Skeletal Animation of Human Normal Motion Patterns and Movement Disorders Using 3D Modeling in Blender

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Abstract— This paper explores the mechanisms of modeling human normal motion patterns and movement disorders using skeletal animation within Blender, a popular open-source 3D computer graphics software toolset. We review existing literature on movement representation and analysis, describe our methodology, present experimental results showcasing modeled motions, and discuss limitations and issues encountered during the process. The main goal is to be able to provide a comprehensive and accurate representation of various gait disorders for the possibility of better understanding and treatment.

Keywords—gait, movement disorders, 3D modeling, Blender, textures, lighting, rigging, animation

I. Introduction

Understanding human motion is crucial in various fields, including biomechanics, animation, rehabilitation, and sports science. Accurately modeling both normal motion patterns and movement disorders offers valuable insights into human health and performance, thus aiding diagnosis, treatment, and prevention of musculoskeletal disorders [1]. In fact, many technological advancements have been made and continue to be made to the point where it has created a dynamic field that holds immense potential to further revolutionize healthcare. For example, it can offer the potential to provide personalized medicine and orthopedics guided by individual movement patterns [2]. In this paper, we explore the potential of using skeletal animation within Blender software to achieve such modeling.

Blender, a widely used open-source 3D creation suite, offers versatile animation tools and a growing community, making it an attractive platform for investigating motion representation. This is made even more accessible to a larger audience through the abundance of open-source, copyright-free resources, tutorials, and ready-made models and animations that can allow others to experiment and create something more within their means. While existing methods like motion capture offer high accuracy, their limitations include cost, accessibility, data processing complexity, and technical complexity. Skeletal animation, on the other hand, presents a more flexible and cost-effective alternative, allowing for artistic expression and manipulation of motion parameters while also being more beginner and user-friendly [3].

This paper aims to investigate the feasibility of using Blender's skeletal animation system to model both normal human motion patterns (e.g., walking, running) and movement disorders (e.g., gait abnormalities). By leveraging Blender's user-friendly interface and animation tools, we aim to:

- Develop animation rigs representing the human musculoskeletal system with varying degrees of complexity.
- Model and animate diverse normal motion patterns based on reference data.
- Create visual representations of movement disorders based on clinical descriptions.
- Evaluate the accuracy of these models through visual comparison.

In this paper, we aim to explore the world of accessible tools for human motion modeling. By demonstrating the potential of Blender for this purpose, we can venture into a more simplified world of motion analysis that allows beginners and anyone with primitive access to resources to have the ability to produce and possibly analyze animation with accurate movement representation.

Following the organization of this paper, in section 2, related works and other relevant research will be discussed. Then, in section 3, the specific movement patterns and disorders that have been modeled are detailed in the description of our modeling methodology and implementation. The results and visuals of the final 3D modeling rendering process are showcased in section 4. This paper finally closes with any conclusions that have been discovered during the modeling process in section 5.

II. Literature Review

Of course, there are several different motion patterns the human body is capable of. There are also a diverse range of movement disorders that affect the musculoskeletal system in the human body. To have a more precise outlook on the process of 3D-modeling normal motion patterns and movement disorders and afterwards the output results of the process by analyzing the precision of such a representation to original source material, only four normal motion patterns (walking, running, jumping, and sit-to-stand) and two movement disorders (Diplegic Gait and Circumduction gait) will be discussed in this paper.

To be able to model human motion and gait, there must first be a preliminary observatory and biomechanical understanding of the human body and how it moves. The human gait is essentially an intricate interplay of body segments and joints during a gait cycle. The efficiency, balance, and potential for injury can be assessed by observing these movement patterns. The general approach to assessing human gait and motion includes the following [4]:

- Observe upper body, pelvis, hips, knees, legs, feet, and ankles from various angles [4].
- Look for symmetry, smoothness, and appropriate range of motion in each segment [4].
- Compare findings to reference data or known patterns of normal gait [4].

In this segment, the assessment of walking, running, jumping, and sit-to-stand gaits will be discussed. Gait analysis is essentially an analysis of the gait cycle and gait speed of an individual. During each gait cycle, a pattern of joint and limb motions is repeated [6]. To assess walking, running, jumping, and sit-to-stand motion patterns or gaits, a general evaluation of the movement of the upper body, pelvis, hips, knees and legs must be made relative to one another. The ranges of motion, symmetry, and smoothness of motion in each segment relatively is taken into consideration to make a complete evaluation on the nature of the individual's gait and condition [4,6].

