Ultimart: Visual Communication Journal
Vol 17 No. 2, December 2024
ISSN: 1979 - 0716, e-ISSN 2615-8124
Faculty of Art and Design
Universitas Multimedia Nusantara

RIGGING SYSTEM DESIGN FOR THE CHARACTER "GERY" IN A 3D CHARACTER ANIMATION COURSE

Eldwin Manuel Sumampouw[1]
Tito Ari Pratama[2]

Received August. 24, 2024; Revised October. 15, 2024; Accepted November. 01, 2024.

Abstract: *A well-planned rigging system design will make it easier for an animator to animate a model. A rigging system is designed to create a controller hierarchy and a joint reinforcement hierarchy to move a model. The rigging system must be created to develop user comfort and to design an efficient system to make it easier for animators to animate the model. This study aims to create an original model named Gery along with a rigging system design that is comfortable and efficient, especially in the design of an innovative facial rigging system. In this study, the author will observe the Stewart model as the foundation for designing the body rigging system and the Mery model as the foundation for designing the facial rigging system. The author applies the leading theory of the rigging system workflow created by Cheryl Briggs as a guideline in the production stage of the work. The author also applies the supporting theory of the body rigging design plan created by Eric Allen & Kelly L. Murdock and the application of the FACS theory reference compiled by Brigita C. Beavis as a guideline in the pre-production stage. The results of this identification will form the basis for designing the Gery model rigging system. This system is efficient and comfortable for learning 3D character animation courses.*

Keywords: *rigging 3D; body rigging; facial rigging*

Introduction

For a 3D animator to be comfortable moving a model, a rigger or rigging artist must speed up the time at the production or animation stage. According to AAA Game Art Studio, a rigger is a job that has a job description to design a movement system through bones and controllers on a 3D character or object so that an animator can move it (AAA Game Art, 2023). In addition, in her book Body Rigging, An Essential Introduction to Maya Character Rigging, Cheryl Briggs emphasizes that rigging is the most basic process before the model is moved, so if the foundation cannot stand firmly, the animation results will not be optimal. Moreover, rigging design must be made as simple as possible so that animators can easily understand the rigging and controller systems that have been designed (Briggs, 2021).

[1]*Eldwin Manuel Sumampouw is a student at the Digital Animation, Multimedia Nusantara Polytechnic (MNP) Tangerang.*

e-mail : eldwin.manuel@student.mnp.ac.id

[2]*Tito Ari Pratama is a lecturer at the Digital Animation, Multimedia Nusantara Polytechnic (MNP) Tangerang.*

e-mail: tito.ari@mnp.ac.id

According to Grant (2024), product manager for animation and rigging at Unreal Engine at Epic Games, he said that a 3D animator is a digital puppeteer, or it can be said that a 3D animator has a job description of only moving a controller on a character according to the principles of animation to bring the character to life through a computer. That is also done by Multimedia Nusantara Polytechnic, where the Digital Animation study program has a course called 3D Character Animation, the purpose of this course is to strengthen students' foundations in understanding how to move the body mechanic model according to the principles of animation, familiarize and understand the controller on the rigging of a model so that students can become reliable animators according to the objectives of the study program.

This research was created based on a case study of students with problems in the course's learning process. Users have constraints on the efficiency and comfort of the rigging system and model controller used during learning. The models used in learning the course are a model named Stewart, a model created by the Animation Mentor team and a model named Mery created by José Manuel García Álvarez and Antonio Francisco Méndez Lora on the Mery Project Free Character for Animator project with evidence of the inefficiency of a learning process. Because the first model does not meet the requirements for one of the learning needs in the course module. The 3D Character Animation 1 course has one of the lessons about facial expression and lipsync, where the first model, Stewart, cannot be used because it does not have a face model topology and face controller system for these learning needs. So when students want to learn facial expressions and lipsync. So, they must use other models, such as the Mery model. This complaint shows that there is a need for technological development that is interpreted in various methods and produces (Pratama, 2023). The interview audience shows that technology affects both artists' emotions and their works.

