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Beat Defender: Integrating Fuzzy Logic into Audio Visualization Video Game

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Abstract

Sound has a vital role in showing the atmosphere in a video game. However, for most people, the sound element in the video game is not overly noticed. So the Beat Defender game was made which highlighted the sound elements in it. This research aims to design and build a game called Beat Defender using fuzzy logic. By using fuzzy logic, components in this game can have artificial intelligence that reacts with sound. Beat Defender is a three-dimensional video game that relies on music as its main component. The player must keep an object from approaching enemies from all directions. The enemy's movements depend on the artificial intelligence of the fuzzy logic algorithm that reacts to the music that being played. To fight enemies, players use audio visualizations that react with sound input from the player's microphone. The programming language used in the making of this game is the C# language. The research process begins with conducting a literature study, then design, development, testing, report writing, and consultation with supervisors throughout the research. After doing research, it can be concluded that designing and building Beat Defender game using a fuzzy logic algorithm is a success.

Keywords: Audio visualization, Beat Defender, Fuzzy Logic, HMSAM.

I. INTRODUCTION

In making or building a video game, many elements must be considered. The elements include images, sound, gameplay, even marketing. To produce a successful video game, a synergy of all elements in this video game is needed [1]. Among these elements, the sound element has a vital role in showing the atmosphere in a game. Through sound, both music and sound effects, the subconscious of the player can be touched. So the experience that the developer wants to convey can be conveyed correctly and adequately [1].

For some people, the sound element in a video game is not too much attention. Not too much attention here means that the music played in video games is just a background decoration [2]. As a result, the music that had wanted to show the atmosphere in video games became inefficient and not on target.

Sound can not only be heard but can also be seen by making animation-based on the sound pieces used. This technique is better known as audio visualization [3]. There are two basic approaches to audio visualization, including real-time animation and preprocessed animation. Real-time animation usually consists of simple objects modified according to music dependence. Preprocessed animation is an animation that has been compiled by the user according to his willingness about certain music [3].

The real way of a music game to improve is to consider music as part of the game decision-making process [4]. Not only music responds to games, but games must also be aware of the music being played [2].

The nature of dynamic music frequency, making video games that use music as a gameplay mechanism requires an approach that can be solved with artificial intelligence. Among the available artificial intelligence, the Fuzzy Logic algorithm is very suitable for dynamic things because this logic does not provide a definite value (boolean, 1 or 0) but among them [5].

With all of the above considerations, this research will design and build Beat Defender game using fuzzy logic algorithms and audio visualization. The synergy of these components is expected to make a video game that is very interactive and also has its artistic value.

II. RELATED WORK

Fuzzy logic has been researched and implemented in various applications, not to mention in game domain. It has been used to optimize the enemy's behaviour in Super Mario Bros Game by Ismail et al. [6] and to strengthen Mathematical logical reasoning in a serious game developed by Sanchez and Lara [7]. Fuzzy logic even has been used to simulate the shopper behaviour in a shopping center simulation [8, 9]. Other basic concepts and related works will be described in this section, such as audio visualization, fuzzy logic algorithm, and HMSAM model.

II.I Audio Visualization

Aspects that must be seen in making an audio visualization are volume, mood, melody, instrument, tempo, visual effects, and others. After that, all these aspects are combined to create a harmonized visualization [3]. Therefore, we need a way to integrate all of them so that they can work together. To integrate it, there is a scheme that can help make audio visualization. As shown in Fig. 1, audio visualization has a plot or scheme and has the main components of a sound analyzer, visualization module and scene editor [3].

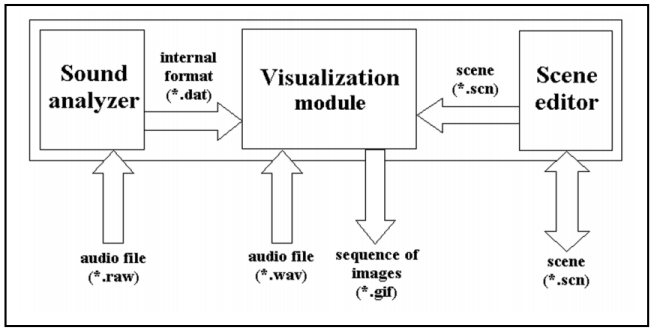

Fig. 1. Base scheme of Video Audio Visualization game [3]

II.I.I Sound Analyzer

The sound frequency that the human ear can catch is in the range of 20Hz-20,000Hz [10]. Audio files that enter the sound analyzer are analyzed and divided into various parts. This range of sound frequencies can be used as various groups as shown in Fig. 2.