For abnormal gaits, any deviations from normal can be potential indicators of weakness, injury, or other underlying conditions. As mentioned previously, having a reference as a standard of normal can help in determining the presence of any abnormalities in an individual's gait. Of course, to diagnose an individual's gait, there are markers that should be present in their gait.

For example, Diplegic Gait is "a type of abnormal gait pattern characterized by spasticity and muscle stiffness, particularly affecting both legs" especially in the lower extremities [7]. An individual with diplegic gait "walks with an abnormally narrow base, dragging both legs and scraping the toes" [8]. The individual is also characterized with "extreme tightness of hip adductor which cause the legs to cross the midline"; this is "referred to as scissors gait" [8]. This condition typically arises from neurological disorders or injuries that affect the central nervous system, e.g. cerebral palsy [7, 8]. The image in figure 1 showcases the posture of an individual with diplegic gait.

Another example is Circumduction gait. "Circumduction is a medical term used to describe the circular movement of a limb. In the case of circumduction gait, a person lifts their leg away from their body in a semicircular pattern to clear the ground while moving forward." [9] The image in figure 2 showcases the posture of an individual with circumduction gait whilst in their gait cycle, and figure 3 showcases their gait pattern.

Fig. 1. Example of a Diplegic Gait Posture. (*Source: Adapted from [8]*)

Fig. 2. Example of a Circumduction Gait Posture. (Source: Adapted from [10])

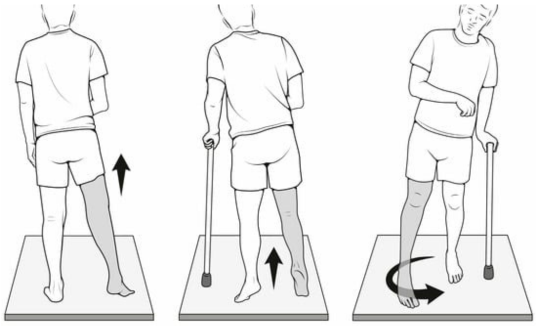

Fig. 3. Circumduction gait pattern. [11]

Now, 3D modeling the aforementioned gaits is possible since there is a basic understanding of how they are positioned in the real world. To start understanding the nature of human motion patterns, a basic 2D model of the human body can be made in the form of a "stick figure". To recognize human motion patterns, Ref. [12] designed a system that classifies motion patterns into three categories: walking, running, and others. Afterwards, the human body is modeled in silhouettes using a stick figure representation. This simplifies the data and allows efficient capture of motion patterns. Next, the recognition task is divided into two stages:

- *Stage 1*: Tracking human motion using a model-driven approach to find the stick figure that best represents the silhouette in each frame.
- *Stage 2:* Classifying the stick figure motions into the three categories using a BP neural network.

To concentrate on the core recognition problem, made a few simplifying assumptions were made:

- All body part motions can be approximated as planar (2D) motions.
- The person moves against a stationary background, allowing for easy silhouette extraction.
- The scene contains only one moving person, and the camera is positioned to capture side-view motion.

Ref. [12] showcases an effective process to recognize human motion patterns through simplifying the human body into a basic skeletal figure (the stick figure) and then seeing how each segment in the skeletal figure interact with one another.

Of course, another more complex method of motion representation is motion capture. It usually uses tracing markers that are put on a participant in order to process and 3D reconstruct the participant's gait. For example, Ref. [13] proposes a novel method for assessing Parkinson's Disease (PD) progression and treatment response using stereoscopic vision and motion capture. this method captures accurate 3D skeletal data by tracking key body joints with stereoscopic cameras in order to reconstruct a 3D representation of the patient's movement. Then, This 3D representation, along with associated gait metrics (walking speed, stride length), forms a "kinesiological imprint" capturing a snapshot of the patient's movement state. By collecting these imprints over time, the system provides a detailed and objective record of disease progression and response to treatment.

III. Methodology

In this project, we employed the latest version of Blender (v4.0.2), the 3D animation software, to model and animate the six aforementioned human walking gait patterns, both normal and those associated with movement disorders. This section details the specific steps involved in this process, including software and hardware utilized, reference and open-source material, skeletal structure design, and animation principles.

A. Setting up the Scene

To create a scene for our character to reside in, we used a bedroom model from TURBOSQUID, a website that offers open-source 3D models for blender (the used model is found in figure 4). Some of the elements found in the bedroom model include a window, a bed, some bookshelves and cabinets, a table, and a desk with its chair. We then changed some features of that bedroom to create our scene.

