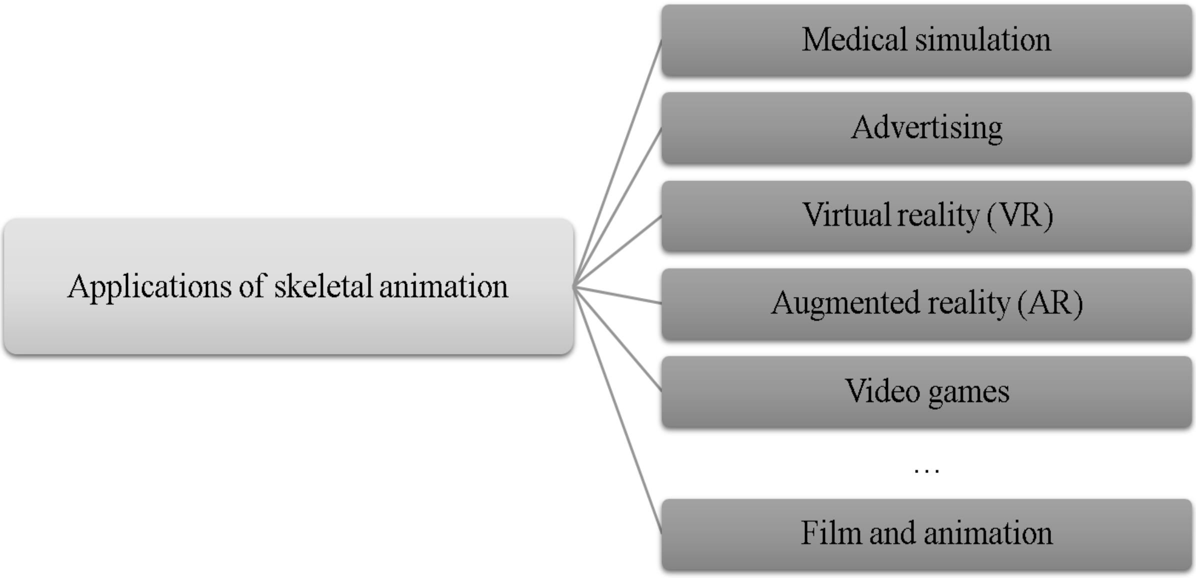


Fig.1. The significance of skeletal animation in various applied fields

Besides the technique is typically used for animating people and organic objects in general, its purpose is to make the animation process more intuitive, allowing the same methods to practically control the deformation of any object - either it a door, a spoon, or a galaxy.

Inverse kinematics allows creation of more natural movements of objects, by controlling the limbs and skeleton joints (figure 2) [9-10].

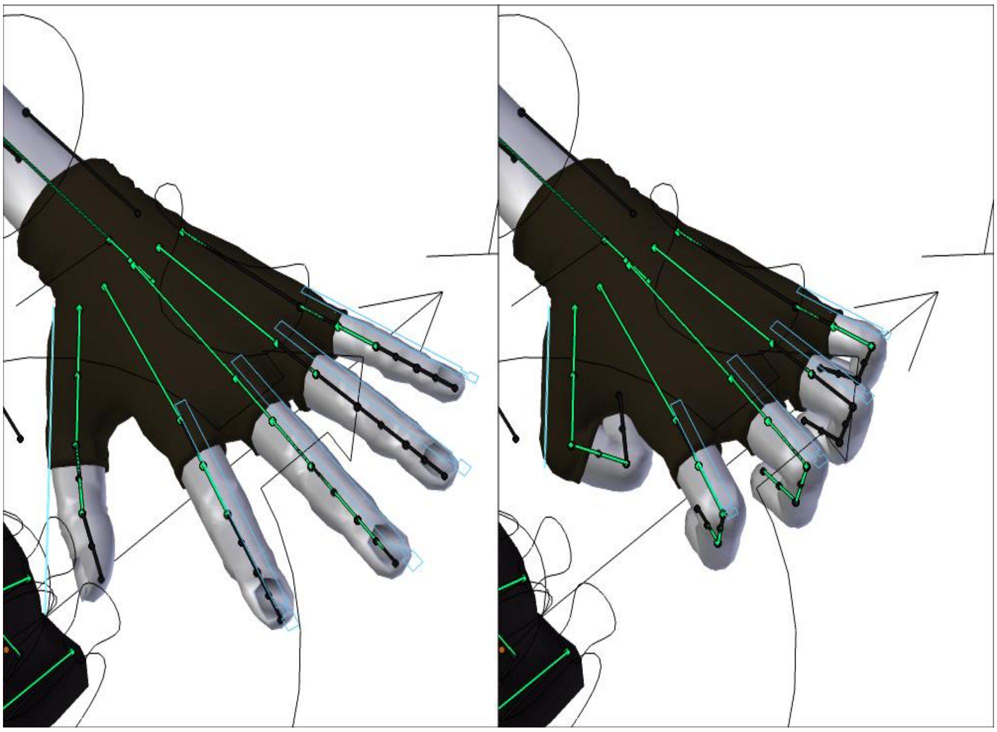


Fig. 2. Existing techniques of skeletal animation

The tools for skeletal animation include:

