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Analysis of Inverse Kinematics Method for Human Movement In 2D Animation

Annisa Rahayu Pangesti
Magister of Informatics Engineering
University of Amikom Yogyakarta
Yogyakarta, Indonesia
annisa.p@students.amikom.ac.id

Ema Utami
Magister of Informatics Engineering
University of Amikom Yogyakarta
Yogyakarta, Indonesia
ema.u@amikom.ac.id

Andi Sunyoto
Magister of Informatics Engineering
University of Amikom Yogyakarta
Yogyakarta, Indonesia
andi@amikom.ac.id

***Abstract*—Creating a 2D animated human character is a challenging task, especially when using traditional techniques. Several problems arise when the scene gets more complicated and requires a large number of frames, making the animation process takes time even longer. Therefore, the animator needs an efficient method for animating human movement to make the process faster and easier. Inverse kinematics is a method that used for animated characters which have articulated bodies by animate the whole chain of joint with just the end effector. However, this method creates body movements that have no limit on the joints and do not match with human anatomy. In this research, we explore the inverse kinematics method to create a turn-around animation and apply the degree of freedom to the character. The result shows that by adjusting the degree of freedom for each joint, it can make the animation process a lot easier and produce an animation that has body movement with an accuracy of 95%.**

Keywords*—*animation, 2d animation, human movement, kinematics, inverse kinematics

I. Introduction

Computer animation has become one of the most profitable industries with high growth rates in each year. As we can see, the presence of animation can be found easily in our daily life, from the television series, commercials, music videos, video/computer games, and films. Even now the use of animations has been extended, to various fields such as architecture, education and health. In 2018, the global animation industry got a total profit of up to $ 259 billion [1].

In Indonesia in 2016, animation, which was incorporated in the Film, Animation and Video sub-sector became one of the sub-sectors that had a significant and massive impact on the national economy, and it becomes one of the creative industry sub-sectors that become priorities and to be the focus on being managed and developed [2]. Even this year, the Creative Economy Agency (Bekraf) predicts that the animation industry will be one of three potential fastest-growing sub-sectors of the creative economy.

The growth of the animation sub-sector has increased to 6.68%, where the figure has reached a position above the average of creative economic growth, which is around 4.38% [3]. However, with this increased growth rate, the contribution to Gross Domestic Product (GDP) is still relatively small at 0.16% [4] and has not contributed significantly to the global animation industry. The main factors that affect it are the limitations of time and costs.

Computer animation, in the form of a film, can be divided into several types, but the most commonly used types are 2D animation and 3D animation [5]. In 2D animation, the objects are flat because they only have 2 coordinates; horizontal axis (X) and vertical axis (Y), while 3D animation has 3 coordinates; X, Y, and Z, where this makes 3D objects have volume/depth, so it can be seen from all directions. Based on the advantages of each type of animation, through this research, we will combine these advantages and focus on one of the stages in 3D animation; rigging.

In the animation, the human is one of the most difficult characters to animate convincingly [6]. Each part of the body moves according to the anatomy of the skeletal system, mainly by a skeletal system that is interconnected with joints so that every animated movement must be done accurately and in detail. The more complex the movements are carried out, the longer the time needed to make the animation. Therefore, we need a method that makes the character movements that can be done more easily, quickly, and match with human anatomy.

In this study, the authors refer to a number of previous studies that discussed topics related to the research that the author would do. Earlier research explains the technique to perfect the inverse kinematics method for human fingers, which also have joints that are connected and form certain angles when moved. Researchers create a solution with closed-form algorithm which can provide accurate positioning when driven model of human finger movement [7]. Another study found that 2D animation has its advantages that are different from 3D, and with the use of digital media can speed up the animation process [8].

From these studies, the animation results are still produce movements that do not match and do not based on their anatomy. The 2D animation results displayed are also only made from one direction, left or right side direction. In this study, we provide a solution to these problems by applying the degree of freedom on a turn-around human 2D animation with inverse kinematics method. So that the movement of each joint will pay attention to the maximum and minimum Degree of Freedom that corresponds to the original object.

II. Kinematics and Human Movement

A. Kinematics

Kinematics is the study of the movement and which have a joint, such as the movements of walking, by calculating the position, rotation, speed, and acceleration all articulated joints and components. In animation, kinematics is divided into two types based on the method of movement.

