Alternating Sword Controller in First-Person Action Game using Fuzzy Logic for Adaptive Enemy

Arby Azyumardi Azra
Study Program in Informatics Engineering, Faculty of Computer Science
Universitas Dian Nuswantoro
Semarang, Indonesia
arbyazra.dev@gmail.com

Ardiawan Bagus Harisa
Study Program in Informatics Engineering, Faculty of Computer Science
Universitas Dian Nuswantoro
Semarang, Indonesia
ardiawanbagus@dsn.dinus.ac.id

Abstract*—Virtual Reality (VR) has become widespread in the gaming industry, but the high cost of VR devices makes it difficult for gamers to own one. This research provides a solution by creating a new First-Person Action game that has Motion Controller using the gyroscope sensor on smartphones. A game with adaptive difficulty is necessary, as playing a game that is too easy or difficult can lead to frustration and boredom. This research applies the Fuzzy method to implement the adaptivity of the enemy to the player. The Fuzzy system will model the player's ability based on their performance in a level and produce an impact on the enemy in the next level. We produced a simple VR game on a smartphone with a Fuzzy system that automatically adapts the difficulty by using "Resistance" as the enemy's new life. As a result, 90.5% of the 14 respondents that faced the difficulties in each of the levels are being adjusted by the game. Even though the experiences of each respondent are different, most respondents can intuitively play the game without asking for help.

Keywords*—Dynamic Difficulty Adjustment, Fuzzy, Motion Controller, Gyroscope, First-Person Action

I. INTRODUCTION

With the advancement of immersive technology and more advanced hardware, *Virtual Reality* (VR) has become an intriguing device for representing the 3D world [1]. Research conducted by Gerling [2] resulted in a questionnaire that concluded that respondents who played games with natural gestures found them easier and more enjoyable, while others experienced difficulty and fatigue. *Virtual Reality* (VR) in a study [3] combined *Oculus Rift*, *Leap Motion*, and *Microsoft Kinect* to create a first-person game. Referring to the prices of each device used in the study, the *Virtual Reality* equipment used is still expensive for the general public to purchase in Indonesia. This hesitation makes game players wonder whether it is worth buying solely for gaming purposes [4].

By relying on the gyroscope, players can experience a more straightforward virtual reality controller that resembles VR. Anik's study [5] found intuitive movement was achieved using an *Arduino-MPU* gyroscope sensor attached to a badminton racket. With the widespread advancement of technology, many smartphones today already have gyroscope sensors [6]. Therefore, this research uses a smartphone as the primary controller for the player's weapon in the game. In a game, one important feature to maximize the player's experience is the selection of difficulty levels. One of the game genres, *First-person* action (FPA), often incorporates this feature. However, if the game's difficulty level does not balance the player's experience, they may become bored or frustrated while playing [7].

One of the applications of the "*Flow Channel*" concept in Fig. 1 is known as *Dynamic Difficulty Adjustment* (*DDA*), a technique to adjust the player's gaming experience by mapping specific player behaviors and parameters. In a study [8] the *Fuzzy Sugeno* method was utilized to implement the *DDA* concept by automatically generating game content using *Procedural Content Generation* (*PCG*) techniques. The game balancing in this research was applied when the player moved to a new map, and parameters such as *Time*, *Health*, *Damage Taken*, *Accuracy*, and *Enemy* were collected from the previous map to map the player's experience. Subsequently, the automatic content generation process was carried out using fuzzy logic, resulting in the output of a new map. Each map created by the fuzzy system had rooms with supporting player items and a more diverse set of enemies based on the fuzzy rules. The researchers successfully demonstrated that the application of game balancing could adjust the player's abilities with a percentage of 84.67% compared to games without game balancing [8].

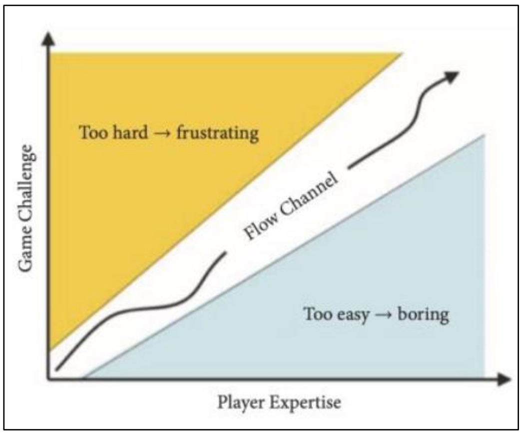

Fig. 1 Flow channel concept represents boredom and frustrating players.