– keyframes determine the moments in time, where the positions and rotations of the skeleton bones are set;

– animation curves define how the position and rotation of the skeleton change between keyframes;
– controllers are important components of skeleton animation in 3D graphics. Some controllers may be linked to others, creating a hierarchical structure for skeleton control. Interpolation determines how controllers move between keyframes to create smooth and realistic motion;
– animation environments such as Blender, Autodesk Maya, Cinema 4D provide tools for skeleton animation.

Related works

The selection of an editor for the future research is based on the following criteria (Table 1):
– cost and availability;
– functionality;
– animation system;
– integration and rendering;
– hardware requirements.

Blender 3D: Blender is completely free and open-source software, available to all users. It is a multifunctional editor that includes tools for 3D modeling, texturing, animation, rendering, and many other objectives [9-10]. Blender also has a powerful skeletal animation system with support for inverse kinematics (IK) and bone systems. It provides the capability to perform rendering and compositing in a single software tool. And it can run on various computers, including less powerful ones, due to its low resource requirements.

Autodesk Maya, Cinema 4D, ZBrush, 3ds Max are commercial software, and the cost of licenses can be high for individual users or studios. All of them have a wide range of functionality, but they may require an integration with other programs to perform specific tasks (e.g., for rendering and compositing). They may require powerful workstations for efficient work with large and complex projects.

Autodesk Maya тalso has a powerful animation system with built-in tools for realistic object movement.

Cinema 4D provides tools for creating complex animations using inverse kinematics.

ZBrush, та 3DS MAX: These programs also support animation, but their main function is modeling and texturing.

Table 1

Comparative characteristics of the editors

Editor	Cost	Functionality	Animation system	Integration and rendering	Hardware requirements
Blender 3D	Free	3D-modeling, texturing, animations, rendering	Skeletal animation system	Rendering and compositing	Low resource requirements
Autodesk Maya	71 263.20 uah.	Require an integration with other programs	Skeletal animation system	Require an integration with other programs	More powerful workstations
Cinema 4D	32 784,00 uah.	Require an integration with other programs	Skeletal animation system	Require an integration with other programs	More powerful workstations
ZBrush	17 336.59 uah.	Require an integration with other programs	Skeletal animation system	Require an integration with other programs	More powerful workstations
3ds Max	64 681,00 uah.	Require an integration with other programs	Skeletal animation system	Require an integration with other programs	More powerful workstations

Creating a 3D model of a human skeleton based on control points in Blender 3D is a process that involves the utilization of various tools and techniques to create an animated skeletal structure, which serves as the basis for realistic character animation.

Various elements are used in this process. Such as the armature (skeleton), control points, and objects that are connected between each other, for creating dynamic and natural movements of the character in virtual space. Control points play an important role, allowing animators to effectively control the movement and behavior of the skeleton.

Using Blender 3D for this process provides a wide range of tools for modeling armatures, placing control points, and interacting with animated objects. Blender's integrated features simplify the rigging and animation processes, allowing animators to focus on the creative process of creating lively and expressive characters.

Such kind of modeling opens up broad possibilities for creating realistic animations, from gaming entertainment content to virtual architectural tours or even scientific visualizations.

In conclusion, for the purpose of the research, the choice of editor for 3D skeletal animation was settled on Blender 3D, as it is a free and powerful tool. However, other programs also have their advantages and may be ideal for specific tasks and professional requirements.

Aims and tasks of the work

The purpose of this research is to improve the method of visualizing human skeletal animation in the Blender 3D environment based on control points by combining frame-by-frame animation and sampling.

To achieve this goal, the following issues have to be covered:

- problem area review;
- adaptation of the proposed approach for accelerated skeleton animation on different types of computing systems (massively parallel system and hybrid computing system);
- experimental investigation to determine the impact on the smoothness of transitions between frames by the number of samples;
- experimental investigation to determine the impact on the visualization execution time by the number of samples;
- proposed solution testing;
- obtained results analysis.

The further development of the research involves the exploration of skeleton animation algorithms. Expanding the capabilities of the adapted method for different types of animations and scenarios. Studying the potential of using machine learning and artificial intelligence to improve animation quality. Exploring new optimization approaches for further productivity enhancement.