Forward kinematics (FK) is a method that works directly with the reference angle of a joint to reach a specific location that each joint is moved individually, and moves in sequence without any purpose. While Inverse kinematics (IK) is a method for turning on objects and shapes that depend on the structure which is an articulated body. Articulated bodies can represent most animated figures such as humans and animals, which consist of joints and links that are connected to each other. This technique is very effective for simplifying complex animations.

B. Human Movement

The human body is able to move from one place to another (locomotion) due to the existence of a frame. Human skeleton is an arrangement of various kinds of bones which are connected to each other by joints/articulation and become a place for attaching muscles so that they can produce motion. Joint is a relationship that occurs in two or more bones. The joints contained in the human body mostly have 1 Degree of Freedom (DoF). Some of them have DoF multiple like on the wrist with 2 DoF, and shoulders that have 3 DoF. Based on the nature of the motion, the joints can be categorized into several joints:

1) Immobile Joints (Synarthrosis): The joints are intermittent relationships that cannot be moved. Example: an inter-bone relationship that forms the skull.

2) Limited Joints (Amphiarthrosis): These joints have limited mobility and the relationships between bones that can be moved in a limited way, only to move closer and away between the two bones. Example: cartilaginous joint that unites the body of adjacent vertebrae

3) Free Joints (Diarthrosis): These joints are relationships between bones that can be moved freely. Diarthrosis joints in humans are divided into five types, namely: pivot joints, ball and socket joints, hinge joints, sliding joints and saddle joints.

III. RESEARCH AND METHODOLOGY

This study uses a Research and Development research method that is descriptive with a quantitative approach. The process of this research can be seen in Flow Chart in Fig. 1.

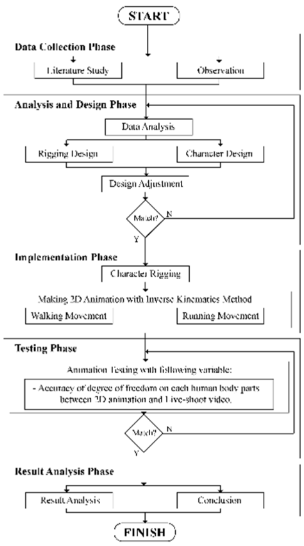

Fig. 1. Flowchart methodology of this research.

IV. ANALYSIS AND DESIGN

The analysis phase is a process to get data about the object of research. In this study, we used human walking and running movements as samples in 2D animation. The analysis carried out includes walking/ running and joint degrees when moving.

A. Movement Analysis

To find out how the movements of the limbs when walking and running, an analysis of the movement is carried out through direct observations recorded in the form of video. Some videos used for observations were also obtained from several sources on the internet, one of which was the endless reference channel on the YouTube site. The reference video is then played through the QuickTime Player version 10.4 as shown below.

Fig. 2. Video reference of human walking movement.

Fig. 3. Video reference of human running movement.

Walking is one of the movements that are often used in animated films and became the first lesson for the animators for the running movement is the hardest thing to do right. Although the walk looks like a simple act, but this movement actually takes brains and nervous systems are coordinated so as to have the ability to plan and predict the actions and reactions. To walk elegantly and efficiently, each system of the body, especially the sense of vision, balance and sensation must be able to communicate in harmony.

Every human being has a different gait that can form a character from each individual. Differences in gait are influenced by several factors such as gender, age, weight, health, moods, and other factors. For example, women will naturally walk with their feet close together, short and straight forward footsteps, different from a man's gait with wider legs when walking compared to women. However, even though every human's gait looks different, all humans have the same walking pattern. In general, the human walking pattern at each step has five phases, as illustrated in Fig. 4 [9].

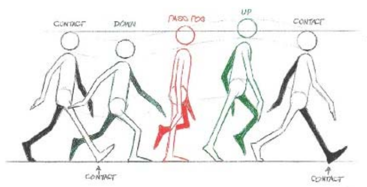

Fig. 4. Human walking phases.

The first phase is the phase contact, which is the stage where one-foot steps forward and touches the floor, then the second phase is Down, when the body moves forward, rests on the foot that had previously moved so that the body position becomes lower than the phase contact. The Phase Pass post is the third stage where the body position is normal as when standing upright with one leg ready to swing forward.