Frequency (Hz)	Octave	Description
16 to 32	1st	The lower human threshold of hearing, and the lowest pedal notes of a pipe organ.
32 to 512	2nd to 5th	Rhythm frequencies, where the lower and upper bass notes lie.
512 to 2048	6th to 7th	Defines human speech intelligibility, gives a horn-like or tinny quality to sound.
2048 to 8192	8th to 9th	Gives presence to speech, where labial and fricative sounds lie.
8192 to 16384	10th	Brilliance, the sounds of bells and the ringing of cymbals and sibilance in speech.
16384 to 32768	11th	Beyond Brilliance, nebulous sounds approaching and just passing the upper human threshold of hearin

Fig. 2. Voice frequency group [3]

Music data or data spectrum (float data type) of the music being played needs to be taken. Spectrum data can be retrieved by the GetSpectrumData () function in the IDE (Integrated Development Environment) Unity. In this function, several parameters are needed, the place variable holds the value, the channel (boolean, left or right speaker output), and Fast Fourier Window (FFTWindow, is a mathematical function that can take the data spectrum). This function returns the value in the form of changes in the data spectrum into data that can be used in the game [11]. Spectrum data that has been obtained can also be accommodated into an array if the object will move a lot later.

II.I.II Scene Editor

In this section, objects in the scene must be defined first. The object can be a basic geometric object (sphere, cube, etc.) or system particles. These objects are formed from the movement of data that changes from sound analyzer parameters. After that, the scene is processed in the visualization module to display.

Audio visualization objects in the form of basic geometric objects cannot be made complex or abstract. In making audio visualization, there needs to be an object that has an abstract form but can still be controlled. Objects must also be able to express the feel of music well. That can answer all of those things is a particle system [3].

II.I.III Visualization Module

The task of the visualization module is to process scene data and sound data. This stage sets the rendering speed of each animation phase that occurs. Performance depends on the reliability of the user's equipment. The optimal speed for rendering an animation frame is 1/25 sec (25 fps). In real-time, there must be some scenes that are difficult to render at that speed, especially when entering complex scenes [3].

II.II Fuzzy Logic Algorithm

Fuzzy logic algorithms are an enhancement of Boolean logic dealing with the concept of partial truth. When classical logic states that everything can be expressed in binary terms (0 or 1, black or white, yes or no), fuzzy logic replaces boolean truth with the level of truth. Fuzzy logic allows membership values between 0 and 1, gray level as well as black and white, and in linguistic form, uncertain concepts like “little”, “pretty”, and “very”. This logic is related to fuzzy sets and probability theory. Fuzzy logic was introduced by Dr. Lotfi Zadeh from the University of California, Berkeley in 1965 [5].

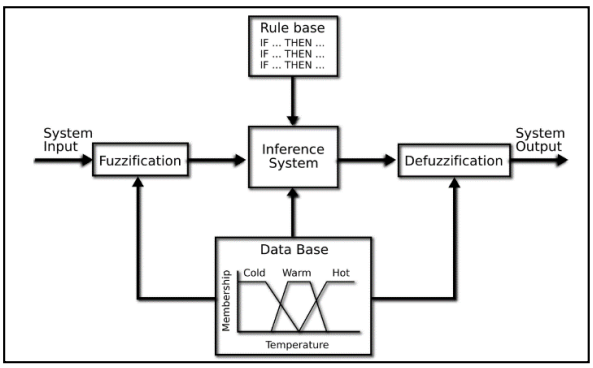

Fig. 3. Fuzzy Logic architecture [12]

Fig. 3 shows, there are three main processes if you want to implement fuzzy logic on a device, namely fuzzification, rule evaluation, and defuzzification [12]. Fuzzy logic is generally applied to problem problems that contain elements of uncertainty, imprecise, noisy, and so on. Fuzzy logic bridges precision machine language with human language that emphasizes the meaning or significance [5].