Results and Discussion

Creating a 3D model of the human skeleton based on control points in Blender 3D is a task that involves several key stages (figure 3) [14]. The stages of this process are described below in detail:

- model and interface preparation;
- armature (skeleton) creation;
- control system development;
- rigging and testing.

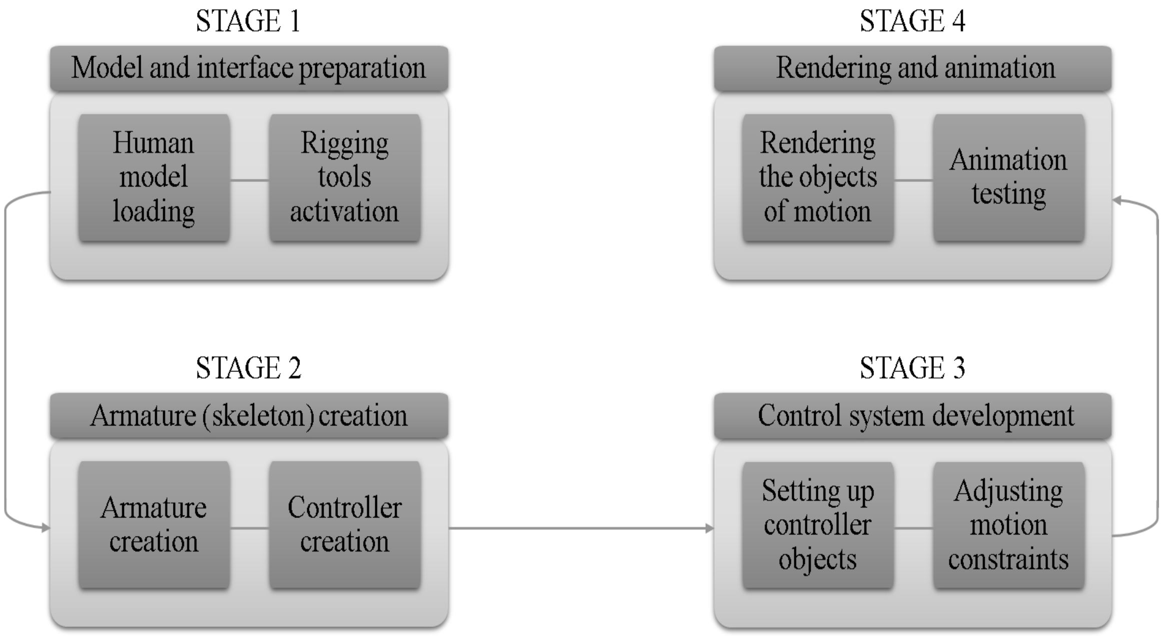


Fig. 3. Stages of skeleton animation development

The first stage of the process of creating a 3D model of the human skeleton in Blender 3D involves preparation, which includes loading the human model and activating the necessary tools.

This stage aims to create a basic environment for further work, where the model will be ready for creating skeletal armature and placing control points. The loaded model and prepared environment will form the foundation for the subsequent stages of the animation process in Blender 3D.

In the second stage of the creation process, the character's movement structure is determined, by the creation of the primary armature or skeleton (figure 4).

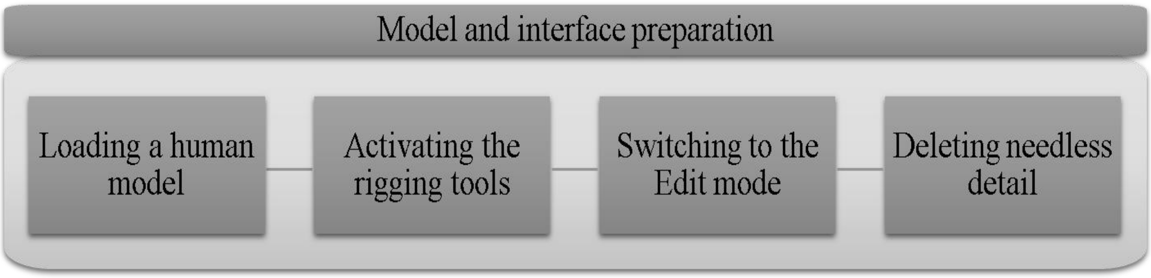


Fig.4. Model and interface preparation stage

This stage aims to create the basic skeletal structure and control points that will be used for further animation work. The armature defines the basic form of movement, while the control points allow active control of the character's behavior and expressions.

The third stage of the 3D model creation process of the human skeleton in Blender 3D, involves control system development. It includes setting up control objects, configuring motion constraints, and preparing for the subsequent stages of animation (figure 5).