Then phase Up, the legs are swung forward with the back of the toe touching the floor (tiptoeing) so that the body position is higher than the postal pass. The last phase is a phase contact like the first phase, but the foot that steps forward is the opposite foot. The hand is in the opposite position to the foot synchronously. When the right foot steps forward, the left-hand swings forward, and vice versa. The speed and magnitude of the angle of the hand swing are influenced by the amount of energy used by the foot.

While the running motion pattern as shown in Fig. 5 [9], has the same phase as the walking movement pattern, namely phase Contact, Down, Post Pass, Up, and return to the Contact with the opposite leg. But when running, the body slightly bent forward to give speed, then the insert image after the phase up showed the position of the floating foot, while the position of the arm bent and swung synchronously in the opposite direction with leg movements.

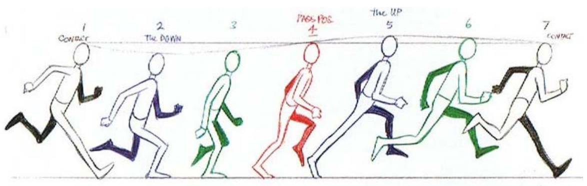

Fig. 5. Human running phases.

B. Analysis of Joint Degrees

The next stage is to analyze the degree in joints of humans. The analysis of the degree of joints aims to determine the degree of freedom of the human bone when moving. From this analysis, it will be known which direction, and how much angle each joint can move. In this study, the joints to be measured consist of several joints that are included in the diarthrosis/synovial joint, which can be shown in Fig. 6.

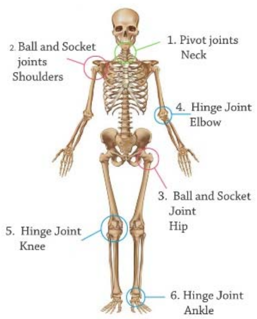

Fig. 6. Measured human joints.

Measurements are taken by taking photos of each joint from the study sample and then measuring it using software so that the minimum and maximum angles of each joint can be known as presented in Table. I.

TABLE I. MEASUREMENT OF DEGREES OF FREEDOM JOINTS

No	Human joints	Body parts	Bone direction	Min Degree of Freedom	Max Degree of Freedom
1	Pivot joints	Between neck and head	Right and Left	60°	120°
			Forward and backward	40°	105°
			Turn to right and left	0°	180°
2	Ball and Socket joints	Shoulder	Forward and back	0°	360°
			Right and Left	0°	360°
3	Hinge joints	Elbow	Forward	35°	180°
			Backward	0°	145°
4	Ball and Socket joints	Hip	Forward and backward	0°	70°
5	Hinge joints	Knee	Forward	60°	180°
			Backward	0	120°
6	Hinge joints	Ankle	Forward and backward	95°	105°

C. Character Design

At the stage of designing human characters, the first step is to sketch characters. To avoid disproportionality or imbalance, human sketch drawings made refer to the Laws of Proportion which form the basis for drawing figures in ideal or legal human form that have a perfect relationship between body size.

The depiction of a proportional figure, irrespective of variations due to sex and so on, is determined by the alignment of the joints that are not changing and are based on the unit of measurement that is appropriate and exactly the measurement of the head. The law of the proportion of Praxiteles stipulates that the total height of the human body is exactly the same as eight heads [10]. The making of sketches and character models in this study was made using Adobe Photoshop CC 2017 software and drawn from four angles in a turn-around movement as seen in Fig. 7.

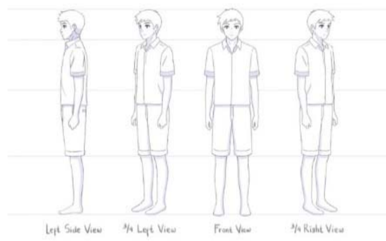

Fig. 7. Character design.

D. Character Rigging Design

After designing the characters, the next stage of the bone structure design based on human anatomy as illustrated in Fig. 8. The design of bone design aims to facilitate the rig making process in the animation stage.