II.II.I Fuzzification

It is a process for converting input from a solid form (crisp) to fuzzy which is usually presented in the form of fuzzy sets with

their respective membership functions [12]. To get the fuzzy value, a straight line equation formula that passes through the intersection of a fuzzy set is used. A membership function has two sets of input and membership degrees (fuzzy values). After obtaining the degree of membership for each input, the next step is to apply logical operators or usually called rules. These rules are in the form of if-then logic that has been set beforehand.

II.II.II Inference System

This process evaluates predetermined rules as a reference to explain the relationship between input and output variables. Variables that are processed and produced are fuzzy. To explain the relationship between input and output Tsukamoto method can be used [12].

In Tsukamoto's method, the implications of each rule take the form of "Cause and Effect" or "Input-Output" [12]. So there are two ways to determine the relationship between variables, as follows.

- Fuzzy Conjunction

$$\alpha = \mu A \wedge B = \mu A(x) \cap \mu B(y)$$
$$= \min(\mu A(x), \mu B(y))$$

- Fuzzy Disjunction

$$\alpha = \mu A \vee B = \mu A(x) \cup \mu B(y)$$
$$= \max(\mu A(x), \mu B(y))$$

The use of logic '∨' or '∪' indicates the use of the method of disjunction in the calculation, which is to find the greatest value. Meanwhile, the use of logic '∧' or '∩' indicates the use of the method of conjunction in the calculation, which is looking for the smallest value.

Evaluation of the rules of relations between variables produces the degree of membership of the expected output. This membership degree is then used to determine the values in the membership output function. How to determine this value can be used straight-line equation formula.

II.II.III Defuzzification

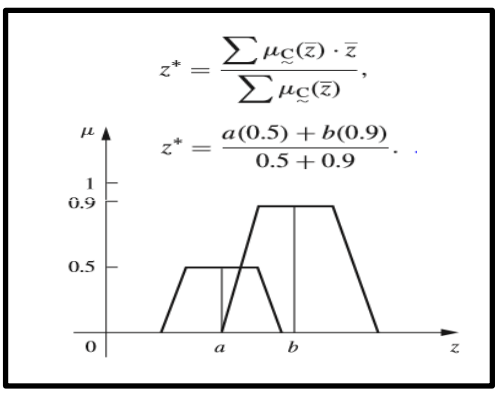

Fig. 4. The Weighted Average Defuzzification method

Defuzzification is the process of changing the fuzzy-shaped variables into definite data (crisp) so that the data can be used [12]. One method that can be used is to use the weighted average method. This method is most commonly used in programs or applications that use fuzzy logic because it is efficient when compiled. Examples of using the weighted average method can be seen in Fig. 4.

II.III Hedonic-Motivation Adoption Model

Fig. 5 shows the structure of the HMSAM model. HMSAM is an alternative model that can be used in the technology acceptance model (TAM) [13]. TAM is one of the models built to analyze and understand the factors that influence the acceptance of the use of computer technology. However, TAM is not ideal or suitable in explaining the usage of pure intrinsic or hedonic systems (for example online games, music, learning about satisfaction, etc.). So, an alternative model system was created, called HMSAM [13].

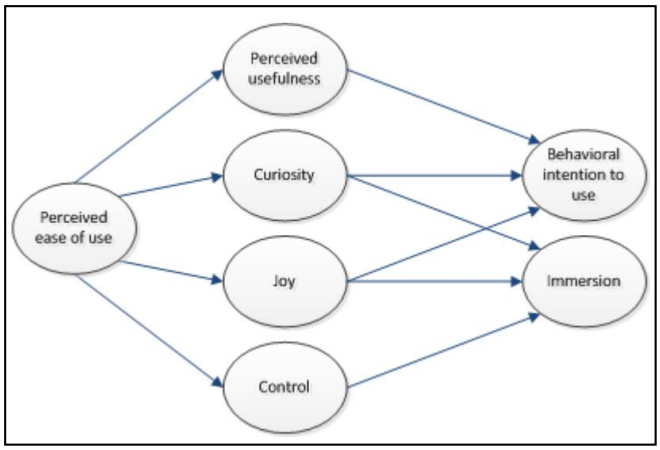

Fig. 5. Structure of the HMSAM model [13]

III. METHOD

In the design of the Beat Defender game, the research methodology used was divided into several stages, namely Literature Study, Documentation, Designing, Making, Testing and Evaluation phase.