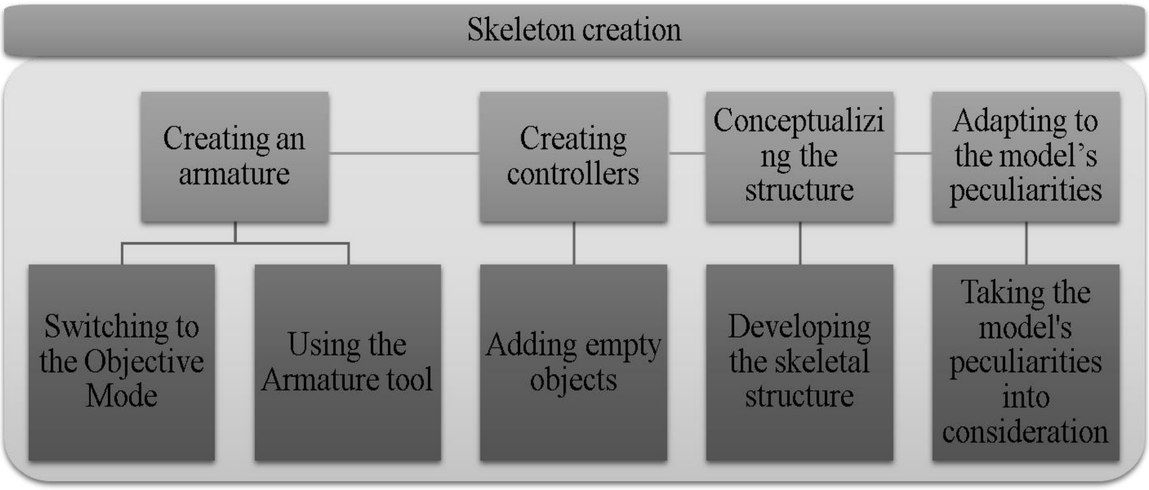


Fig. 5. Skeleton creation stage

This stage is aimed at creating a stable control system that allows animators to effectively control character movements. Establishing a connection between control points and the armature is crucial for further animation and provides the opportunity for creative influence on the liveliness and expressiveness of the character.

The fourth stage of this process involves an animation and detailed motion tuning. This stage allows the keyframes assignment, to create smooth transitions between movements, and enhance the animation with additional effects (figure 6).

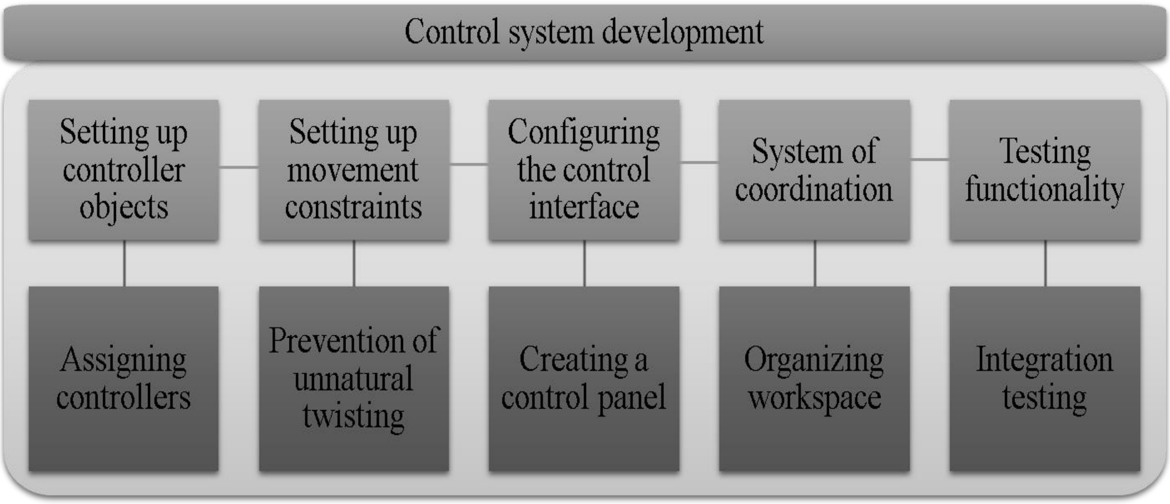


Fig. 6. Control system development stage

The animation and movement adjustment stage is the final stage in the animation process and allows create lively and expressive movement for the 3D model of the human skeleton (figure 7). Careful motion tuning and the use of various effects add realism and dynamism to the animation.

