Computer Standards & Interfaces 66 (2019) 103361

Contents lists available at ScienceDirect

Computer Standards & Interfaces

journal homepage: www.elsevier.com/locate/csi

Using artificial intelligence for modeling of the realistic animal behaviors in a virtual island

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ARTICLE INFO

Keywords:
Animal behaviors
Artificial intelligence
Fuzzy logic
Unity 3D modeling
Virtual environment

ABSTRACT

The remarkable development of the computer graphic techniques enables the creation and management of more realistic games and virtual environments. However, placing the Artificial Intelligence (AI) in a virtual world get making these environments both more interactive and more believable. One of the most ambitious goals of the AI is to create virtual worlds in which a big number of virtual characters or humans being interacted and behave in an autonomous way. For this purpose, placing embodied intelligence characters in a virtual world offers a unique opportunity to evaluate the AI concept.

This paper introduces a Virtual Island developed in an innovative way based on fuzzy rules at the user interaction mechanism. We have used fuzzy tactics to create AI-based animals having various behavior types from an eagles' perspective which called 'Flight Simulation'. The simulation utilizes an eagle flying over the airspace of the Island of Chios. The AI on the ground is triggered by other animals when they enter a radius area with a certain speed defined in the software. It then decides how to behave according to health, behavior type and confidence level. Also, there is non-AI sparrow herd placed over the island to make user understand how fast he is and give the user sense of speed what can be called as an in-project feature. Consequently, the used Fuzzy Tactics have been tested in realized Unity 3D simulation. The results of the study have proven that the virtual environment consisting AI-based animals has a good performance in terms of animal-user interactions and provided satisfactory results in run time.

Abbreviations

AI	Artificial intelligence
ANN	Artificial neural network
BP	Back propagation
COG	Center of gravity method
FL	Fuzzy logic
GPU	Graphic processors
MF	Membership function
VE	Virtual environment
VR	Virtual reality

1. Introduction

Along with the last decades, computer science technology has been boosted its capabilities with increasing acceleration. Hence, today computers are capable of providing better graphic qualities and making more complex calculations thanks to the graphics processors (GPUs). As a result of this innovation, virtual environments (games and virtual reconstructed areas such as cultural, historical or natural sites) have become more realistic, and many people have considered them as an indispensable part of daily lives.

While virtual areas are usually used as a stage for games, sometimes they are only designed for users to visit also. Regardless of the purpose, visiting the reconstructed areas through computer graphics is exciting application for peoples. There is a significant amount of related work. For instance, virtual reconstruction of cultural and historical monuments of the Middle Volga [1] and 3D visualization of cultural heritage sites of Soli, Cyprus [2] are studies focusing on the accurate data acquisition, geometric representation, texture, lighting and accurate perception of models. In a similar way to these studies, one of the aims of our study is also to model the Chios Island located on the East Aegean Sea with Unity3D to create a virtual travel environment for the users. On the other hand, in the more comprehensive studies, computer-generated characters have started being used to increase the attractiveness of the Virtual Environments (VEs) by guiding, contributing to learning process, engaging the users or only entertainment [3]. Here, the user can move around, meet and interact with other virtual

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https://doi.org/10.1016/j.csi.2019.103361
Received 21 March 2019; Received in revised form 28 May 2019; Accepted 15 June 2019
Available online 17 June 2019

Nomenclature

μ	Membership function
μ_A	A fuzzy subset A of X
$\mu B(x)$	A degree of membership of x in B

characters. Second Life by Linden Lab [4] has emerged into the best known example of a 3D multiuser virtual world where users navigate and interact within the environment. In another study [5], KaraKter was used to VR-based training. The KaraKter moves in special ways to Karate, approaches the athletes and performs appropriate attacks depending on the behavior of the human. The result of the study showed that the athletes accepted KaraKter as a real competitor. Similarly, Gulec et al. [6] has been designed a virtual environment for training of soccer referees. This study has been proposed a VE providing a realistic soccer stadium to allow the referees to manage the match as if they were in a real stadium atmosphere. At the end of the study, the referees have a positive attitude towards the system. Moreover, the findings of the study show that virtual environments can be used as an educational tool to enhance experience level of the soccer referees.

VEs are generally inhabited both human-controlled and AI-controlled characters. But, the modern approach requires AI to play a key role in the VEs, since its poor use or its absence can be a negative factor. The usage of AI is particularly important for providing believability, efficiency and high quality content (e.g. missions, meshes, textures) [7,8]. AI is classically described as “the scientific understanding of the mechanisms underlying thought and intelligent behavior and their embodiment in machines” [9]. This scientific mechanism is widely used to have realistic behaviors in games and VEs. Virtual reality intelligence usually works in the background, and it does not appear for users who enjoy the emerging character behaviors.