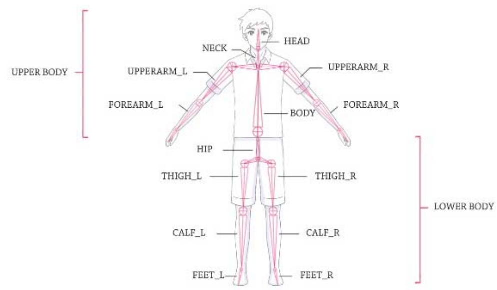

Fig. 8. Character rigging design.

Based on the bone design, a relationship between bone design and a description of objects included in the linking hierarchy, parent and child, are made. Parent is an object that becomes a reference to other objects, so that if there is a change, the child will also change. However, changes made to children will not affect the parent.

TABLE II. DESIGN OF RELATIONSHIP BETWEEN BODY PARTS

Object/Layer /Peg Name	Parent Object	Child Object
Master	-	Upper_Body
Upper_Body	Master	Lower_Body
		Head_Neck
		Body
		Hand_R
		Hand_L
Hand_R	Upper_Body	Upper_Arm_R
Upper_Arm_R	Hand_R	Lower_Arm_R
Lower_Arm_R	Upper_Arm_R	Palm_Finger_R
Hand_L	Upper_Body	Upper_Arm_L
Upper_Arm_L	Hand_L	Lower_Arm_L
Lower_Arm_L	Upper_Arm_L	Palm_Finger_L
Lower_Body	Master	Hip
		Leg_R
		Leg_L
Leg_R	Lower_Body	Thigh_R
Thigh_R	Leg_R	Calf_R
Calf_R	Thigh_R	Feet_Leg_R
Leg_L	Lower_Body	Thigh_L
Thigh_L	Leg_L	Calf_L
Calf_L	Thigh_L	Feet_Leg_L

V. METHOD IMPLEMENTATION

A. Making 2D Character

The 2D character making phase is done using the Toon Boom Harmony Premium software with reference to the character designs that have been made before. Making each character's body part is drawn on a different layer and grouped into a group layer based on the direction/angle of view.

The image layer is then arranged based on parent/child categories. The top layer is the master layer as the parent which serves to store all the layers of the body part that is in the layer below it. Then each layer is divided into two categories of body parts, namely the upper body and lower body which serves as the parent for each other body part that is directly connected with each body. To facilitate the preparation, each layer is named in the same format, namely AngleofView_BodyPart_Description, as seen in Fig. 9.

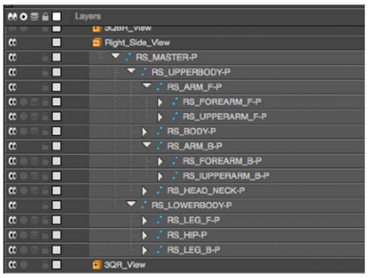

Fig. 9. Layout of each group.

B. 2D Character Rigging

The first stage is to apply the inverse kinematics to determine the pivot of every part of the character. Pivot is a core point that is used as the axis of an object. After each pivot is determined, using the inverse kinematics tool, the overall rig of the character will be formed automatically.

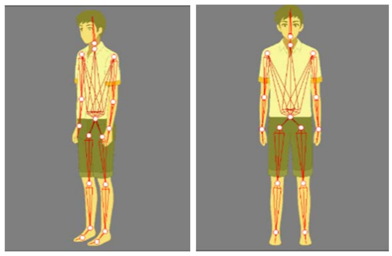

Fig. 10. 2D Character Rigging.

Then the joint freedom degrees of each bone are adjusted using the inverse kinematics tool based on the previous joint degree analysis. It is intended that the movement generated animation of the character can look like actual human movement with the limits of a minimum and maximum movement of anybody owned.

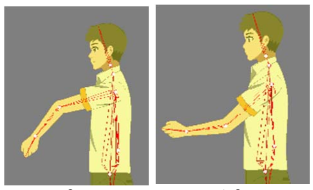

Fig. 11. Setting min/max degree of freedom (before and after).

Fig. 11. shows that before the min/max degree angle is applied, the character's arm can be moved freely in all directions, so that the resulting movement as in the elbow is not in accordance with human movement. Whereas after applying the min/max degree angle, the character arm movement will still produce an articulation angle that matches the original human movement even though the end effector on the character's arm is moved in all directions.