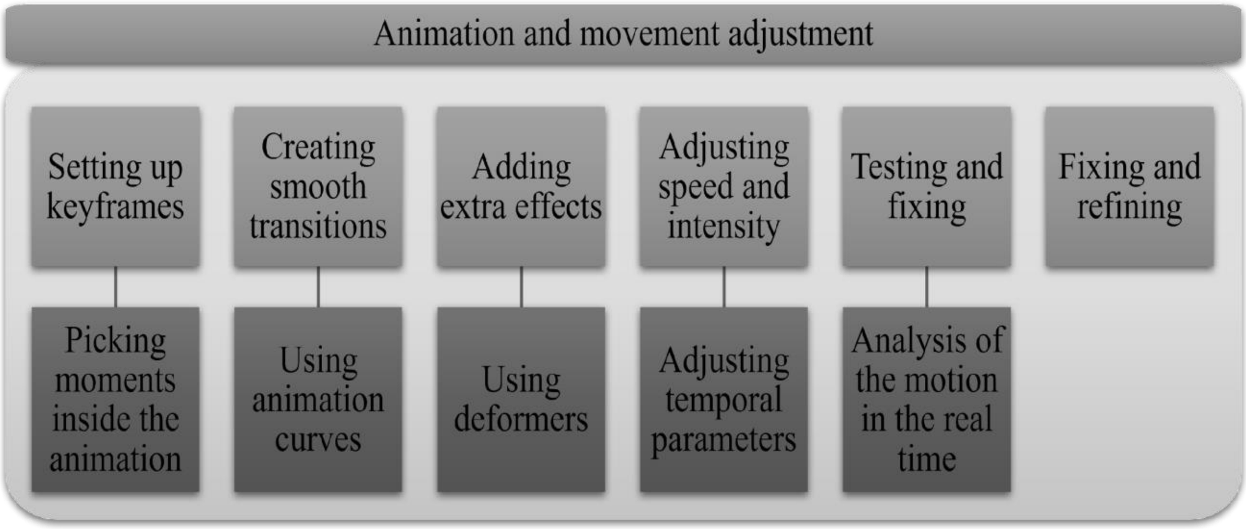


Fig. 7. Animation and movement adjustment stage

The performance of skeleton animation visualization depends on the processor speed, integration and compatibility of graphic cards, driver compatibility, and RAM, among other factors. The advantage of rendering on the CPU is the ability to access a large amount of RAM memory, allowing the user to easily render scenes with a large amount of data. The advantage of rendering on the GPU is the ability to free up CPU resources for other tasks while providing high rendering performance. It's possible due to support of special graphics processing technologies such as CUDA or OpenCL, which efficiently utilize the computational power of the GPU for rendering, using a significantly larger number of cores and parallel computing units.

When processing complex scenes (many objects, detailed geometry, lighting and shadows, textures and materials), the GPU provides a more advantageous rendering time difference.

One of the main challenges of the traditional method of skeleton animation in Blender 3D is the increased rendering time, especially for large or detailed scenes. This problem is important to address, as significant time costs can limit the creative process and productivity.

