**Motivation for the study**

The production of 3D animation is increasingly focused on enhancing the figure effect, story content, and audience experience to cater to the growing demand for visual stimulation, spiritual enrichment, and interactive engagement. As audience expectations evolve, there is a pressing need to leverage advanced technologies that can deliver immersive and dynamic experiences. Virtual Reality (VR) animation stands out as a promising frontier in this regard. However, realizing the full potential of VR animation requires significant advancements in both technical capabilities and creative methodologies. This study is motivated by the necessity to explore and develop innovative approaches that can enhance the realism and interactivity of 3D animations in VR environments. By integrating Virtual Reality Modeling Language (VRML) and fuzzy model recognition, this research aims to improve the visual fidelity, interactivity, and overall performance of 3D animations, thus contributing to the future development of VR animation.

**Choice of Methods**

1. **Virtual Reality Modeling Language (VRML):**
   * **3D Shapes and Scenes Creation:** VRML is employed for its robust capabilities in creating detailed 3D shapes and scenes. Its features enable the generation of complex stereoscopic animations that are essential for a compelling VR experience.
   * **Texture Mapping and Lighting Effects:** VRML allows for sophisticated texture mapping and lighting effects, which are crucial for achieving high visual realism in 3D animations. These features enhance the aesthetic appeal and depth perception in the virtual environment.
   * **User Interaction:** The ability to establish user event responses in VRML facilitates interactive experiences, which are vital for engaging audiences in a VR setting. This interaction layer helps in creating a more immersive and responsive animation.
2. **Script Programming Integration:**
   * **Extending Functionality:** By incorporating script programs written in Java, JavaScript, or VRML Script language through the Script node, VRML's capabilities are significantly extended. This integration allows for more complex behaviors and interactions within the 3D scenes, thereby enriching the user experience.
3. **Fuzzy Model Recognition:**
   * **Enhanced Recognition:** Applying fuzzy model recognition improves the system's ability to recognize and simulate various elements such as text, music, and language within the 3D animation. This enhancement is crucial for creating more intelligent and context-aware animations.
   * **Improved Frame Rate:** The use of fuzzy models contributes to optimizing the image frame rate, ensuring smooth and consistent visual performance. This optimization is essential for maintaining the immersive quality of VR animations without compromising on responsiveness.

By combining VRML, script programming, and fuzzy model recognition, this study aims to push the boundaries of what is possible in 3D VR animation. The methods chosen are geared towards achieving high visual fidelity, interactive richness, and optimal performance, thereby setting the stage for future advancements in the field of VR animation.

**Reproducibility**

Ensuring reproducibility in this study is crucial for validating the results and enabling other researchers to replicate the work. This section outlines the specific computing infrastructure, including the operating system, hardware, and other relevant technical details, used to achieve the results presented in this paper.

**Computing Infrastructure**

1. **Operating System:**
   * The study was conducted on a computer running Windows 10 Pro (64-bit). This operating system was chosen due to its widespread use and compatibility with a variety of software tools required for VRML and 3D animation development.
2. **Hardware:**
   * **Processor (CPU):** Intel Core i7-9700K 3.6 GHz. This high-performance processor is capable of handling the computational demands of 3D rendering and real-time animation tasks.
   * **Graphics Card (GPU):** NVIDIA GeForce RTX 2080 Ti. This GPU provides the necessary graphical processing power to render complex 3D scenes and maintain high frame rates, which is critical for VR applications.
   * **Memory (RAM):** 32 GB DDR4. Sufficient RAM is essential for smooth performance, especially when dealing with large 3D models and extensive real-time data processing.
   * **Storage:** 1 TB SSD. A solid-state drive ensures fast read/write speeds, which is important for quickly loading and processing 3D assets and animations.
3. **Software:**
   * **3D Modeling and Animation Software:** Blender 2.90.1. Blender was used for creating and editing 3D models and animations. It supports VRML and integrates well with the scripting languages used in this study.
   * **VRML Tools:** X3D-Edit 4.0. This tool was used to create and edit VRML files, enabling the development of detailed 3D scenes and interactive elements.
   * **Scripting Languages:** Java SE Development Kit (JDK) 14 and Node.js 12.18.3 for JavaScript. These scripting environments were used to extend the functionality of VRML through custom scripts.
   * **Statistical Analysis Software:** MATLAB R2020a. MATLAB was utilized for analyzing the relationship between the number of triangles and the frame rate, providing insights into the performance of the 3D animation scenes.
4. **Additional Tools and Libraries:**
   * **Web Browser:** Mozilla Firefox 78.0, used for testing and viewing VRML content.
   * **Fuzzy Logic Toolbox:** MATLAB’s Fuzzy Logic Toolbox was employed for implementing fuzzy model recognition, enhancing the animation’s ability to recognize and simulate text, music, and language.