Fuzzy logic is an approach that can model a player's behavior. Fuzzy values range from 0 to 1 for each membership degree. Fuzzy uses verbal language such as "*very slow*", "*somewhat moderate*" and "*very fast*" to represent the intensity of *fuzzy membership degrees* [8]. In this study, we proposed to develop a new first-person shooter game with natural gesture implementation using the gyroscope on iOS smartphones. The goal of the game is to defeat boss in 3 levels. Player modeling is used by performing fuzzy logic to determine the base health of enemies or non-player characters (NPCs) in each subsequent level.

II. Research Method

To balance the enemies or NPCs in the next level, player modeling is required to generate feedback for the player. The feedback can take the form of items or attributes that assist the player when experiencing difficulty and items or attributes that create challenges when the player is performing well [7]. In first-person games, the creation of health items for the player when they face difficulties is one form of *Dynamic Difficulty Adjustment* (*DDA*) implementation in the game. Fig. 2 illustrates the correlation of the immersive controller, specifically the gyroscope on a smartphone, by combining it with a fuzzy system that capable of providing a sense of adaptive difficulty to the player within this research. Research conducted by Darius [9], utilizing the gyroscope on a smartphone for an FPS game, demonstrated that 83.3% of the 30 respondents found it comfortable to play. However, the gyroscope in that research was used to change the player's point of view rather than controlling the player's weapon (first-person action), resulting in a less immersive experience.

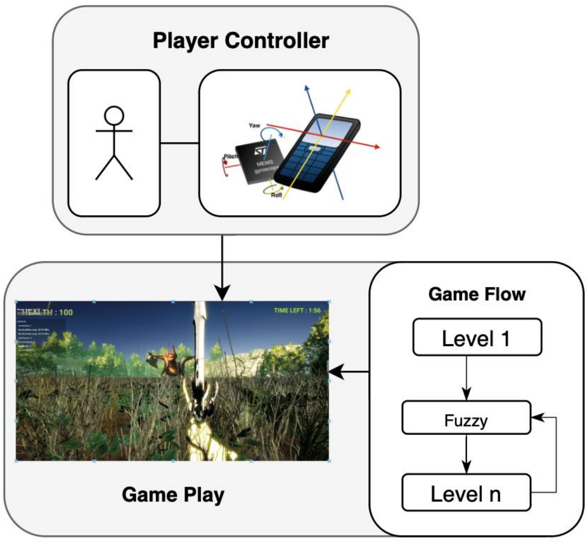

Fig. 2 The use of phone's gyroscope as our game controller.

In implementing the gyroscope in this study, the intuitive interaction between the player and the smartphone (client) is bridged by Wi-Fi, which distributes orientation and rotation parameters to a laptop/PC (server) in real time. Subsequently, the parameter processing occurs on the server side, causing the player's weapon to move in accordance with the smartphone controlled by the player. This research utilizes a fuzzy system that can generate resistance based on player data collected after completing a level or stage. As it can be done intuitively, there are no specific limitations or standards for game development [10] or fuzzy design.

Fig. 3 illustrates on how fuzzy logic system influenced this research. It outlines the process of capturing gyroscope data from the player's smartphone, transmitting this data to the server, and using a fuzzy logic system to adjust the game parameters dynamically. The flowchart depicts each step, starting from data collection, processing through the fuzzy logic system, to the final adjustment of game resistance based on the player's performance. This adaptive mechanism ensures that the game's difficulty is tailored to each player, maintaining an engaging and challenging experience.

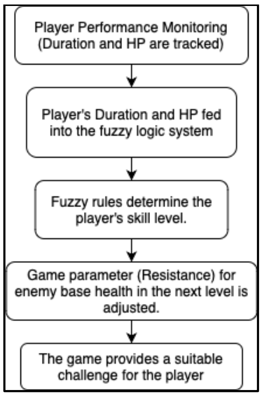

Fig. 3 How fuzzy logic influences gaming activities.