The author conducted a case study by distributing the Stewart and Mery model comfort level questionnaire. The questionnaire results stated that in addition to using two models as evidence of the inefficiency of a learning process, the Stewart and Mery models also have problems with their comfort levels, especially in the body rigging and facial rigging systems. Rigger artist needs to study a lot of things. Not only to understand on how to assemble a technical rig in virtual; they must be able to analyze and experiment the rigging system so that the character can be animate perfectly (Arshad* et al., 2019, p. 4138). The following is a description of the case study of the issues in the Stewart and Mery models based on the case study.

Stewart Model Case Study

Figure 1. Stewart Model
Source: Stewart Free Animation Rigs (2014)

Based on the results of the Stewart model comfort level questionnaire data, it can be seen that 20 out of 24 students have several problems with the Stewart model, namely, Inverse Kinematics (IK) & Forward Kinematic (FK) Interface, Pole factor and Facial rigging. The remaining

four students have no problems with the Stewart model. The following is a description of the Stewart model problem analysis:

a. Inverse Kinematics (IK) and Forward Kinematics (FK) Interface

Inverse Kinematics (IK) & Forward Kinematic (FK) Switch is a system in the Stewart model that exchanges the movement support function on a controller located on the hands and feet. Based on the results of the Stewart model comfort level questionnaire data, one of the problems with the Stewart model lies in the naming of the interface or display of the IK & FK switch system found in the controller option, making users confused when looking for the IK & FK switch attribute location.

b. Pole Factor

The Pole factor is a rigging controller that moves the knees and elbows. According to the results of the Stewart model comfort level questionnaire data, the model has one problem: the pole factor controller on the character's knees and elbows often experiences problems with rotated joints, making the user uncomfortable.

c. Facial Rigging

According to the results of the Stewart model comfort level questionnaire data, it can be seen that the model has one problem, namely the limited expressions that can be used due to limited face topology. Face topology is a mesh creation flow on a model designed according to human facial references. The model does not have a face topology flow, which makes it unable to be moved or used when the user wants to learn to animate an expression.

Mery Model Case Study

Figure 2. Mery Model
Source : Mery Project Free Character for Animator (2016)

Based on the results of the Mery model comfort level questionnaire data, 20 out of 24 students have several problems with the Mery model, namely naming face controller, limit information, lip sync system, and IK Problems. Only 1 student does not have a problem with the Mery model. The following is a description of the Mery model problem analysis.

a. Naming face controller

According to the results of the Mery model comfort level questionnaire data, the model has a problem with the naming of the face controller located on the face control panel. This naming problem makes users uncomfortable when they want to find a parameter that they want to move. This is inefficient because it makes users lose time when looking for parameters.

b. Limit Information

Based on the Mery model comfort level questionnaire, the face system rigging, particularly the limit information section, has issues. This section, meant to keep character movement within limits, is missing in the Mery system.

c. Lypsync System

According to the results of the Mery model comfort level questionnaire data, it can be seen that the model does not yet have a lipsync system that requires users

to move the lip model topology one by one to have a lip pose according to the reference, this is time-consuming and inefficient compared to having a lipsync system that has been provided.

d. IK Problem

According to the results of the Mery model comfort level questionnaire data, the model has a problem with the IK controller for the feet and hands. Mery mode also has a problem with the model's elbow being left behind when using the IK system movement feature. This can happen when a rigger incorrectly connects or ignores the constraint hierarchy of a controller, causing the elbow and knee controllers to be left behind when moving the IK controller.

Based on the case study, this research aims to create a comfortable rigging system for students by developing original characters and improving on the Stewart and Mery models. The focus is on addressing previous design issues to enhance the learning experience. Additionally, a character named Gary was developed as the study's object. This aims to increase the originality of the author's work besides being an initial effort to create branding. This is because one of the efforts to introduce this brand to the public is to create a visual identity (Rahmadini, 2023), so that the author also makes his own character without using other people's character models.