C. Animation Process

The stage of making the animation begins by making a keyframe that determines the starting and ending points of each transition, which then includes an in-between frame. Each frame consists of one static image that is displayed in a measure of speed called Frame Rate with its unit, Frame Per Second (FPS). In this study, the number of movement frames made was 24 with 5 keyframes according to 5 phases.

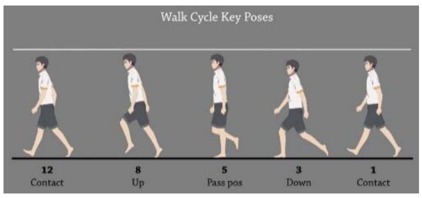

Fig. 12. Walk Cycle Key Poses.

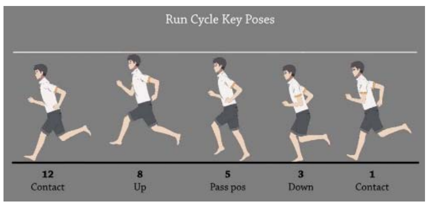

Fig. 13. Run Cycle Key Poses.

In this study, the walking and running movements have different movements from previous studies. There are turn-around movements of the body so that 2D animation can appear to have volume and is not limited to only from front or back and side angle. The turn-around phase can be seen in Fig. 14.

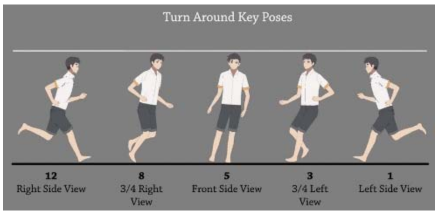

Fig. 14. Turn Around Key Poses.

The next step is to add the in-between drawing in the middle of each keyframe to make it looks smooth and then render it and export it into a .mov video.

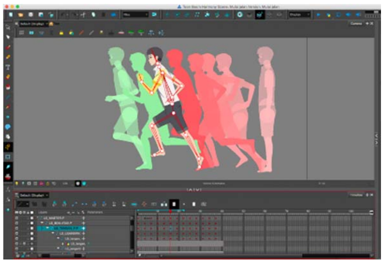

Fig. 15. 2D Animation Process.

VI. RESULT

The results of 2D animation are tested by comparing the degree of the angle formed by each joint in the body part with the live-shoot video. This test aims to determine the accuracy of the similarities between the two videos. This test used Tracker software, which can record the angles of each body part that is formed in each frame. Tested body parts include head, elbows, and knee.

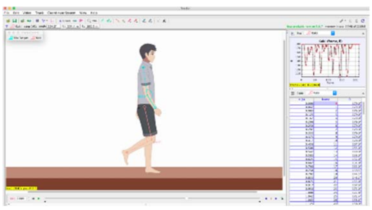

Fig. 16. Animation testing with Tracker software.

t (s)	frame	θ
0.000	0	179.0°
0.083	1	179.0°
0.125	2	179.0°
0.167	3	179.0°
0.208	4	179.0°
0.250	5	179.0°
0.292	6	179.0°
0.333	7	179.0°
0.375	8	179.0°
0.417	9	179.0°
0.458	10	170.0°
0.500	11	167.0°

Fig. 17. Table view of angle measurement.

The test results are displayed in graphs as in Fig. 16, and tables as in Fig. 17. The following are comparison graphs made based on the graph of the test results.

A. *Walking Movement*

The following are the comparison graph from 2D animation video and live-shoot video on each body part in the human walking movements. The vertical axis (y) in the graph shows the protractor angle, and the horizontal axis (x) shows the sequence of frames.

1) *Head*

As seen in Fig. 18, movement in the head joint does not change even though the body moves freely. This is indicated by the value of the degree of joint on the head, which is 0° from the first frame to the last frame, which is frame 215, meaning that the joints on the human head are included in the dead joint (the immobile joint).

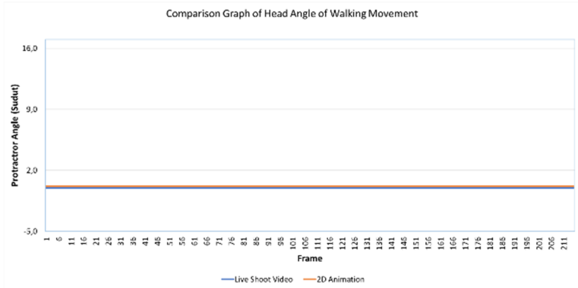

Fig. 18. Comparison graph of head angle in the walking movement.