A research study [11] was conducted to model players using fuzzy logic by utilizing several inputs from the players, namely remaining health-points (*HP*), remaining time (*TIME*), task-solving ability (*SOLVE*), previous difficulty level (*DIFFICULTY*), player's shooting accuracy (*ACCURACY*), and the number of player attempts (*TRY*). Subsequently, random sampling of players was performed to generate the knowledge base through experimentation. This study used two inputs with three classes each selected as parameters to be collected when the player completes each level. Fig. 4 shows the flow of the fuzzy system's implementation, which consists of three main stages.

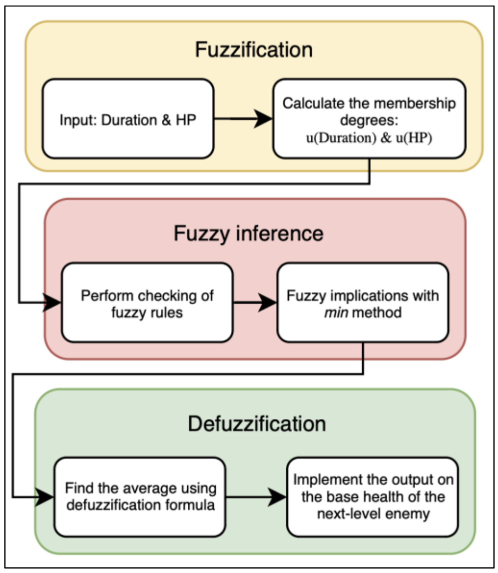

Fig. 4 Flow of Fuzzy.

A. *Input variables*

The input parameters collected after the player completes the game are the duration of the player facing enemies (*Duration*) and the player's remaining health points upon completing the game (*Health Point*). Both of these input parameters will provide feedback to the enemies at the next level. The attribute that will impact the enemies is *Resistance*, which represents a character's resilience against player attacks. *Resistance* becomes the new base health for enemies in the next level. After defining the input and output parameters, fuzzy membership degrees are created for each input parameter as follows:

1) Duration: {fast, normal, slow}

Fig. 5 represents the duration of the player facing enemies in each level. It ranges from 0 seconds to 120 seconds at each level. The duration of a player facing a level determines their gaming ability. A shorter duration indicates a lower player ability, and vice versa.

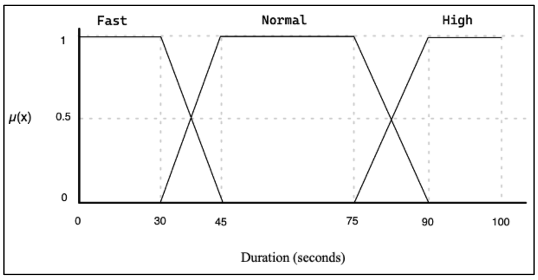

Fig. 5 Membership functions for the input variable "*Duration*".

2) HP: {low, medium, high}

Health Point is obtained after the player completes a level. It ranges from a maximum of 100% to a minimum of 0%. The *HP* parameter indicates the level of the player's ability to face enemies in a level. A higher HP indicates greater ability. The membership function of HP can be seen in Fig. 6.

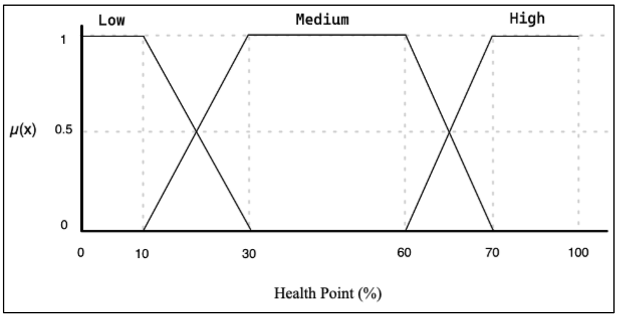

Fig. 6 Membership functions for the input variable "*HP*".

As for the membership degrees of the output parameter: *Resistance {less, medium, much}*. It represents the resilience of a character against player attacks. The *Resistance* value is obtained by enemies in each subsequent level based on the player's performance in the previous level. *Resistance* serves as the new base health for enemies in the next level. A singleton membership function is used to represent the multiplier. It consists: 0,25 (*less*); *0,50* (*medium*); 0,75 (*much*) as a multiplier of the enemy's base health.