This research also creates various questions that are answered through this research:

1. How to design an efficient and comfortable rigging system for Animation students in 3D Character Animation courses?

Methodology

This research was conducted using in-depth interview method, combined with practice-based research obtained. Because the output of this research is useful for animation students, the researcher conducted a survey and interview with animation students in the scope of animation lectures at the Multimedia Nusantara Polytechnic. The researcher's hope from the character "Gery" is used for internal students, which later from further research if there is further data and can be developed outside the campus, the researcher plans to open this character for animation class learning media in the future.

Technically, The rigging theory in this study is divided into two major stages, namely body rigging and facial rigging. For the execution stages of body rigging and facial rigging are based on the theory from the book entitled "An Essential Introduction to Maya Character Rigging" by Cheryl Briggs as the application of the leading theory in the design process (Briggs, 2021). The author uses two theories when designing a rigging system at the foundation stage of body and facial rigging. At the foundation stage of body rigging, the author uses the theory from the book "Body language: Advanced 3D Character Rigging by Allen & Murdock" (Allen & Murdock, 2008). At the foundation stage of facial rigging, the author uses the research theory from the scientific work of facial rigging design by Brigita Cindy Beavis (Beavis, 2023).

1. Body Rigging.

According to Briggs (2021), body rigging involves designing a joint system and controllers for a model's body parts, enabling animators to move the model

easily. Briggs outlines three key stages in rigging: skeleton setup, control rig setup, and skinning character, which form the foundation of the research design.

A. Skeleton Setup

According to Briggs (2021), creating a strong and accurate foundation for making a rigging system and character controller will depend on the frame structure or skeleton setup that is placed and built correctly.

B. Control Rig Setup

A rigging controller is an invisible object to the camera with the function of moving bones or joints that have been arranged according to the model's shape. The controller helps the animator move joints indirectly and set a character's initial position more easily. Briggs said that if the skeleton setup stage is complete, the next stage is to pay attention to the controller rigging. Control rig setup is one of the crucial stages in the rigging system that connects joints to the controller, designs a comfortable controller, thinks about the hierarchy between controllers, and so on.

c. Skinning Character

The last crucial stage is skinning the character. Briggs said, this stage is crucial for connecting the bone design to the model's mesh and requires an understanding of weight painting, where the rigger assigns weights to the 3D model's parts to align character movements with the animator's expectations.

Rigging is the bridge between the initial modelling phase and the subsequent animation process, bringing characters and objects to life by allowing animators to manipulate 3D movements and expressions with precision (Dupré, 2023). According to Allen & Mudrock (2008), when we want to design a rigging for a character, we have to think about three things as the primary foundation, namely how to plan the creation of a rigging system (planning your rig), How to create a character that suits the rigger's needs (creating a character) and finding out what the animator needs in the rigging system (finding what animators need). One of the exciting things is about planning your rig process.

When the model and the animator's needs are available, the next stage is to start making a rigging design plan based on data that has been obtained from a model that already has a topology that suits the rigger's needs and the animator's needs data. The rigging planning stage can be made from the joint placement plan on the character (Planning joints), the controller design plan (Planning Controller) and the attribute plan (Planning Attribute).

2. Facial Rigging

According to Briggs (2021), Facial rigging involves designing a joint system and controllers that mimic the facial muscles of living creatures, allowing animators to easily move a character's face in an animated scene. Briggs divides several workflow sequences or workflows that discuss facial rigging in detail, as in Figure 3.

According to Briggs (2021), to make facial rigging, two techniques can be used, namely joints and blend shape. This is also supported by the statement from Allen and Murdock (2008) that facial rigging design is divided into two types of techniques: joint-based rig and morphs/blend shapes, where the joint-based rig is a framework that prioritizes the joints system to move geometry. At the same time, morphs/blendshapes is a technique for creating movement gallery assets based on the Facial Action Coding System

(FACS). Briggs divides three major stages in designing a facial rigging system: the blendshape system, face system and face controller.