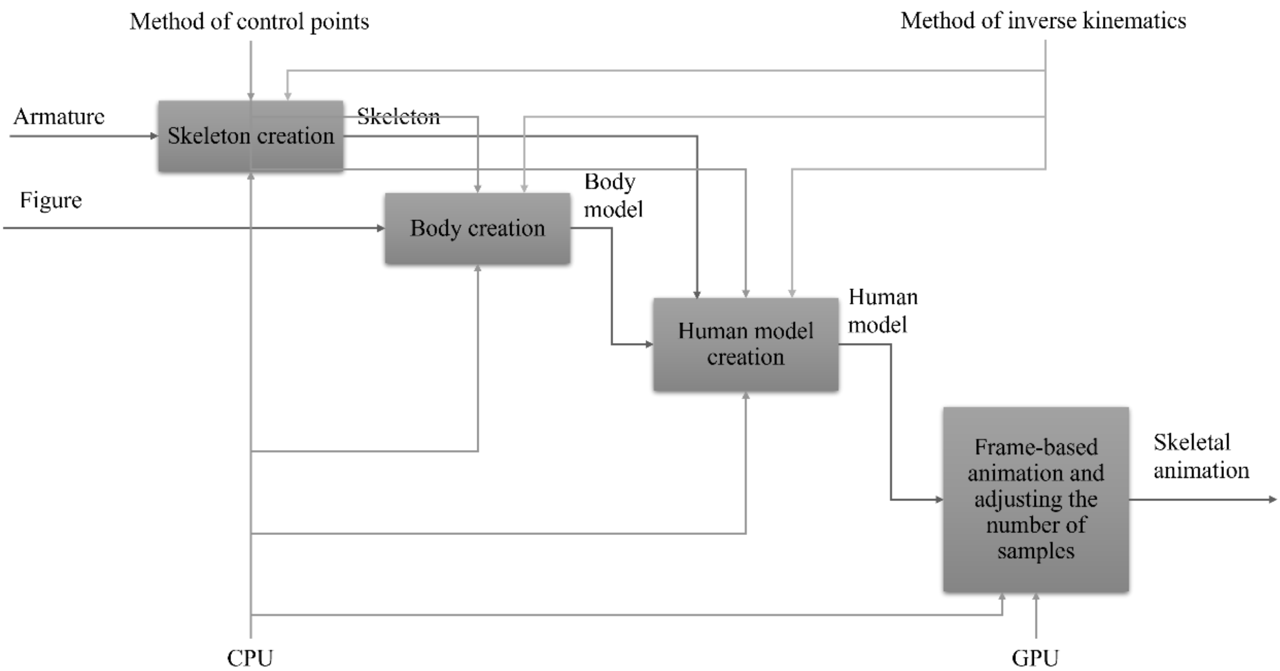


Fig. 8. Functional diagram of the proposed approach for accelerating an animation

One way to reduce rendering time, with saving high animation quality as is to optimize renderer parameters through some changes in the workflow (figure 8):

1. Reducing the number of samples for managing lighting and shadows can significantly reduce rendering time without a noticeable loss of image quality
2. Rendering animation frame by frame instead of rendering the entire animation as a single block allows controlling the rendering process and, if necessary, pausing or resuming the process without unnecessary system load
3. Using the GPU also allows distributing the load across a large number of stream processors, achieving acceleration.

The approximate model of the human body, which will be used in the study of skeleton animation, is shown in the figure below.

a) b)

Fig. 9. a) human body model, b) skeleton animation armature

The foundation of the human body model consists of the skeleton armature, which is an invisible support structure securely embedded in the virtual animated form (figure 9). The skeleton armature plays a critical role in stabilizing and controlling the movement and dynamics of this digital representation of the human figure.

By combining two important methods - frame-by-frame animation and the use of varying numbers of samples - it has been achieved a significant improvement in the quality and realism of displaying the movement and dynamics of skeleton animation.

The first step in improving rendering was the utilizing of frame-by-frame animation. This method allows for saving and reproducing animated images frame by frame, defining the exact position and state of each object in each frame. The usage of this method has directly allowed for achieving a high level of realism in the movements, but we aimed to go further.

The second key element of our approach was integrating the number of samples into the rendering process. The number of samples determines how many times each point in the image or video is considered and calculated for each color and lighting. Increasing the number of samples leads to more detailed and refined images, reducing artifacts and improving quality. The combination of frame-by-frame animation and an optimal number of samples has allowed to achieve an effect that goes beyond the capabilities of each method separately. Movements have become smoother, details of animated objects have gained realism, and rendering time has been accelerated.

This approach to rendering skeleton animation is an example of how the integration of different methods can lead to synergistic effects and significant improvement in the visual experience. Enhanced rendering of skeleton animation opens up new possibilities for creating larger 3D objects.

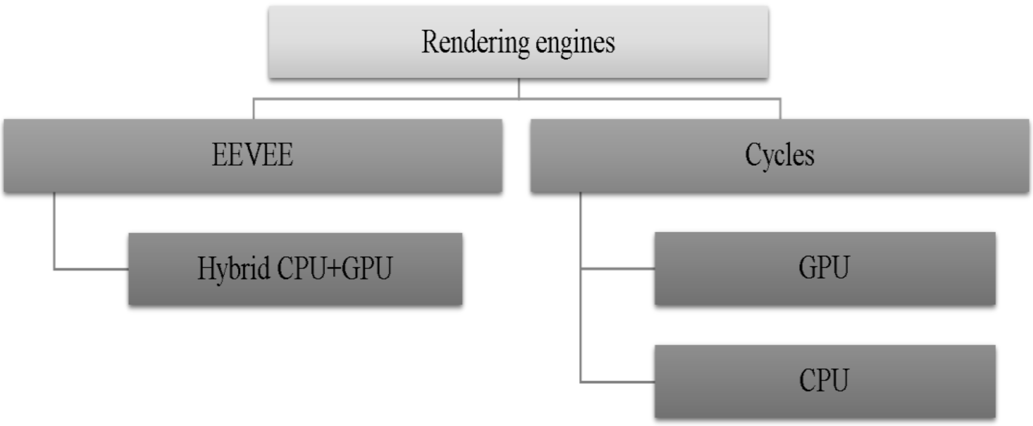


Fig. 10. Investigated computational architectures

Within the scope of the study, the setting of 250, 500 and 1000 frames were used to create frame-by-frame animation. This volume allowed for analyzing the performance of movements processing and dynamics of skeleton animation on various computational architectures with Blender 3D engines (figure 10).