B. Fuzzy Rules

Once the input-output variables and their sets have been defined, a fuzzy rule table is needed to govern the adaptive logic at each level. The creation of fuzzy rules needs to be specified in IF-THEN clauses to be recognized by the computer and processed in the fuzzy inference engine [12]. The rules are formulated according to the number of membership degrees for each input. It is known that the membership degrees have three classes or ranges for the two inputs, namely *Duration* and *Health Point*. Therefore, rules will be created accordingly, resulting in a total of 9 rules that can be seen in Table 1.

TABLE I. FUZZY RULES

Rule	**IF Duration (D)**	**IF Health Point (HP)**	**Resistance**
1	Fast	Low	Less
2	Fast	Medium	Much
3	Fast	High	Much
4	Normal	Low	Less
5	Normal	Medium	Medium
6	Normal	High	Much
7	Slow	Low	Less
8	Slow	Medium	Medium
9	Slow	High	Medium

C. Implementation

1) Fuzzification

After the player completes a level in the game, data from the two input variables, represented as numerical values, are collected to be converted into linguistic values using fuzzy membership functions. Each input has three classes. This conversion process forms the knowledge base for the intuitively created rules. The input variables and their respective classes are presented in Fig. 5 andFig. 6. As shown in Fig. 7, each input parameter will be computed with three classes represented by fuzzy membership degrees.

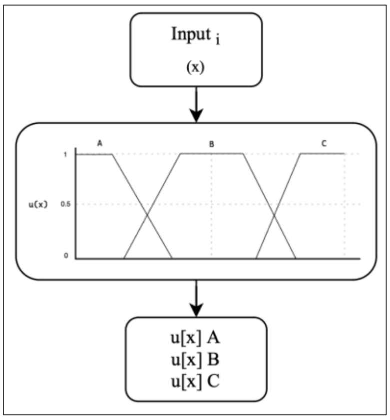

Fig. 7 Flow of Fuzzy membership function.

2) Fuzzy rules and inference

After calculating each class in each input, membership degrees are obtained. Each membership degree is calculated using the *min* method to obtain the smallest value representing each input as illustrated in Fig. 8. The *min* method is used to obtain values from the set of rules that have been created, totaling 9 rules. Therefore, with the defined input parameters, the *min* method can be expressed in Eq. (1).

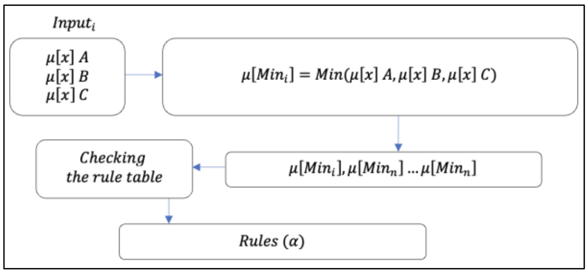

Fig. 8 Flow of checking the inference engine based on the rule.

$$a = MIN\big(\mu(Duration), \mu(HP)\big) \quad (1)$$

Where α-predicate represents the membership degree of each rule, μ(*Duration*) is the membership function for the input parameter "*Duration*", and μ(*HP*) is the membership function for the input parameter "*HP*".

3) Defuzzification

Defuzzification is needed to find the average value from inference engine result [12]. Defuzzification performed using the following Eq. (2).

$$z = \frac{\Sigma \alpha i z i}{\Sigma \alpha i} \quad (2)$$

The final value is applied to the enemy using a formula created intuitively. The calculation of the final value of *Resistance* applied to the enemy can be expressed in Eq. (3).

$$BH' = BH_i + (R_i \times 100) \quad (3)$$

BH' represents the new base health for the enemy in each level, and R_i is the final value of *Resistance* obtained from the defuzzification process. However, based on the collected two initial data from the players (Table 2). By using Eq. (3), there is an imbalance in the base health of the enemy when transitioning between levels, resulting in difficulties for the respondents while playing. Therefore, the formula above is further extended with Eq. (4). The overall defuzzification process can be seen in Fig. 9.