**Description of models used:**

1. **VRML Models:**
   * **Type:** VRML (Virtual Reality Modeling Language) models are used for creating and describing 3D objects and scenes.
   * **Justification:** VRML is specifically designed for rendering 3D graphics and supports features such as texture mapping, lighting effects, and interactive elements. Its compatibility with various scripting languages (Java, JavaScript, VRML Script) allows for the creation of dynamic and interactive 3D environments, making it an ideal choice for this study focused on VR animation.
2. **Fuzzy Models for Recognition:**
   * **Type:** Fuzzy logic models are used for recognition tasks within the 3D animation, such as interpreting text, music, and language.
   * **Justification:** Fuzzy logic provides a robust framework for handling uncertainty and imprecision, which are common in real-world recognition tasks. By using fuzzy models, the system can make more nuanced decisions and improve the realism and interactivity of the 3D animation.

**Evaluation Method**

1. **VRML Models:**
   * **Method:** The VRML models were evaluated based on their visual fidelity, rendering performance, and the effectiveness of user interactions. User feedback and qualitative assessments were conducted to gauge the immersive experience provided by the VRML scenes.
2. **Fuzzy Models:**
   * **Method:** The evaluation of fuzzy models was performed through simulation tests where their ability to accurately recognize and respond to text, music, and language inputs was measured. Performance metrics such as recognition accuracy and processing time were recorded.

**Selection Method**

1. **VRML Models:**
   * **Criteria:** Models were selected based on their complexity, visual appeal, and ability to demonstrate various VRML features (e.g., texture mapping, lighting, interactivity). Additionally, models that maintained high frame rates and did not overly burden the system's resources were preferred.
   * **Process:** An iterative process of modeling, testing, and refinement was followed. Initial models were created and tested for performance and visual quality. Based on test results, models were adjusted and optimized until the desired balance between visual quality and performance was achieved.
2. **Fuzzy Models:**
   * **Criteria:** Selection criteria included the model's ability to handle diverse inputs, adaptability to different recognition tasks, and computational efficiency.
   * **Process:** Various fuzzy logic configurations were tested in controlled scenarios to determine their effectiveness in recognizing specific patterns and inputs. The configurations that provided the highest accuracy and performance were selected for integration into the 3D animation system.

**Assessment Metrics (Justification)**

1. **Frame Rate (FPS):**
   * **Justification:** Frame rate is a critical metric for evaluating the performance of 3D animations, particularly in VR environments where a high and consistent frame rate is necessary to ensure a smooth and immersive experience. A frame rate of over 40 FPS is targeted to provide a fluid visual experience without noticeable lag.
2. **Recognition Accuracy:**
   * **Justification:** For fuzzy models, recognition accuracy is essential to ensure that the system correctly interprets text, music, and language inputs. High accuracy enhances the interactivity and realism of the animation, contributing to a more engaging user experience.
3. **Rendering Time:**
   * **Justification:** Rendering time measures how quickly the system can generate and display frames. This metric is important to ensure that the animation runs smoothly and that the system can handle complex scenes without delays.
4. **User Interaction Responsiveness:**
   * **Justification:** Responsiveness to user inputs is crucial for interactive VR applications. This metric evaluates how quickly and accurately the system responds to user actions, which is vital for maintaining immersion and user engagement.

**Limitations/validity:**

1. **Hardware Dependency:**
   * **Limitation:** The performance of 3D animations, particularly in VR environments, is heavily dependent on the hardware used. The high-performance CPU, GPU, and large RAM specified in the study may not be available to all users, potentially limiting the reproducibility and accessibility of the results.
2. **Software and Platform Constraints:**
   * **Limitation:** The study relies on specific versions of software tools and platforms, such as Blender 2.90.1, X3D-Edit 4.0, MATLAB R2020a, and Windows 10 Pro. Updates or changes to these tools and platforms could affect compatibility and functionality.

**Validity:**

The study's methodology is rigorously designed, with careful selection and evaluation of models, thorough testing of performance metrics, and controlled conditions for real-time performance assessment. This ensures that the results accurately reflect the effectiveness of VRML and fuzzy models in enhancing 3D animation.