Figure 3. Facial Rigging Workflow Stages
Source : Briggs, Cheryl (2021)

Meanwhile, According to Beavis (2023), she used the Facial Action Coding System (FACS) developed by Ekman, Friesen, and Hager (2002) as the foundation for creating facial rigging. FACS is a comprehensive system used to measure all observable movements on the human face. FACS uses a series of codes called Action Units (AU) to mark specific movements on the human face (Ekman & Rosenberg, 2005). According to Beavis (2023), The combination of these Action Units reflects facial expressions linked to specific emotions.

3. Creation Method

The author created an original 3D character rig named Gery, inspired by the Stewart body rigging system and the Mery facial rigging system. The Gery rigging system is developed by applying primary and supporting theoretical foundations to the design and execution stages. For the character itself, it was inspired by the author's brother when she was 10 years old. The style used is similar to Mary, but the researcher wanted to make it simpler and easier to understand. All types of modelling in Gery's design affect the mood and style of the characteristics and functions because, in addition to differentiating it from Stewart and Mary, it will also create different demeanours and characters and also have values and feelings for the audience (Arby & Widiastomo, 2024).

The Gery model has a main focus on the superior facial rigging design system that is more comfortable and efficient, especially with the lipsync system feature which is one of the mainstay features to make it easier for users when animating speaking scenes in an animation. The Gery model includes labeled controls for each facial muscle movement, enhancing user comfort in operating the rigging system. Additionally, it features a limited information system on each controller to prevent movements that could cause model penetration or overlap, addressing issues found in older models.

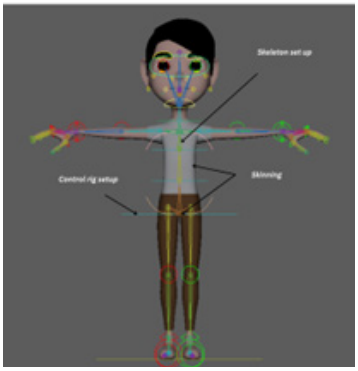

Figure 4. Gery and His Rigging
Source : Author's Documentation (2024)

The Gery model includes an additional face-mounted controller for movement, providing an alternative to animating the face via a control panel. This design aims to enhance user comfort with the facial rigging system. The model's creation emphasizes comfort and is grounded in theoretical design principles. In terms of shape, the Gery model is designed with an anatomical body shape according to the Stewart model and a facial rigging system that matches the facial anatomy of the Mery model but is updated according to the needs and comfort of the user, because each arrangement and placement of the controller will adjust to the needs of the artist (Satriawan & Apriyani, 2016).

4. Production Work Stage

a. Pre-Production Stage

The pre-production stage in Gery's rigging model design has five stages before designing; namely, the first stage is the stage of establishing an idea or concept. The second stage is observing previous models so the author can design accurately based on data and updated references from previously used models. The third stage is a literature study where the author applies the theory that has been collected. The fourth stage is the form experiment; at this stage, the author provides an innovation plan for an efficient facial rigging system experiment. The fifth stage is the exploration of form and technique, at this stage the author focuses on exploring the lipsync system as a facial rigging system plan that will be the main advantage of the Gery model. In addition, Gery is considered necessary in animating characters with art and emotion from the animation storyline later (Aprianto et al., 2023).

The idea or idea for creating the Gery model rigging system is based on the results of a case study of the Stewart and Mery model rigging problem which became the author's basis in designing to provide a solution to an existing problem. The researcher seeks references for body and facial rigging systems in their design work. To achieve this, they observe the Stewart model for body rigging and Mery's body for facial rigging, both used in a 3D character animation course.

Implementing rigging for both body and facial also looks at observation and evaluation first. This is important, especially since it allows riggers and animators to identify and correct errors or deficiencies in the rigging process, speeding up production time (Abdillah, 2021). To speed up rigging production, it is crucial to minimize the time spent finding and fixing mistakes. The process involves observation evaluation, where body rigging data is collected from Stewart's model observations. Briggs' theory (2021) guides the rigging design, focusing on key stages such as skeleton setup, control rig setup, and skinning. Allen & Mudrock's theory (2008) is used to understand animator needs, create characters, and plan rigs before production begins. This approach ensures the design system is effective and meets user requirements.