TABLE II. THE RESULTS OF INITIAL DATA WITH INITIAL FORMULA

No	Level 1		Level 2			Level 3		Fit
	W	R	BH	W	R	BH	W	
1	True	0.92	192	False	0.22	122	False	No
2	True	0.52	152	False	0.22	122	False	No

W represents the victory value determined when a player can defeat the enemy until the health reaches 0%. *R* represents the resistance value obtained from the defuzzification process. *Fit* represents the player-expressed difficulty level. Level 1 has 100% *base-health* for enemies to initiate a model of the player's ability.

$$BH' = \left(\left(\frac{R_i}{2}\right) + R_i\right) \times 100 \quad (4)$$

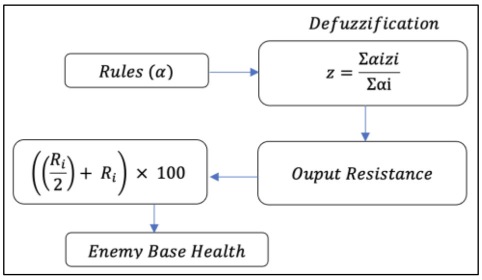

Fig. 9 The overall defuzzification process.

III. RESULT AND DISCUSSION

In Fig. 10, we can observe the final outcome of the developed game. It shows a smartphone being used to wirelessly control a sword in the game wirelessly to fight against enemies. These enemies have been assigned new base-health values in level 2 and level 3, derived from the fuzzy modeling process. During the data collection from 14 respondents, the researchers provided smartphones as clients and laptops as servers to standardize the player's experience.

Fig. 10 Alternating sword by swinging wireless mobile phone with gyroscope.

A total of 14 respondents have played the game from levels 1 to 3 to determine the changes in base health with the output parameter of *Resistance* in fuzzy logic; the record can be seen in Table 4. The fuzzy system calculates the *Resistance* after the player completes the first level, and then the system processes the input parameters from the player. Subsequently, the output is applied as the new base health for the second level and onwards. Fig. 11 visually demonstrates the variation and adaptive nature of the game's Resistance parameters based on player performance across different levels. If a player obtains a high resistance output at a certain level, it means that the player has adequate skills at that level. Fig. 12 demonstrates that the average Resistance output is higher in Level 2 compared to Level 1, indicating that the game's adaptive mechanism increases the Resistance as the level progresses. Fig. 11 and Fig. 12 do not have *Resistance* output at level 3 because this research limits the levels to only 3 levels.

TABLE III. THE RESULTS OF ALL RESPONDENT WITH FINAL FORMULA

No	Level 1		Level 2			Level 3		Fit
	W	R	BH	W	R	BH	W	
1	True	0.92	138	True	0.52	78	True	Yes
2	True	0.37	55	True	0.52	78	False	Yes
3	True	0.52	78	True	0.92	138	True	Yes
4	True	0.52	78	True	0.52	138	True	Yes
5	True	0.37	55	True	0.92	138	False	Yes
6	True	0.52	78	True	0.92	138	False	Yes

7	True	0.52	78	True	0.52	78	False	Yes
8	True	0.52	78	True	0.92	138	False	Yes
9	True	0.52	78	True	0.92	138	True	Yes
10	True	0.37	55	True	0.37	55	True	No
11	True	0.52	78	True	0.92	138	False	Yes
12	False	0.22	33	True	0.52	78	True	Yes
13	True	0.52	78	True	0.52	78	True	Yes
14	True	0.52	78	True	0.92	138	False	Yes

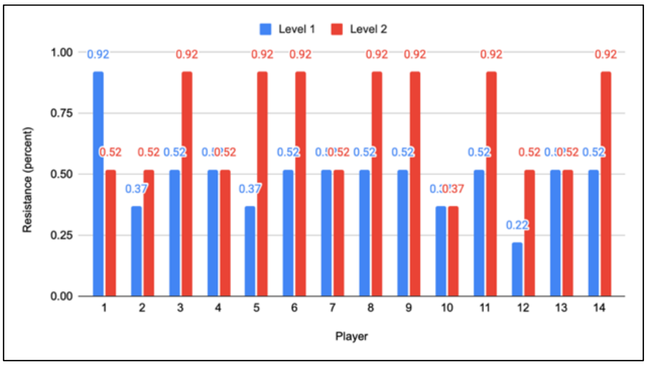

Fig. 11 The differences in the output Resistance for each player.

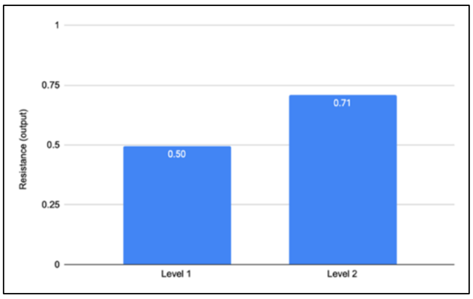

Fig. 12 The differences in the average output Resistance.