III.I Video Game Design

We use flowchart diagrams in designing the video game, while the interface is designed by using some mockups. After that, we fill in the plan for the use of assets in the form of tables. We are then designing a questionnaire based on HMSAM for the trial phase.

The process of using fuzzy logic algorithms, used by the guidelines stated by Zadeh [12]. Referring to this guideline, fuzzy logic algorithm architecture in Beat Defender games can be seen in Fig. 6.

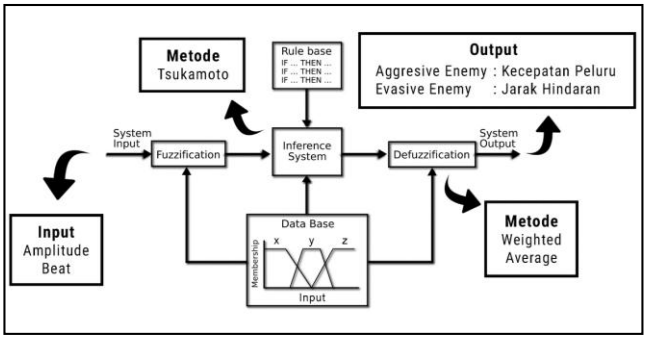

Fig. 6. The architecture of the Fuzzy Logic algorithm in Beat Defender game

From this diagram, several things need to be known before using fuzzy logic algorithms, namely the input of this algorithm and the inference rule of each type of enemy. In this game, fuzzy logic algorithms only accept two types of input namely amplitude and beat. This input is still in the crisp form (the correct input, if in boolean between 1 or 0) and obtained differently. Applications are designed using UML language which is divided into four diagrams namely use case, activity, class, and sequence diagrams.

Amplitude is the average value of the sound frequency obtained from eight audio bands belonging to the user's microphone input sound. The amplitude value is changed in such a way that has a value ranging from 0 to 10. Amplitude is categorized into three sets namely weak (with the smallest value of 0 and the largest value is 5), medium (has a range of 0-10), and hard (with the smallest value that is 5 and the biggest value is 10).

While the beat is the average value of the frequency obtained from the first and second audio bands that belong to the input music that is playing in the game. The beat value is changed in such a way that it has values ranging from 0 to 10. The beat is categorized into three low sets (with the smallest value of 0 and the largest value is 5), medium (has a value range of 0-10), and high (with the smallest value that is 5 and the biggest value is 10).

Each type of enemy has a different inference rule. There are two types of enemies designed to have artificial intelligence using fuzzy logic algorithms as follows.

1) Evasive Enemy

The evasive enemy is an enemy that can dodge when the audio visualization beam attacks. The distance is classified into three sets, namely short, medium and far distance. The value of avoidance ranges from 0 to 10. Inference rule of the evasive enemy is as follows.

- R1. If the amplitude is weak and the beat is high, then the distance is short
- R2. If the amplitude is medium and the beat is medium, the distance is not good
- R3. If the amplitude is hard and the beat is low, then the distance movement is far away

2) Aggressive Enemy

The aggressive enemy is an enemy that can shoot a bullet in a span of between 1 to 5 seconds. The speed of a bullet is classified into three sets, namely a slow, ordinary and fast bullet speed. The inference rule of the aggressive enemy is as follows.

- R1. If the amplitude is weak and the beat is low, the bullet speed is slow
- R2. If the amplitude is medium and the beat is medium, the speed of the bullet is rather slow
- R3. If a hard amplitude and high beat, the bullet speed is fast

After knowing the input amplitude, beat, and the inference rule of each enemy, a new fuzzy logic algorithm can be applied. When the player enters the gameplay scene, the fuzzy logic algorithm is already running.

III.II Testing Phase Design

It takes several parts that must be determined in advance, one of which is a statement in the questionnaire. The statement contained in the questionnaire uses references to HMSAM. This model has thirty-nine statements and is divided into eight categories [13].