The application of facial rigging theory is divided into three stages, namely observation evaluation, application of main theory, and application of supporting theory. Observation evaluation is the stage where the author collects facial rigging data from observations of the Mery model as the basis for the form and creation system. Using the main theory in body rigging design, the author uses Briggs' theory (2021) as the basis for production. This theory is relevant to the significant flow process of design production, namely blend shape, face system setup, and face controller. In the application of

supporting theories, the author uses references to Beavis' scientific work (2023) as the foundation stage of design, namely the application of the Facial Action Coding System (FACS) before entering the production stage.

Researchers also conduct experiments and explorations before starting production, both in terms of body mechanics and facial expressions, that can be checked and studied. This kind of foundation is considered quite important in starting rigging production because researchers see the need to interpret the visible and more impactful result to touch the heart of the audience with the great system and arts (Pratama & Rosita, 2023, p. 14).

b. Body Rigging Production

The production process of body rigging is divided into two main stages: the foundation stage and the execution stage. The process is informed by theories from literature and user research. The author first studied user needs before starting character production, ensuring that the character design aligns with audience preferences. For the Gery character, the modeling process adhered to these preferences, incorporating a well-designed face topology, joint topology, and five fingers. However, the Stewart character lacks these features.

The researcher used the Mery character as a reference for the facial rigging stage. As for the joints themselves, the researcher designed the thigh, elbow, shoulder, and neck joints with more polygons than other parts to facilitate the joint process and joint movement. The same thing also applies to the production of the finger parts.

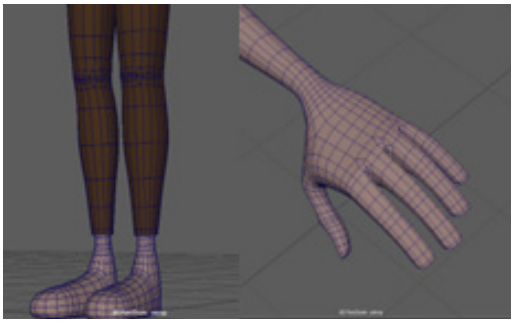

Figure 5. Topology of The Knee and Toes
Source : Author's Documentation (2024)

The researcher mapped the rigging for the character, focusing on the joint hierarchy and necessary controllers, particularly for the arms and legs, which are crucial for movement. They also designed a controller type that fits the body rigging system and will be finalized during execution. Additionally, they created an attribute system to assist users in animating the controller, which is divided into hand and foot parts.

The execution begins with the skeleton setup process by setting the join and designing the body rigging system. The analysis is based on the previous foundation stage. Such as Body Hierarchy Join, Base Left Arm Hierarchy Joint, Base Left Leg Hierarchy Joint, and up to the mirroring stage after all models are completed so that we do not produce twice, so the system on the left will be duplicated for the right body. Then, the process is to perform the Reorientation Joint Axis, install Inverse Kinematic (IK) and Forward Kinematic (FK) Joints and start the Constraint Parent process. The Constraint Parent is an important step that connects systems such as joints and controllers by bringing all values to objects such as translate, scale and rotates. However, here the researcher tries to work effectively by only bringing the rotation value for the needs of the arms and legs, called

Constraint Orient. The flow can be seen in the following image.

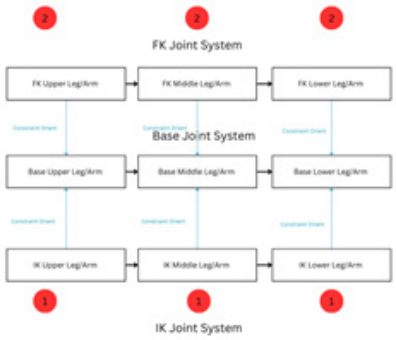

Figure 6. Constraint Orient IK & FK To Base Joint Workflow
Source : Author's Documentation (2024)

The researcher developed a Controller Setup model by arranging the controller based on Hierarchy Points. This approach was inspired by Stewart's character from the foundation stage. Then, the researcher also created a controller for the IK and FK systems where each controller represents a system that the controller parents. Then, the value is set via attribute using the node editor. Then, in the final stage, the researcher does a controller-to-join constraint to connect the controller that has been placed according to the join to each join using the parent constraint earlier.