Based on Fig. 14, it can be observed that players who experience a decrease in *duration* when facing enemies in levels 1 and 2 are more numerous, accounting for 72% of the total, compared to players who experience an increase in *duration* (28%) (Fig. 13). This indicates that the majority of players are becoming more efficient in handling enemies as they progress from level 1 to level 2. In contrast, players who experience a decrease in duration in levels 2 and 3 (Fig. 16) are fewer, accounting for 36%, compared to players who experience an increase in duration in levels 2 and 3 (Fig. 15), which accounts for 64%. This suggests that the difficulty spike between levels 2 and 3 might be higher, causing more players to take longer to complete the levels.

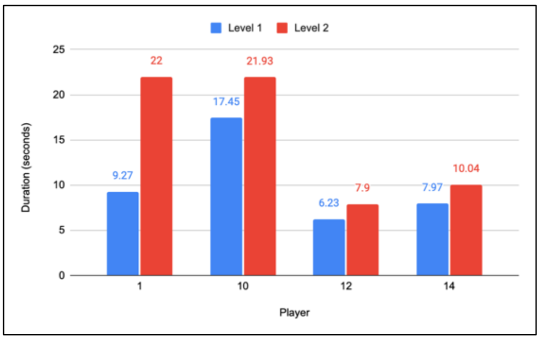

Fig. 13 The increase of *Duration* in levels 1 and 2.

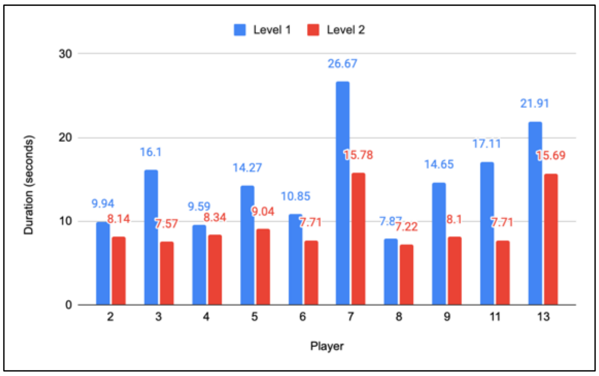

Fig. 14 The decrease of *Duration* in levels 1 and 2.

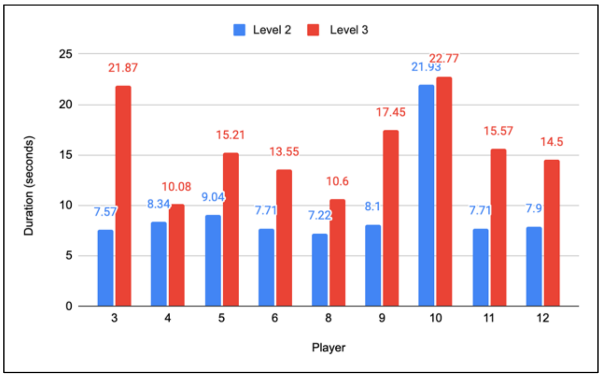

Fig. 15 The increase of *Duration* in levels 2 and 3.

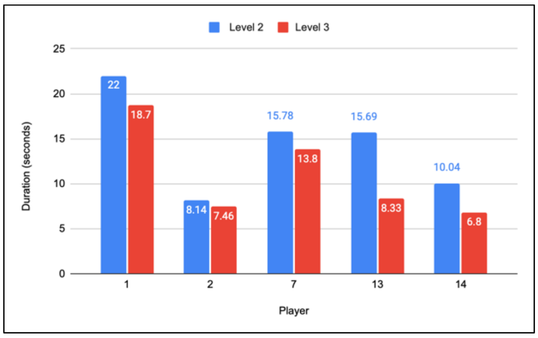

Fig. 16 The decrease of *Duration* in levels 2 and 3.

Similar to duration, the increase (or stability) and decrease in the player's remaining HP are related to the output Resistance. In Fig. 17, it can be seen that the remaining HP obtained after the player completes the game increases (or remains stable) when facing enemies in levels 1 and 2, accounting for 85% of the total, compared to players who experience a decrease in remaining HP (15%) (Fig. 18). This indicates that most players are able to maintain or improve their health points when transitioning from level 1 to level 2, which might be due to improved skills or better understanding of game mechanics. The remaining *HP* experiences a decrease in level 2 and level 3 (Fig. 20), accounting for a larger percentage (72%), compared to players who experience an increase (or stability) in remaining *HP* in levels 2 and 3 (Fig. 19), which accounts for 28%. Meaning the increased challenge posed by level 3, where most players are losing more health points, indicating that the game's difficulty curve is effectively pushing the limits of the players' abilities.