A number of different AI approaches have been used to address the problem of believable behavior generation. Gutierrez et al. [10] enhanced virtual crowds by using hierarchical finite state machine for populating the Colosseum. State machines contain specific states for related occasions. In the game loop, these states can change according to the gameplay or the rules. The negative aspect of this method is that it can be problematic to improve and change the application [11].

Neural networks have been offered as a solution to developers for simplifying the coding of complex state machines [12]. Artificial Neural Network (ANN) algorithms have been effectively applied to VEs due to their robustness in the face of damage or missing inputs, their working speeds and tolerability of noisy inputs [13]. Sait and Raza [14] adopted ANN as a processing tool to create peoples' virtual presence by using inputs such as their images and videos. In an interesting study by Jia and Zhenjiang [13] employ the Back Propagation (BP) neural networks to carry out the self-learning intelligence of the agents and Enforced Sub-Population (ESP) neural networks to solve the task assignment problem of collaboration.

There are numerous studies particularly on Expert Systems in literature. It is one of the most mature, popular and successful branches of applied AI. They are software systems designed to transfer the decision-making capabilities of the human experience to a computer [15]. PEGASE [16] is an example designed to teach decision-making in VE. It concentrates on the representation of knowledge about the environment. Likewise, Viciana-Abad and Reyes-Lecuona [17] proposed a Virtual Reality (VR) based training simulator for medical emergencies. The main purpose of this study is to show how patient behavior is modeled by means of an Expert System.

Fuzzy Logic (FL) algorithms introduced to deal with vague and imprecise problems [18] have been extensively implemented within the games and interactive VEs to provide more human-like decisive behavior since 1996 (officially introduced in the Game Developer Magazine by O'Brien) [19]. And, since then it has been presented as a great method, with its several advantages over other AI techniques, for designing the game artificial intelligence [8]. FL is a well-known technique to add AI to any VE with comparatively little effort, since it does not require prerequisites other than the basics of Boolean logic. Moreover, without any knowledge about the system, experts can decide fuzzy rules through a linguistic way [20]. In fuzzy logic approach, there is no need define troublesome mathematical models to complex behaviors. The main reason of this is that input-output mapping of fuzzy rules is non-linear [21]. In addition, fuzzy rules are separated from the interference engine, and therefore, rules can be added or removed easily. Another meaning of this that it can be easily maintained by spending less time developing the system [11]. One of the other important advantages in the choice of FL in the gaming industry is that it has a low computational cost [22].

Although Fuzzy Logic has been used in marketable games extensively, this has been limited with fuzzy state machines or simple interference engines in many applications. On the other hand, it has found the deserved place in academic studies and has been used to overcome various tasks related to game research [8]. Sumpeno et al. [23] proposed a Fuzzy Interference System to create a life-like virtual character that can express emotions from a text input. In another notable contribution [24], a fuzzy logic system is presented to calculate the action states of a computer controlled character. In here, the information of ammunition and health level formed the input data of the fuzzy system. Another recent work by Solucicek [11] et al. created a controller for enemy drones having radar of certain distance radius. When a spaceship is detected by radar, drones containing the fuzzy controller calculate the position and distance of the starship to explode itself. Additionally, fuzzy logic was used to programming of behavior of the enemy ghosts in a Pac-Man version [25]. The authors concluded that fuzzy logic provides adaptability to user performance. This means that even if all similar setups of ghosts are same, the game will be like a different game. Another works on this subject have been summarized in a number of survey papers [8,26,27].

On the other hand, researchers [8,11,25] mention some disadvantages of FL usage in VEs. Firstly, fuzzy systems require a field expert to identify the rule sets and define the input and output variables. Otherwise, it may be very difficult to create an adequate rule set. Moreover, incorrectly defined rules can significantly increase the computational cost. FL system also depends on the inputs. Creating too many inputs to the interference engine causes the exponential increase of the rules. This also a negative impact on the computational cost. To solve this problem, Thor [28] offered the use of single-state outputs, hierarchical behaviors and parallel and independent behavior layers. In another interesting work, Kuo and Ou [29] proposed a hybrid approach integrating FL and genetic algorithm in the RoboCup Soccer game simulator. The technique attempted to improve the best rule of fuzzy system by using genetic algorithm. The authors stated that it can be used efficiently to control an autonomous robot making decision based on environment information in a game. A commonly known mistake is to think that FL is used to create human-like behaviors. However, FL can also be used easily to model the behavior of any animal such as escape or avoidance behaviors, fear and aggression situations.