At the end of production, the researcher performed a skinning setup to connect the model to its joints, allowing it to move using the rigging controller. This involved applying weight painting to ensure natural movement during animation. The process was complex and required trial and error, as improper weight assignments could lead to unnatural movements. Adjustments were necessary to achieve realistic results.

c. Facial Rigging Production

The production process of facial rigging follows the main and supporting theories stated in the literature study. The process is divided into two major stages, namely the foundation stage and the execution stage.

In the foundation stage, the author describes three parts in designing the foundation of facial rigging, namely the description of the results of the FACS analysis between Beavis' work and Gery's model, then using and describing AU with a comparison between Beavis' work model and Gery's model and combining AU to produce an expression foundation. So this stage is divided into three: facial action coding system, action units, facial movement, and expression.

Facial muscles are complicated, especially regarding natural and realistic facial expressions. Of all the muscles in the human head structure, there are eleven types of muscles that produce facial expressions (Faigin, 2008, p. 63). The researcher uses the FACS system to design and map a character's facial expressions and movements through action units. Once mapping is done, they proceed to the facial movement and expression stage, creating expressions that will be used on the expression control panel for the Gery character.

Facial expressions play an important role because almost all aspects of interaction and communication are done face-to-face (Yan et al., 2013). At this stage, in addition to using the foundation stage, the author also uses the main theory from Briggs. According to Briggs (2021), to making a body rigging system is divided into three significant stages in the process: blendshapes, face system, and face controller.

Gery's blendshape model has five asset galleries with a total of 23 blendshapes. The blendshape design includes various

facial expressions and movements: eyebrow up, eyebrow down, eye close, lower eye up, cheek up, open jaw, lips up, lips down, mouth blow, mouth deflated, nose up, and nose down. It also features a lipsync system blendshape and an expression blendshape. The design process involves adjusting the model's side movements using a shape editor's flip target parameter to ensure symmetry by mirroring the right side's vertex displacement to the left side.

Then, the face system design was carried out after the author had completed the blendshape stage. The function of this stage is to connect the overall blend shape parameters to the controller system because when connecting the blendshape to the main controller/main controller, it will not be flexible when used. The reason is that the blendshape only represents one value when connected, meaning that it can only use one translate to represent one blendshape, while to design a controller with a flexible system, other parameters are needed besides one translate. So a face system is needed to bridge the blendshape and the main controller. And keep in mind the more memory is used, adjusting to the number of blendshapes in production (Pirmansah, 2024, p. 27). The researcher minimizes it by using a combination of blendshapes, which will later make the Gery character file size not too large.

At the end of the process, the researcher designed a face controller in two stages. The first stage involved creating a control panel that links the face controller's parameters with a main controller face. This was done after connecting the blendshape to face controller A. The results of this control panel are illustrated in the provided picture.

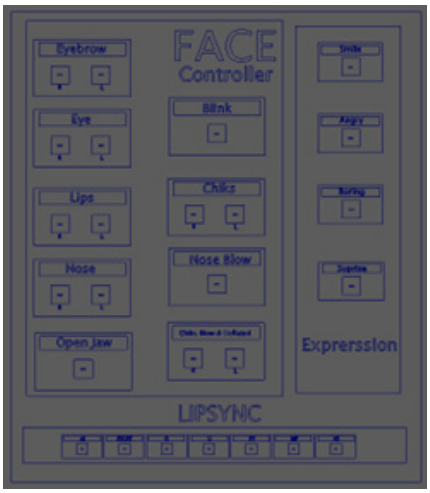

Figure 7. Control Panel
Source : Author's Documentation (2024)

Result

The results of the body rigging system are described based on the results of applying the main theory and supporting theories. The following is a description of the results of applying the theory. With results of the facial rigging system are described based on the results of applying the main theory and supporting theories too.