The results provide a correlation between the players' efficiency (measured by duration) and their survivability (measured by remaining HP) with the output Resistance of the game. The adaptive nature of the game's difficulty, as evidenced by the varying Resistance values, is designed to challenge players and enhance their skills progressively. The increase in difficulty from levels 1 to 2 seems to be well-balanced, allowing most players to improve their performance. However, the transition from level 2 to 3 presents a significant challenge, leading to longer completion times and decreased health points for a majority of players, thereby validating the effectiveness of the adaptive difficulty mechanism in the game.

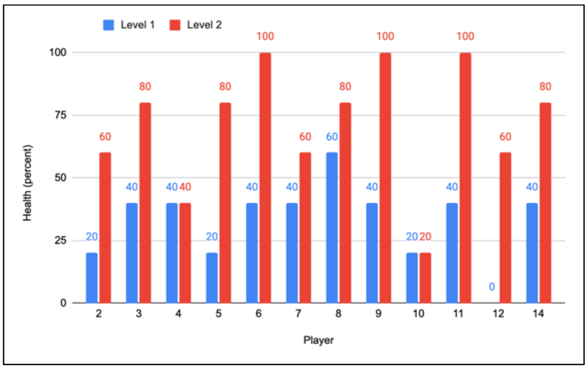

Fig. 17 The increase or stability of *Health Point* in levels 1 and 2.

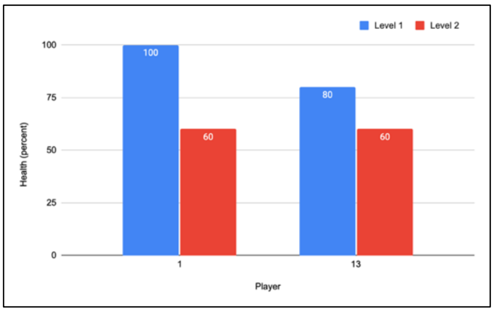

Fig. 18 The decrease of *Health Point* in levels 1 and 2.

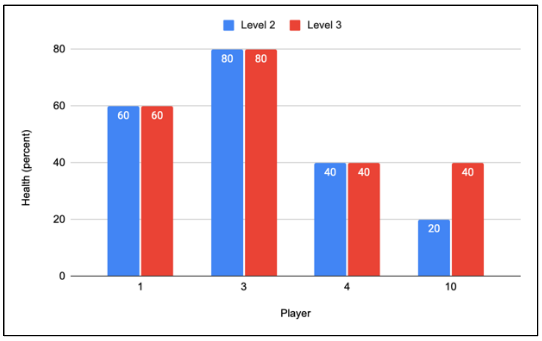

Fig. 19 The increase or stability of *Health Point* in levels 2 and 3.

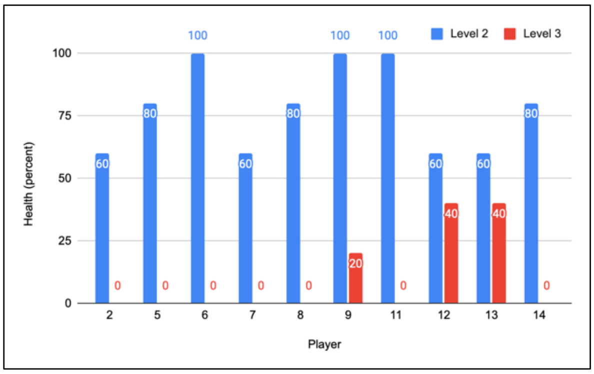

Fig. 20 The decrease of *Health Point* in levels 2 and 3.

Fig. 21 shows the changes in the first level with an *average duration* of 13.56 seconds, the second level with 11.23 seconds, and the last level with 14.05 seconds. Fig. 22 illustrates the changes in the average remaining player's *HP* in the first level with a value of 41.43%, the second level with 70%, and the last level with 22.86%. The calculation can be understood based on the average output *resistance* in level 1, which is smaller than the average output in level 2 (Fig. 12).