By using fuzzy logic concepts, this research mainly aims to develop a virtual environment which contains intelligent animals which have various behavior types from an eagles' perspective which called ‘Flight Simulation’. The behavioral relationships among the animals on the island ground are carried out according to the other animals' distance, speed and status of aggression. The main contribution of this research is to show how virtual environments can help build interaction between users and virtual characters based on the fuzzy logic method. Furthermore, the main difference of this study from other studies is that AI-based animals in the virtual environment interact with each other and provide a more realistic experience to the users who just want to watch the environment with equipment's such as VR headsets. In our work, we have selected the Chios Island (Greece) as a virtual environment, and modeled there with Unity 3D. Our work has been extended with Arduino Uno connected to Gyro (6-Axis) to increase the user interaction by giving much control of the eagle.

The paper is structured as follows: In Section 2 we detail materials and methods employed in our study, and then we introduce the 3D modeled environment. The fuzzy logic theory and its mathematical model are overview in Section 3. In Section 4, we present our fuzzy logic approach to create of various behavior types of the animals and show how FL is used in our study. The conclusions of this study and some guidelines to the future works are given in Section 5.

2. Creation of the 3D virtual island model

2.1. Unity3D

The modeling of smoke, water, tree, plant and flowers in a virtual environment requires complex processes and time [30]. We have chosen Unity 3D in this project because it allows to easily develop 3D visualization, real-time 3D and other interaction types. The Unity 3D supports the physics engine, common script, collision detection component, particle system, terrain creation tools and rich development tools [31]. The Unity 3D is a cross-platform game engine. So, it can create executable programs working on Windows, Android, Web, Flash and IOS [32]. In addition to all advantages of Unity 3D, we have used some assets in this project for producing more realistic surface effects and enhance the performance.

Map Magic World Generator has been used to create, shape and manage terrains and placed natural objects on the virtual island. It has a lot of features for shaping terrains and objects such as stones, trees, flowers and textures. It uses a graph including generator nodes such as noise, blend, curve, erosion, forest and so on. This node-based interface is needed for determining creation logic.

On the other hand, Hx Volumetric Lighting asset provides realistic volumetric sun light into the virtual environment represented by this paper. The purpose to use such an asset was mainly making the environment bear real contents from life. Moreover, it is also a handy tool for improving the quality of virtual content and creating user orientation sense.

The sea object modeled in an island environment must have some characteristics such as liquidity, reflection and refraction. The aim is building the water surface appearances more truly. The Realistic Water asset has been used to improve the sight of the horizon and to show the terrain as an island. It has a lot of settings provide to water color, modify dynamic ripples, flow direction, underwater effect, wave animation, depth, buoyancy, transparency, reflection, foam, distortion and caustics [33].

In our project, the developed environment needed FPS (Frames per Second) optimization because there was a lot of polygons in the terrain and placed objects. Advantage Render System is a very powerful and efficient optimization system to improve for large projects. The asset helps to render the objects which are in a list and a close range by reducing the number of triangles and vertices. So, our project has been become more applicable for different platforms.

2.2. Arduino and gyro control

Arduino Uno, an open source platform which consist of connection ports, digital input/outputs, PWM outputs, analog inputs and UART TTL serial communication. With these all features, Arduino Uno is a powerful and economical hardware for gathering environmental data [34]. Our work has been extended with Arduino Uno connected to Gyro (MPU6050 6-Axis) to increase the user interaction by giving much control of the eagle. The main purpose of the program is to get the movements of the Gyro sensor, which is connected physically to Arduino, on the basis of axis and to send them to Arduino as output data. The sample circuit connection of Arduino and Gyro sensor is shown in Fig. 1.

2.3. Virtual environment

The environment has been designed to simulate Chios Island (Greece) geography and nature. As mentioned in Section II, there was too many different materials and assets using to create and to beautify the environment in the project. To create the island with its natural real shape, the raw data of the island has been taken from the terrain party [35], and then the Map Magic asset has been used for modeling the island. The different screenshots of the virtual island are presented in Figs. 2–4.

3. Fuzzy sets and fuzzy logic theory

The description of Fuzzy Logic was used firstly by Lotfi A. Zadeh within his famous seminal work "Fuzzy Sets" in 1965 [36,18]. Zadeh defined Fuzzy Logic as "a kind of logic using graded or qualified statements rather than ones that are strictly true or false. The results of fuzzy reasoning are not as definite as those derived by strict logic, but