After that the level of approval of a statement is determined. This level is divided into seven groups that range from strongly disagree to strongly agree. Each group has its score. Depending on the form of a statement that can be positive or negative, it can also be reversed in the order of the scores. Then determine the highest and lowest values on this Likert scale. The highest score is 210, obtained by multiplying the highest score of the approval level (7) with the total respondents (30). As for the lowest score is 30, obtained by multiplying the lowest score level of approval (1) with the total respondents (30).

Finally, the interpretation criteria are determined which are divided into seven criteria and have a range of distances with intervals of 14.3%. Explanation of these criteria is as follows.

- Number 0% – 14.29% = Very bad
- Number 14.3% – 28.59% = Not good
- Number 28.6% – 42.89% = Somewhat less well
- Number 42.9% – 57.19% = Enough
- Number 57.2% – 71.49% = Somewhat good
- Number 71.5% – 85.79% = Good
- Number 85.8% – 100% = Very good

IV. RESULT

The following are the results of the implementation and trial of the design that has been made. The results of the research is a video game for PC (Personal Computer) which objects in this game depend on sound.

Fig. 7 shows the interface display in the main menu section. On this page, there is a game logo, and four buttons, namely the play button, options, tutorials, and credits. Behind him looks outer space and audio visualization that moves according

to the music playing menu. If the play button is pressed, it will move to the select music menu. If the options button is pressed, it will move to the options menu. If the tutorial button is pressed, it will move to the tutorial menu. If the credits button is pressed, it will move to the credits menu.

Fig. 7. Main Menu display

Display select music can be seen in Fig. 8. On this page, there is a list of music that can be played. In the list, there is a button that says the title, creator and duration of the music. The player can press the button to hear the music footage that will be played. If the player has determined the music you want to play, the player can press the ok button to enter the gameplay page. The player can return to the main menu by pressing the back button.

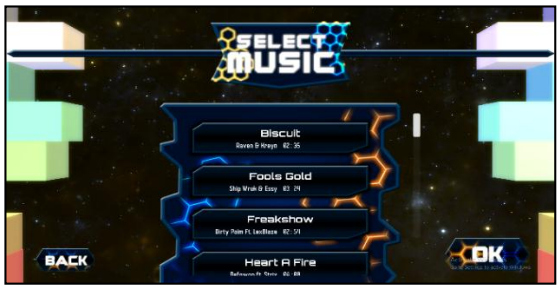

Fig. 8. Select Music display

In Fig. 9 displays the interface on the gameplay page. This section is the most important part because here is where players will play and where fuzzy logic is implemented. Seen above the screen is the title of the music played, the duration of the music, the rest of the player's life and the score obtained. In the middle of the screen, there is an object played by the player, Planet Joget-Joget. On the left of the screen, there is a bar that shows the rotating limit of the object being played, and at the bottom right of the screen, there is an audiovisual that reacts to the music being played.

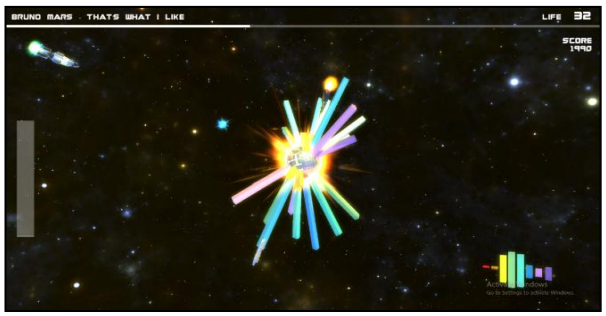

Fig. 9. Gameplay display

If the player manages to survive the enemy attack until the music is finished in other words winning the game, the player will enter this page. Display results can be seen in Fig. 10. On this page, there is information in the form of scores obtained, remaining life and total score. Also, there is high-score information, namely the name of the highest score holder and the nominal score. Below the screen, there are three buttons, namely the retry button, select music, and play menu. If the player wants to try playing again with the music, the player can press the retry button. If the player wants to change the music played, the player can press the music select button. If the main menu button is pressed, it will return to the main menu page.