To achieve maximum visualization quality and reduce artifacts, different numbers of samples (30, 60, 128, 256, 512) were considered in the preparatory stage. Increasing the number of samples to 512 results in extremely smooth movements and invisible transitions between frames, providing a realistic character, but it requires more computational resources. At the same time, experiments with 30 samples showed skeleton movements quite jerky and unstable. The moments of movement seem somewhat discrete.

The investigated engines in Blender 3D (EEVEE and Cycles) allowed for analyzing the rendering performance on different computational architectures - CPU and GPU depending on the sample values of 60 and 128, the number of frames of 250, 500, and 1000, as well as the frame rate labeled at 30 frames per second. The goal of the research was to achieve an optimal balance between speed and realism in reproducing animation details.

The use of EEVEE under these parameters proved to be very effective in terms of rendering speed. The characteristics described above showed that the EEVEE rendering engine, combined with the method of frame-by-frame animation and variable sample count, accelerates the rendering of human skeleton animation up to 46.5% with 1000 frames and using 128 samples (table 2).

Table 2

The comparative values of rendering skeleton animation using the EEVEE engine in a hybrid computational environment (CPU+GPU)

Number of processing frames	Number of samples	Frames frequency, FPS	Rendering time for different animation formats, min	
			Proposed method of rendering skeleton animation	Traditional method of skeleton animation
250	60	30	0:01:25	0:02:05
	128		0:07:55	0:12:50
500	60		0:04:16	0:07:21
	128		0:15:34	0:27:45
1000	60		0:09:23	0:16:27
	128		0:28:35	0:52:45

Changes in animation parameters (number of frames and samples) affect rendering speed. Increasing the number of frames has a greater impact on rendering compared to changing the number of samples. Under the specified conditions, the speed increase ranges from 39% to 46.5%, which makes the research results meaningful for small model sizes. The percentage of rendering time using the combination of frame-by-frame animation and sample count can be considered significant, but at small values of the number of frames and samples, the difference in rendering time is not that big.

Table 3

Comparative values of rendering skeleton animation using the Cycles engine with CPU calculations

Number of processing frames	Number of samples	Frames frequency, FPS	Rendering time for different animation formats, min	
			Proposed method of rendering skeleton animation	Traditional method of skeleton animation
250	60	30	0:01:50	0:02:08
	128		0:07:35	0:10:12
500	60		0:05:05	0:07:40
	128		0:16:15	0:25:30
1000	60		0:10:02	0:16:32
	128		0:29:45	0:51:27

The next investigated rendering engine in Blender is Cycles, which provides detailed and realistic rendering of skeletal structures and movements. Cycles can utilize both GPU and CPU for parallel computation and rendering acceleration.

Using the Cycles engine for CPU calculations showed that the combination of frame-by-frame animation and sample count accelerates the rendering of human skeleton animation up to 42.5% with 1000 frames and using 128 samples (table 3).

Under the specified conditions, the speed increase ranges from 26% to 42.5%. The percentage of rendering time using the combination of frame-by-frame animation and sample count can be considered from medium to high, depending on the number of frames and samples in animation rendering. Rendering using Cycles with CPU showed a worse result than using the EEVEE engine in a hybrid computational environment, but these values are not critically low, which makes the research results meaningful for small model sizes.

Using the Cycles rendering engine for GPU calculations with CUDA technology showed that the combination of frame-by-frame animation and sample count accelerates the rendering of human skeleton animation by up to 55% with 1000 frames and using 128 samples (table 4).

Table 4

Comparative values of rendering skeleton animation using the Cycles engine with GPU calculations

Number of processing frames	Number of samples	Frames frequency, FPS	Rendering time for different animation formats, min	
			Proposed method of rendering skeleton animation	Traditional method of skeleton animation
250	60	30	0:00:58	0:00:86
	128		0:05:25	0:08:25
500	60		0:04:76	0:06:54
	128		0:12:27	0:22:20
1000	60		0:7:15	0:14:45
	128		0:22:67	0:50:25

The research allowed for identifying significant advantages of using the GPU, particularly CUDA technology, compared to the central CPU during rendering skeletal animation in Cycles in Blender. The GPU proved to be much more efficient in parallel computation, which is especially important when processing large amounts of data, as in the case of skeletal animation. The CUDA technology enables the use of parallel computation on thousands of graphic processor cores, which is a key factor in significant computation acceleration.