Fig.4. 3D bedroom model. (Source: TURBOSQUID)

1) Adding floor textures: we added a floor texture to the bedroom floor by using an image of darkwood planks from the Rock Cut Brewing Company website then changing the image from an object to a vector as well as adding and altering bump to create a "bumpy" wood texture and altering subsurface color for "tinting" the wood [14].

2) Adding wall and ceiling textures: For the walls, we used a wallpaper image off of Amazon and simply connected the "Object" output of the Texture Coordinate node to the "Vector" input of the Mapping node.

3) Adding a rug texture: To add a rug to the floor, a rug image was used from the "Wilson and Dorset" website. Through a combination of object settings alterations (such as clumping, emissions, interpolations, etc..), we create a "fuzzy" or "hairy" rug texture [15].

4) Setting up the window background and lighting: To create a sunlit room with a background out of the window, we created a form of ambient lighting that shines through the bedroom's window and added a background render to represent the view outside of the bedroom. The background is an image from Poly Haven [16].

*5) Adding glass textures:*To add texture to the window's glass panes, we linked a glass texture from an open-source .blend file.

6) Adding other elements to the scene: We also added two sconce lamp models, found from Free3D website, to the bedroom as well as added a point lights to them so that the lamps would be "ON" [17]. An additional moon-shaped lampt is added on the shelves using a moon image from SBCODE and added emissive lighting to it. Furthermore, we also added emissive lighting to the lamp on the desk.

After finishing the bedroom’s setup, we packed all the files used into one .blend file. The reason being is that if that same .blend file was opened on another computer that does not contain the necessary texture file or if the paths linking the texture file to the .blend file are incorrect or have changed, Blender creates a pink space in place of the texture that is not found. By packing all the files into the .blend file we avoid such a complication at the cost of a larger .blend file.

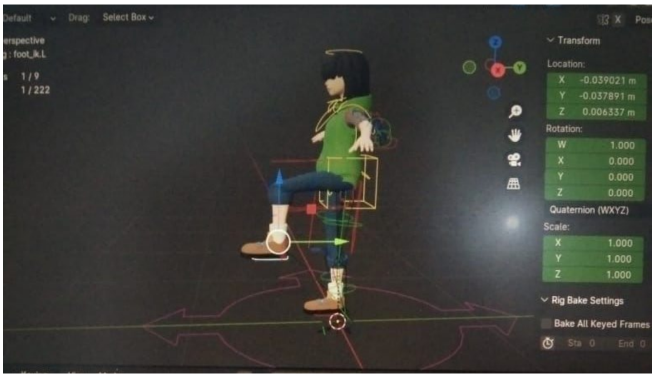

Fig.5. The character model and armature used.

B. Character Modeling and Rigging

Before starting the animation, we first created a character model and rigged it. We started with a premade character model offered by “Blend Swap”, which is a website containing many open-source blender models. The model we used is shown in figure 5. Since this model did not have an armature or rig, we added a rig to it.

We constructed the model’s skeletal foundation or armature by employing the "Basic Human (Meta-Rig)" option offered by Blender. This generates a pre-built skeletal structure tailored for human proportions. To tailor the armature to fit the model’s proportions, we enter "Edit Mode" to adjust the armature's bones. By stretching, shrinking, and rotating the bones, we ensure a precise fit with the character's form. To control complex movements, we create an Inverse Kinematics (IK) rig by navigating to the "Data" tab and selecting "Generate Rig".

For the model (or flesh) to move when the armature (skeleton) moves, we must bind both together. With both the character and rig selected, we choose the "With Automatic Weights" option. This crucial step assigns control over the character's mesh to the corresponding bones, enabling smooth deformations during animation.

To start animating the character, we transition into "Pose Mode." Here, we directly manipulate the bones, creating a wide range of poses and movements. Each adjustment to the bones results in a corresponding deformation of the character's mesh, bringing our creation to life.

C. Animation

The main data acquisition method employed was direct animation. Using this method, animation keyframes were manually defined based on anatomical reference data and established gait cycle principles. To start animating there are a few principles that must be adhered to:

- Applying inverse kinematics (IK) to drive the skeletal animation based on manually defined keyframes.
- Utilizing realistic muscle deformations and joint rotations to achieve natural-looking movement.
- Implementing ground contact constraints and foot placement adjustments for accurate footstrike and push-off phases.
- Adhering to principles of anticipation, follow-through, and exaggeration for dynamic and engaging animation.