2) *Elbow*

Fig. 19 shows that the angle of the elbow of each frame in both videos produces the appropriate value so that it forms a similar pattern with a range of angles between 105°–180°.

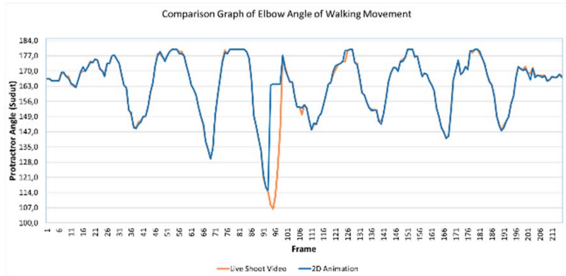

Fig. 19. Comparison graph of elbow angle in the walking movement.

3) *Knee*

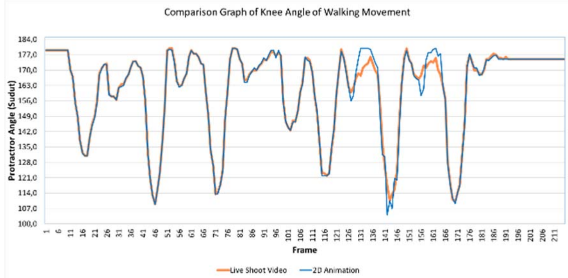

Fig. 20. Comparison graph of knee angle in the walking movement.

B. *Running Movement*

1) *Head*

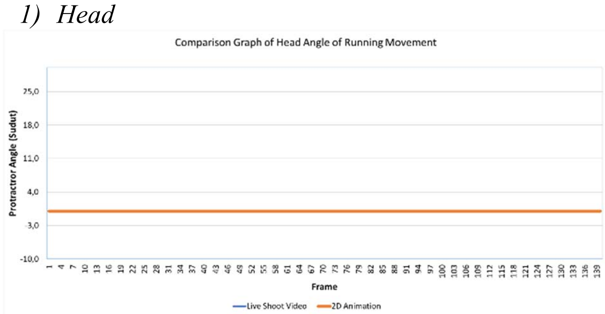

Fig. 21. Comparison graph of head angle in the running movement.

2) Elbow

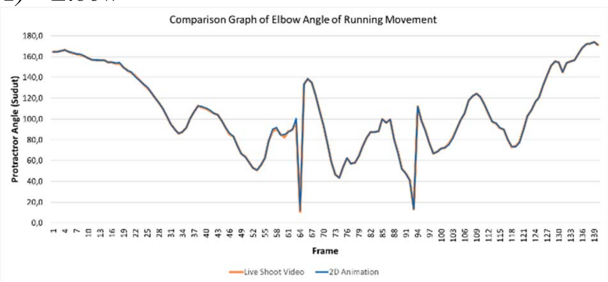

Fig. 22. Comparison graph of knee angle in the running movement.

3) Knee

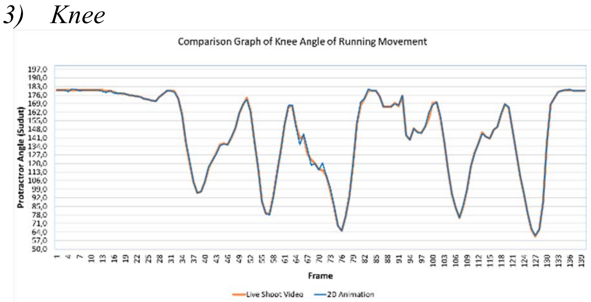

Fig. 23. Comparison graph of knee angle in the running movement.