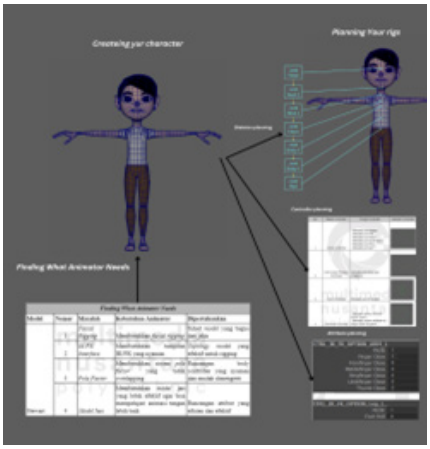

Figure 8. Results of Applying the Theory of Body Rigging
Source : Author's Documentation (2024)

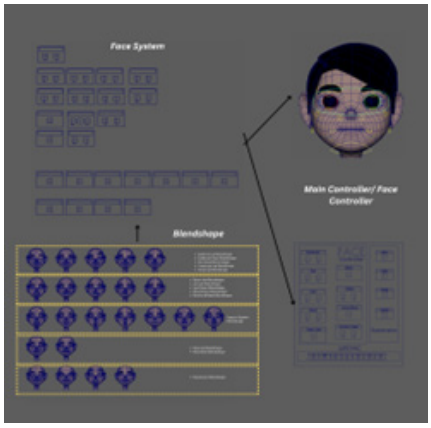

Figure 9. Results of Applying Briggs Theory to Facial Rigging
Source : Author's Documentation (2024)

Discussion

The researcher experimented by directly providing and interviewing experts from the MNC Animation Studio's artist rigger. The Gery model is feasible or can be used for animation learning needs, but there are still several rigging systems that can be developed and improved by the author so that the work is even more perfect. Based on expert input, a professional rigging system should incorporate several additional systems. Interviews with students suggest that the Gery model is effective for learning 3D Character Animation, but improvements are needed. Issues such as overlapping extra face controllers causing mesh penetration have been noted. Overall, while the Gery model is suitable for teaching, enhancing it with additional systems could elevate it to a professional standard.

Conclusion

The design of the rigging system on the Gery model is based on the results of data observations on the body rigging and facial rigging systems on the models used previously in the learning process of the 3D character animation course, namely the Stewart and Mery models. The system design is also based on several theories that the author applies at the stage before the creation of the work or the foundation stage, namely the stage of applying supporting theories and the stage when creating the work or the execution stage, namely the stage of applying the main theory. Technological developments have a huge influence in rebuilding behavior and giving meaning itself (Pratama & Nugroho, 2023, p. 417).

The Gery model is designed to provide solutions to problems obtained from the previous model, especially in the comfort of the facial rigging system, which prompted the author to create an experiment or innovation in the form of a controller and rigging system with experimental results, namely, lipsync system, extra face controller and limit information system as the main advantages of the Gery model. I hope that the model can improve the comfort of learning at Multimedia Nusantara Polytechnic, Digital Animation Department in the 3D character animation learning process. Researchers have also submitted Intellectual Property Rights (IPR) so that no one can copy the legality and ownership of the system because the system has been legalized.

The Gery model has some issues in its rigging system, including problems with the automatic twisting of arm and leg IK systems and the hair system and controller. While it is suitable for learning 3D character animation, experts and users suggest that updating these systems could enhance its functionality and elevate it to a professional standard.

References

AAA Game Art, S. (2023). What Is Rigging In 3d Animation And What Does It Mean? 3d Rig Of Character Design 3D Model. Art Outsource Service Studio. https://aaagameartstudio.com/blog/what-is-rigging-in-3d-animation/

Abdillah, T. R. (2021). Optimasi Proses Produksi Animasi 3d Dengan Menggunakan Metode Controller Rigging Wajah. Jurnal TIKA, 6(03). https://doi.org/10.51179/tika.v6i03.812

Allen, E. M., & Murdock, K. (2008). Body language: Advanced 3D character rigging. Wiley Pub.