We used the skeletal structure we prepared earlier and the animation principles to create a realistic walking animation loop. This is done by focusing on capturing the key characteristics of human walking, such as:

- Heel strike, mid-stance, and toe-off phases
- Arm swing coordination
- Pelvic rotation and tilt
- Natural knee flexion and extension
- Foot pronation and supination

Our main references to observe key movements and abnormalities for the two movement disorders – Diplegic gait and Circumduction gait – are found in Ref. [8 and 10]. Since we researched the characteristics of both gaits and understood how they differ from a typical, healthy gait, we then modified the skeleton rig based on the observed characteristics of both gait patterns. For Diplegic Gait, focus on abnormalities in hip and knee flexion, while for Circumduction Gait, emphasize exaggerated hip abduction and extension. Lastly, we Iterate on the animation, making adjustments to ensure accuracy and realism. One such adjustment includes the addition of a walking cane whilst animating Circumduction Gait.

For the sit-to-stand motion, we used an additional open-source chair model from the Free3D website and mapped the character’s gait cycle to it. The walking, running, and jumping gaits were simply animated using direct animation the same way the movement disorder and sit-to-stand motion pattern is animated.

Finally, once we have finished the model and animation, we used visual analysis to compare the animated walking motion to real-world walking videos, paying attention to overall fluidity, naturalness, and anatomical accuracy.

Fig.6. The final bedroom and model produced – View 1

Fig.7. The final bedroom and model produced – View 2

IV. Experiments and Results

This section showcases the results of our efforts to model human normal and abnormal motions using skeletal animation in Blender. We present mainly qualitative evaluations, highlighting the strengths and limitations of each modeled motion.

A. Visualizations:

1) Normal Motions: We have modeled 4 motion patterns – walking, running, jumping, and sit-to-stand.

For the normal walking gait, we needed to make sure that the animation was fluid and that the arms and upper body moved in sync with the lower body and legs to ensure that fluidity and smoothness. (see figure 8)

For the normal running gait, the relative limb to lower/upper body motions are quicker since the step time between one step and the next decreases. To accommodate that, a greater range of motion in the joints is displayed. (see figure 9)

For the normal forward jumping gait, it requires a push using the legs and hips against the floor whilst simultaneously maneuvering one of the legs forward. This means that a greater degree of extension in the ankles, knees, and hip is required. (see figure 10)

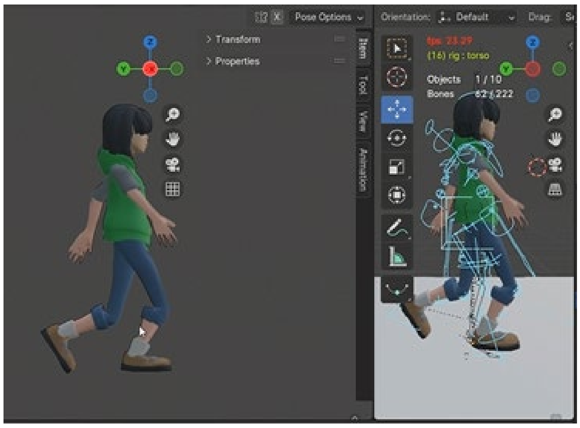

Fig.8. an animation still from the modeled normal walking gait

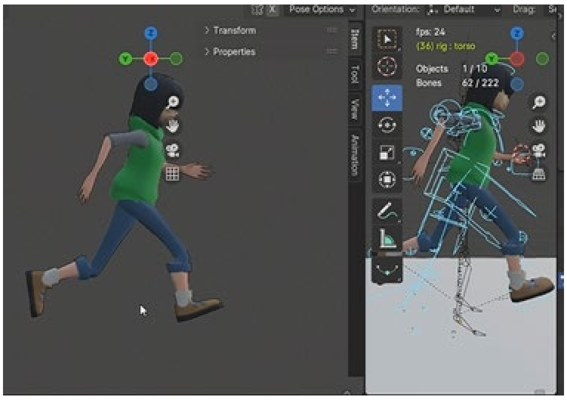

Fig.9. an animation still from the modeled normal running gait

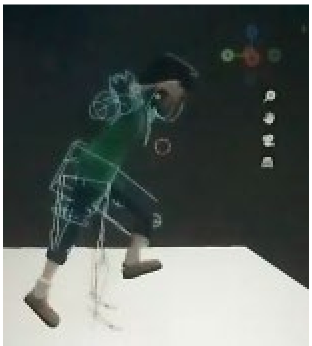

Fig.10. an animation still from the modeled normal jumping gait

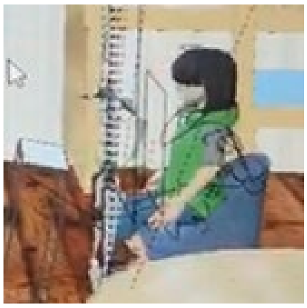

Fig.11. an animation still from the modeled normal sit-to-stand gait

For the normal sit-to-stand gait, a center of gravity shift from between the legs to the extended hips occurs. This requires the bending of the hip, knee and ankle joints to support the shifting in weight. (see figure 11)

2) Movement Disorders: Movement disorder have characteristic gait deviations, and some have a great visual impact in the animation.