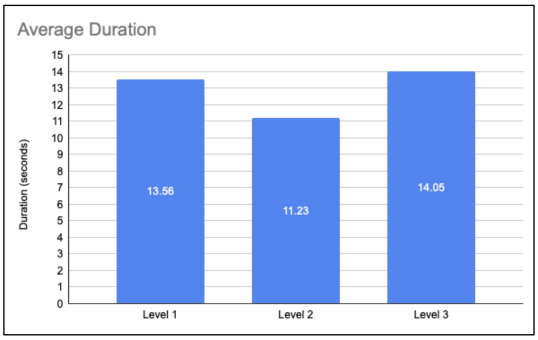

Fig. 21 The average of *Duration* in each level.

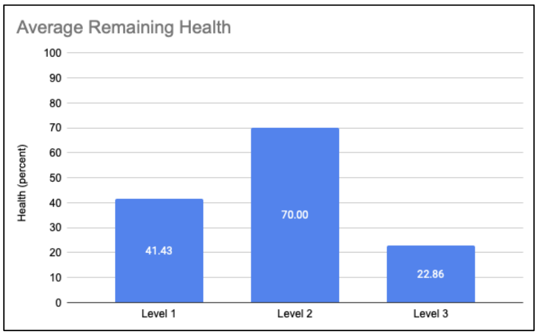

Fig. 22 The average of remaining *Health Point* in each level.

Fig. 23 represents the respondent's feedback regarding the enemy adjustments using fuzzy in this study. In Fig. 24, respondents who reported the changes in difficulty level were not suitable experienced boredom because according to the respondents, the difficulty level remained the same in each level. This uniqueness in the way players perceive the game's difficulty aligns with the concept of the *Flow Channel* depicted in Fig. 1.

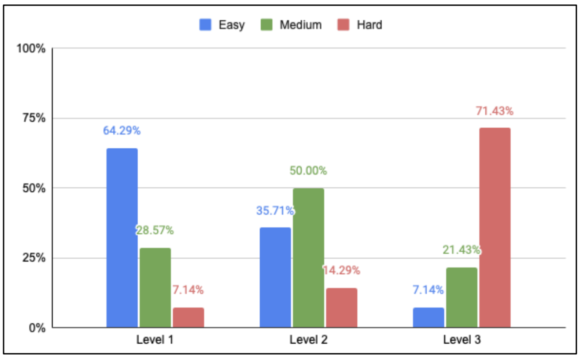

Fig. 23 The differences in difficulty levels in each level according to the respondents.

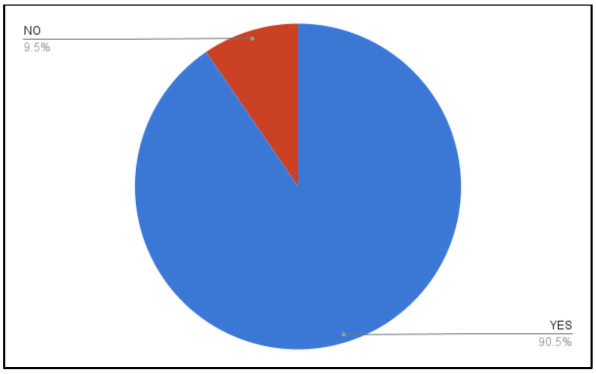

Fig. 24 The percentage of DDA adequacy in each level according to the respondents.

IV. Conclusion

The fuzzy algorithm in this research was able to model the player and make the enemy adapt to the player's skills automatically when completing each level. The output *Resistance* has three classes: "*Less*", "*Medium*", and "*Much*" which update the base health of the enemy in the next level. Based on the testing conducted in this research, the fuzzy system successfully adjusted the player's experience with the output Resistance, resulting in a decrease in *duration* and an increase in remaining Health in levels 1 and 2. Then, the player experienced an increase in *duration* and a decrease in remaining Health in levels 2 and 3. According to the respondents, the movement on the gyroscope was not so optimal. Therefore, in future research, player movement classification can be performed using the concept of Human Action Recognition (HAR).

Additionally, incorporating randomized elements, achievements, leaderboards, and unlockable content can significantly increase the game's replay value. These features encourage players to replay levels to experience different scenarios, achieve higher scores, and unlock new content. Furthermore, enhancing the narrative with branching storylines and multiple endings based on player performance can motivate players to explore different outcomes.

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