Aprianto, H. D., Suyanto, M., & Purwanto, A. (2023). Efektivitas Rigging Pada Aset Karakter Animasi 3D. JIPI (Jurnal Ilmiah Penelitian Dan Pembelajaran Informatika), 8(3), 857–863. https://doi.org/10.29100/jipi.v8i3.3988

Arby, S. P., & Widiastomo, Y. M. (2024). Adapting "Tickle Fickle" Comic Strip to an Animated Short Film. In R. Ihwanny & S. Hakim (Eds.), Proceedings of the International Moving Image Cultures Conference (IMOVICCON 2023) (Vol. 20, pp. 227–239). Atlantis Press International BV. https://doi.org/10.2991/978-94-6463-390-0_22

Arshad, M. R., Yoon, K. H., & Manaf, A. A. A. (2019). Physical Rigging Procedures Based on Character Type and Design in 3D Animation. International Journal of Recent Technology and Engineering (IJRTE), 8(3), 4138–4147. https://doi.org/10.35940/ijrte.C5484.098319

Beavis, B. C. (2023). Perancangan Rig Tokoh Ayu Untuk Menampilkan Variasi Ekspresi Wajah Dalam Film Animasi 3D [Multimedia Nusantara University]. https://kc.umn.ac.id/id/eprint/25349/

Briggs, C. (2021). An Essential Introduction to Maya Character Rigging (2nd ed.). CRC Press. https://doi.org/10.1201/9781315771403

Dupré, G. (2023). Rigging in Animation: Definition, Process & Challenges. CG Wire. https://blog.cg-wire.com/rigging-in-animation/

Ekman, P., & Rosenberg, E. L. (Eds.). (2005). What the face reveals: Basic and applied studies of spontaneous expression using the facial action coding system (FACS) (2nd ed). Oxford University Press.

Faigin, G. (2008). The artist's complete guide to facial expression (Nachdr.). Watson-Guptill.

Grant, J. (2024). What is a 3D animator? Unreal Engine. https://www.unrealengine.com/en-US/explainers/animation/what-is-a-3d-animator

Pirmansah, I. A. (2024). The Effect of Combining Rig Joint and Blendshape Methods on Faces to Increase Efficiency in 3D Animation. SMART: Jurnal Teknologi Informasi dan Komputer, 3(1). https://doi.org/10.58222/smart.v3i1.784

Pratama, T. A. (2023). Pandangan Terhadap Ketidaksadaran Masyarakat Menjadi Seorang Pakar dalam Kasus Sepakbola di Twitter. Jurnal Penelitian Humaniora, 1(1). https://doi.org/10.21831/hum.v1i1.52752

Pratama, T. A., & Nugroho, H. (2023). Games, Speed Effect dan Dampaknya terhadap Manusia: Dromologi dalam Perkembangan Game Online Mobile MOBA (Multiplayer Online Battle Arena). Jurnal Kawistara, 13(3), 402. https://doi.org/10.22146/kawistara.75218

Pratama, T. A., & Rosita, E. (2023). Implementation of Augmented Reality

for Isometric works at Animation Art Exhibition (Animaxtion). Ultimart: Jurnal Komunikasi Visual, 12–25. https://doi.org/10.31937/ultimart.v16i1.3111

Rahmadini, S. (2023). Studi Komparasi Maskot-Maskot Non-Manusia dalam Menggambarkan Citra Institusi di Media Sosial. CandraRupa : Journal of Art, Design, and Media, 2(2), 105–112. https://doi.org/10.37802/candrarupa.v2i2.446

Satriawan, A., & Apriyani, M. E. (2016). Analisis dan Pembuatan Rigging Character 3D Pada Animasi 3D "Jangan Bohong Donk." Jurnal Teknik Informatika, 9(1). https://doi.org/10.15408/jti.v9i1.5580

Yan, W.-J., Wu, Q., Liang, J., Chen, Y.-H., & Fu, X. (2013). How Fast are the Leaked Facial Expressions: The Duration of Micro-Expressions. Journal of Nonverbal Behavior, 37(4), 217–230. https://doi.org/10.1007/s10919-013-0159-8