For Diplegic Gait, it is characterized by spasticity and stiff and hypertonic muscles, particularly in the legs and hips, leading to limited flexibility and range of motion and impaired coordination. The thighs are drawn inwards, creating a "scissors" appearance while walking, and the knees are often bent, making it difficult to extend fully during the gait cycle. There is also a difficulty raising the toes off the ground, leading to a flat-footed gait. This creates a short stride length. (see figure 12)

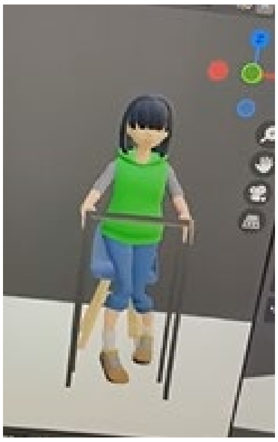

Fig.12. an animation still from the modeled Diplegic Gait

For Circumduction gait, the affected leg swings in a wide, circular arc outwards instead of following a straight path towards the front. The hip may appear "dropped" on the swinging side due to weak abductors. foot often trails behind the body rather than landing directly in front. This creates a shorter stride length due to the inefficiency of the circular movement. (see figure 13)

Fig.13. an animation still from the modeled Circumduction Gait

B. Discussion and Analysis:

1) Successes: we have successfully modeled each gait by implementing its gait characteristics. This way they are easily differentiated and accurately represented. Relative motions between limbs is also taken into consideration since it plays a crucial role in how an individual controls their gait. In figures 6 and 7, the output result is shown with the character residing within a bedroom scene. Scales and ratios are taken into consideration.

2) Limitations: There are a few limitations to relying on the visual qualities of 3D model's representation. For example, the ranges of motion may not be very precise and there could be issues with character collision and objects warping within the scene. If objects are not placed correctly or if they are not the correct opacity they may appear as if they are levitating. Also, there could be issues with the slow rendering speed and the large memory space needed to store all assets of the model correctly.

V. CONCLUSIONS

Using Blender v4.0.2 to model and animate human walking gaits (normal and movement disorders), we can achieve some form of representation and understanding of human motion patterns. The availability of open-source models and textures that can be utilized for the scene and character allows the modeling process to be cost-effective and user-friendly. For character animation, a skeletal armature with IK rigging was constructed and keyframes were implemented onto the character-skeleton rigging to replicate most motions. To ensure accurate depiction of movement disorders, reference data and medical resources were consulted. Then, through visual analysis, the animations are compared to real-world videos for fluidity and anatomical accuracy.

Four normal gaits (walking, running, jumping, sit-to-stand) and two movement disorders (Diplegic, Circumduction) were successfully modeled. Visualizations showcase distinct features of each gait within a bedroom scene. Limitations include potential inaccuracies in range of motion, character collision, and rendering speed.

Overall, this paper demonstrates the feasibility of using Blender to model and animate diverse human walking gaits, including normal and abnormal patterns. While visual limitations exist, the project successfully translates gait characteristics into visually distinct animations within a 3D environment.

MEMBER CONTRIBUTIONS

This paper represents the culmination of the team's hard work and dedication in the project. The team consists of five members in total. While I, Basmala, was mainly responsible for compiling the final document, the insights and contributions of each team member were invaluable. Luna is our team's leader and worked in conjunction with Sara and Rana to 3D model the two aforementioned movement disorders in Blender. In addition to that, Sara and Rana rigged the skeletal model that was used to model all the human movement pattern animations discussed in this report; they worked on rigging and setting up the average normal walking, running, jumping, and sitting human movement patterns in blender as well. Yasmin worked on the shading, lighting, and textures of the scene/room the character resides in. Of course, the contributions outlined above provided a strong foundation of attempting to divide the work into individual feasible segments, but the process remained fluid. Team members were actively encouraged to share insights and work together to solve any identified issues, ultimately enhancing the final outcome.

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