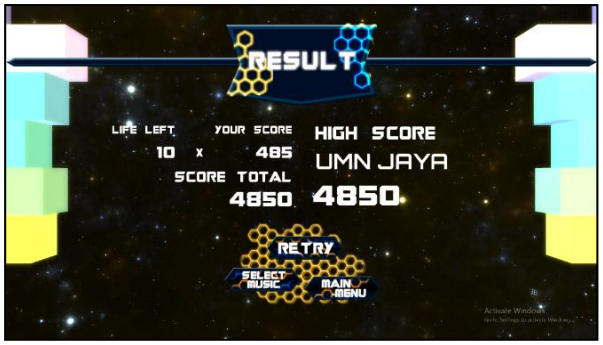

Fig. 10. Gameplay result

V. DISCUSSION

After the video game has been designed and built, testing is done by distributing questionnaires based on HMSAM. The questionnaire uses a Likert scale and is distributed to 30 students of Multimedia Nusantara University [14, 15]. After that, the results are evaluated and can be seen in Table 1.

Table 1. Questionnaire results

HMSAM Aspect	Result	Criteria
Joy	64.08 %	Somewhat good
Control	53.9 %	Enough
Focused Immersion	60.62 %	Somewhat good
Temporal Dissociation	62.33 %	Somewhat good
Curiosity	56.63 %	Enough
Perceived Ease-of-Use	69.68 %	Somewhat good
Perceived Usefulness	66.16 %	Somewhat good
Behavioral Intention to Use	66.16 %	Somewhat good
TOTAL	**62.45%**	**Somewhat good**

After seeing and analyzing the data obtained, from the eight categories tested, there were no categories that entered the interpretation criteria under the 'Enough' criteria. However, the Beat Defender game also does not have a high value. Proven by the data obtained that most categories are included in the criteria of “Somewhat good”. If the average of the eight categories of HMSAM is calculated, the result obtained is

62.45%, and the value is included in the criteria of "Somewhat good".

For the trial category, the control category gets the lowest value of 53.9%. This category tests whether the player's control in the game is satisfactory or not. Although the value is lower than all categories, this shows that the variety or variation that can be controlled is enough for the player to complete a round of games. Whereas for the category of perceived ease-of-use gets the highest score of 69.68%. This category discusses the ease of learning and playing a video game. This shows that the way to play this game is not complicated. Besides, the explanation of playing the video game on the tutorial page is well explained, and the feedback of the player with the interface is well explained, so it does not confuse the player.

VI. CONCLUSION

From the research on the design of the Beat Defender game using fuzzy logic algorithms, it can be concluded that the video game has been successfully designed and built using the IDE Unity that uses the C # programming language. This three-dimensional video game relies on sound as its main component. The player must guard an object against an enemy that is approaching from all directions. Enemy movement depends on artificial intelligence from fuzzy logic algorithms that react to the music being played. To fight the enemy, players use audio visualization that reacts by inputting the sound from the player's microphone.

After that, the video game was tested using a questionnaire based on HMSAM. The evaluation results of the test found that the control category obtained the lowest value of 53.9% and entered the criteria of 'Enough'. Whereas the category of perceived ease-of-use obtained the highest score of 69.68% and included in the criteria of "Somewhat good". Overall, Beat Defender scored 62.45% and entered the criteria of "Somewhat Good".

Based on the research that has been done, the suggestions for further research are as follows.

1. Although you have used audio visualization and use fuzzy logic so that the enemy can move according to the music being played, Beat Defender still has space to get better than enough results. For example by increasing the control section for the HMSAM category because according to the data obtained, this category has the lowest value. The way to play this game is quite simple, making it easier for players to control and learn it. If variations or variations of play are added to the game, it will give more control to the video game. If a new control is added, it will compensate for the controls that the user feels so simple that this can provide additional value for the control category.
2. The trial process can also use other instruments such as GUESS (Game User Experience Satisfaction Scale) [16]. GUESS has fifty-five statement items included in the nine subscales. This instrument is useful for measuring the level of satisfaction of a game that is psychometrically validated and comprehensive so that for further research, it can be done by comparing HMSAM and GUESS to get more accurate results or using GUESS instruments only.
3. At first, when conducting a trial, the requirement that the respondent can fill out the questionnaire is enough to play only one round of the game. After undergoing research, the duration of playing the game must also be considered because this can affect the results of the questionnaire.

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