After getting the data, the calculation is done to determine the accuracy of 2D animation using the inverse kinematics method for the live-shoot video. Tolerance value in this context is the magnitude of the difference between actual conditions versus ideal conditions, to the extent that the difference is not a functional failure or a significant reduction in function. To calculate the accuracy value on each body parts between 2D animation and live-shoot video on walking movement using the following formula:

1. *Walking Movement*

The following are data obtained from tests:

- Angle deviation tolerance value = 1°
- Σ frame walking movements = 215
- Σ frame head angle with tolerance <1° = 215
- Σ frame elbow angle with tolerance <1° = 204
- Σ frame knee angle with tolerance <1°=186

$$Accuracy = \frac{\Sigma\, frame\ with\ tolerance < 1°}{\Sigma\, frame\ walking\ movements} \times 100\ \% \qquad (1)$$

a) Head Angle Accuracy (HAA):

$$\text{HAA} = \frac{215}{215} \times 100\ \% = 100\ \%$$

b) Elbow Angle Accuracy (EAA):

$$\text{EAA} = \frac{204}{215} \times 100\ \% = 94{,}88\ \%$$

c) Knee Angle Accuracy (KAA):

$$\text{KAA} = \frac{186}{215} \times 100\ \% = 86{,}51\ \%$$

d) Walking Movement Accuracy:

$$Accuracy = \frac{(HAA + EAA + KAA)}{3} \qquad (2)$$

$$= \frac{(100\ + 94{,}88 + 86{,}51)}{2}$$

$$= 93{,}80\ \%$$

2. *Running Movement*

The following are data obtained from tests:

- Angle deviation tolerance value = 1°
- Σ frame running movements = 140
- Σ frame head angle with tolerance <1° = 140
- Σ frame elbow angle with tolerance <1° = 136
- Σ frame knee angle with tolerance <1°=123

To calculate the accuracy value on each body parts between 2D animation and live-shoot video on running movement using the following formula:

$$Accuracy = \frac{\Sigma\, frame\ with\ tolerance < 1°}{\Sigma\, frame\ running\ movements} \times 100\ \% \qquad (3)$$

a) Head Angle Accuracy

$$\text{HAA} = \frac{140}{140} \times 100\ \% = 100\ \%$$

b) Elbow Angle Accuracy:

$$\text{EAA} = \frac{136}{140} \times 100\ \% = 97{,}14\ \%$$

c) Knee Angle Accuracy:

$$\text{KAA} = \frac{123}{140} \times 100\ \% = 87{,}86\ \%$$

d) Running Movement Accuracy:

$$Accuracy = \frac{(100 +\ 97{,}14 + 87{,}86)}{3} = 95\ \%$$

VII. Conclusions

The test shows that by implementing a degree of freedom limitation on inverse kinematics method can produce 2D animation that matches human anatomy with a high level of accuracy. The application of the degree of freedom on the immobile joint (synarthrosis) and stiff joints (amphiarthrosis) has no effect on movement so that in making 2D animation of human movements, it only requires a degree of freedom setting on the free joints (synovial). This method also can be used in the turn-around movement in 2D animation.

References

[1] "Global Animation, VFX & Games Industry: Strategies, Trends & Opportunities 2019", Research and Markets, January, 2019. [Online]. Available: https://www.researchandmarkets.com/reports/4721808/global-animation-vfx-and-games-industry. [Accessed: August 24, 2019].

[2] Creative Economy Agency, "OPUS – Creative Economy Outlook 2019", Jakarta, October 2018.

[3] Creative EconomyAgency, Central Bureau of Statistics, "Statistical Data and Survey Results – Creative Economy", Jakarta, March 2017.

[4] F. Rochman, H. Subiyantoro, Faridah, N. C. Umam, National Animation Development Plan 2015-2019, Jakarta: PT. Republik Solusi, March 2015.

[5] Ferguson, "Ferguson's Careers in Focus: Animation", New York: Infobase Publishing, 2010.

[6] R. Steve, "Character Animation: 2D Skills for Better 3D", London: Taylor & Francis, 2013.

[7] D. Roel, Arjan E., Stappen F., "A Closed-Form Solution for Human Finger Positioning", *Proceedings of the 8th ACM SIGGRAPH Conference on Motion In Games*, Paris, pp. 73-72, November 2015.

[8] Corrigan. N. C, "Outta This World: Merging Classic Animation Styles With Modern Technologies and Design", Ohio, August 2017.

[9] W. Richard, "The Animator's Survival Kit: A Manual of Methods, Principles and Formulas for Classical, Computer, Games, Stop Motion and Internet Animators", United Kingdom: Faber & Faber, 2009.

[10] Sterling. Publishing Co., "Art of Drawing the human Body", Sterling Publishing, 2004.