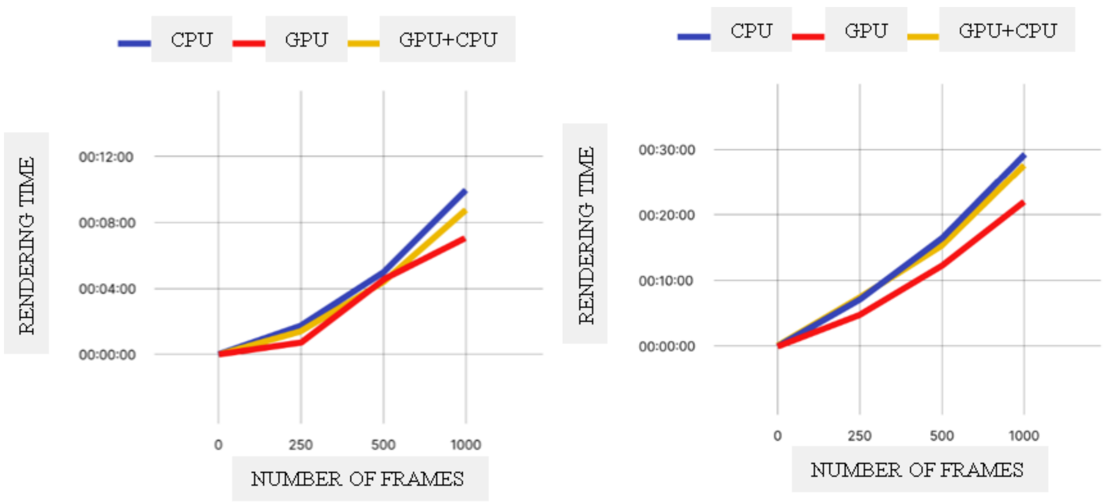
Table 5 presents summarized data for three performed experiments, demonstrating the advantage of performing computations and rendering on the GPU over computations on the central processor.

Table 5

Analysis of the obtained acceleration along performing skeletal animation on different types of computational systems on GPU, CPU, and on a hybrid computational system

Number of frames	Number of samples	Rendering acceleration		
		GPU	CPU	GPU+CPU
250	60	31%	26%	39%
250	128	34%	28%	40%
500	60	39%	32%	43%
500	128	45%	36.7%	44.2%
1000	60	50%	39%	45%
1000	128	55%	42.5%	46%

Considering the difference in productivity between GPU and CPU in rendering, it is important to choose the computational resource correctly depending on the specific task. In case of skeletal animation, the GPU usage with CUDA technology proves to be optimal (figure 11).



a) **b)**

Fig. 11. The comparative dependency graph of skeletal animation execution time to number of samples for CPU and GPU at: a) 60 samples; b) 128 samples

According to the research data, the rendering acceleration is determined not only by the workload (number of frames and samples), but also by the type of computing system - GPU and CPU. With an increase in the number of frames and samples, the rendering time also increases, but the acceleration ratio remains stable. The CUDA technology, which utilizes the GPU, is significantly faster on its own, but using the CPU in combination with the GPU (GPU+CPU) allows significant acceleration, especially with a small number of frames and samples. However, as the number of frames and samples increases, rendering with CUDA technology is significantly more efficient than a hybrid computing system.

The development of technologies in the GPU field and the continuous improvement of the technical characteristics of graphics cards can lead to even greater productivity growth and reduce rendering time.

Conclusions

During the research, analysis and improvement of visualization methods for human skeleton animation in the Blender 3D environment were carried out, particularly based on control points for limb movement control. The work includes an analysis of the impact of the number of samples on the smoothness of transitions between frames and the visualization execution time to achieve a balance between quality and efficiency, as well as the improvement of the method through adaptation for execution on the GPU.

The investigated engines of Blender 3D (EEEVE and Cycles) allowed for analyzing the rendering performance on different computing architectures (CPU and GPU) depending on the sample values, set at values 60 and 128, the number of frames, set at 250, 500, and 1000, as well as the frame rate with a mark of 30 frames per second. The aim of the research was to achieve an optimal balance between speed and realism in reproducing animation details. To achieve this goal, three experiments were conducted, the results showed the following: the use of the graphics processor using the Cycles engine gave a rendering acceleration result of 43%, starting from minimal values to maximum, while the acceleration of the hybrid system using the EEVEE engine showed an acceleration of only 15.2%.

By combining two important methods - frame-by-frame animation and using different sample counts - it was achieved a significant improvement in the quality and realism of displaying motion and dynamics of skeletal animation. Such an approach allowed a significant reduction in the rendering time of skeletal animation.

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