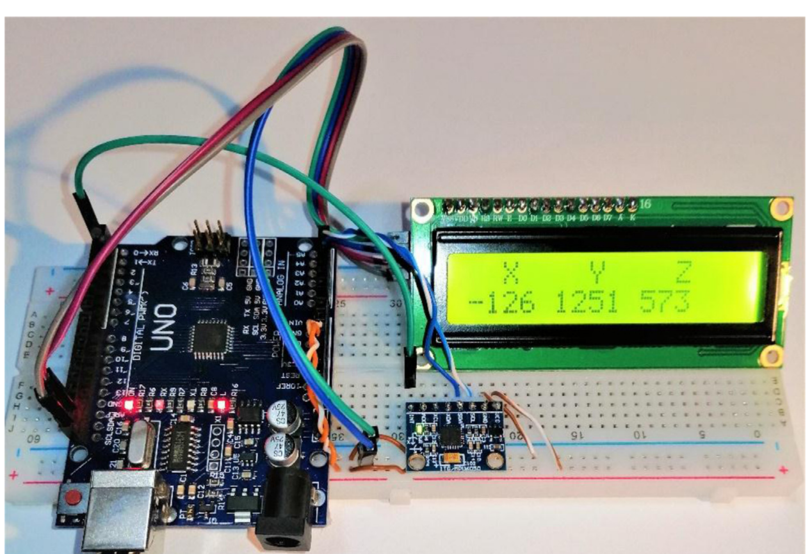


Fig. 1. Virtual Island gyro control circuit with Arduino.

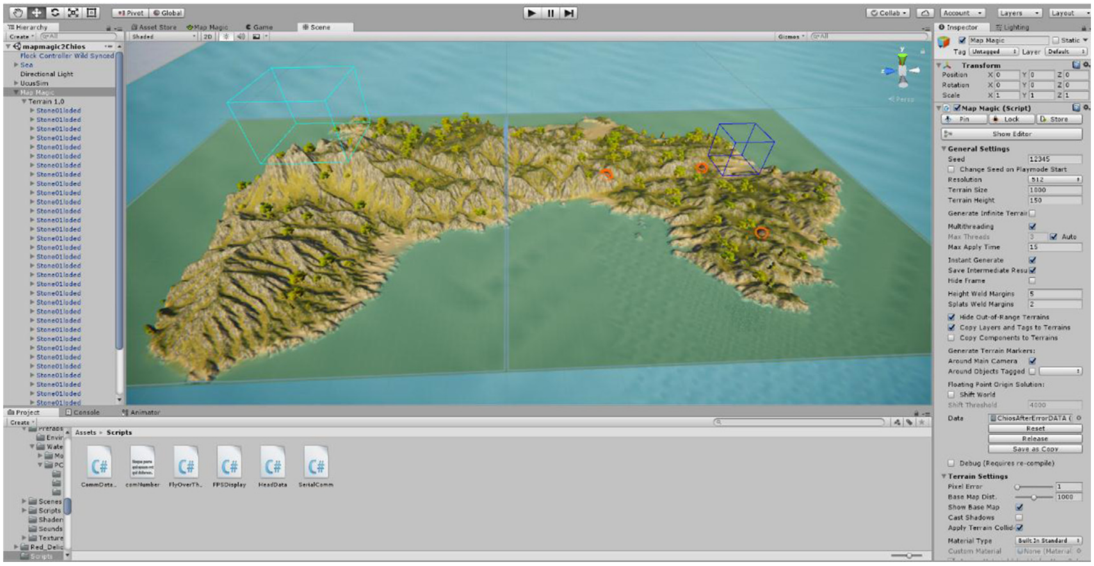
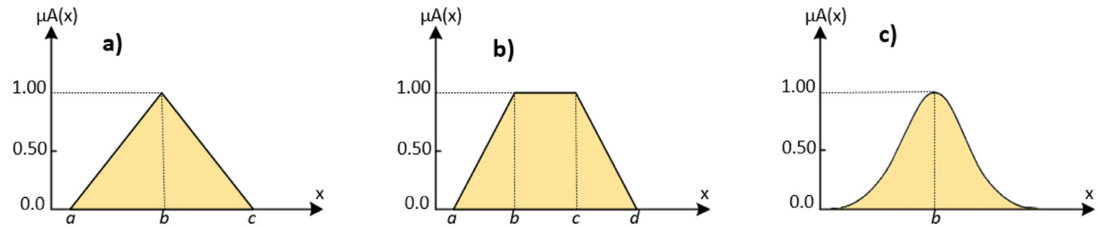


Fig. 2. The 3D model of Chios Island scene 1.

Fig. 3. The 3D model of Chios Island scene 2.

Fig. 4. The 3D model of Chios Island scene 3.



$$\mu_A(x) = \begin{cases} 0 & x \le a \\ \frac{x-a}{b-a} & a < x \le b \\ \frac{c-x}{c-b} & b < x \le c \\ 0 & c < x \end{cases}$$

$$\mu_A(x) = \begin{cases} 0 & x < a \\ \frac{x-a}{b-a} & a \le x \le b \\ 1 & b \le x \le c \\ \frac{d-x}{d-c} & c \le x \le d \\ 0 & x > d \end{cases}$$

$$\mu_A(x) = e^{-\frac{(x-b)^2}{2k^2}},$$

k is a standard deviation

Fig. 5. Examples of fuzzy memberhip functions and their mathematical expressions (a) Triangular, (b) Trapezoidal, (c) Gaussion.

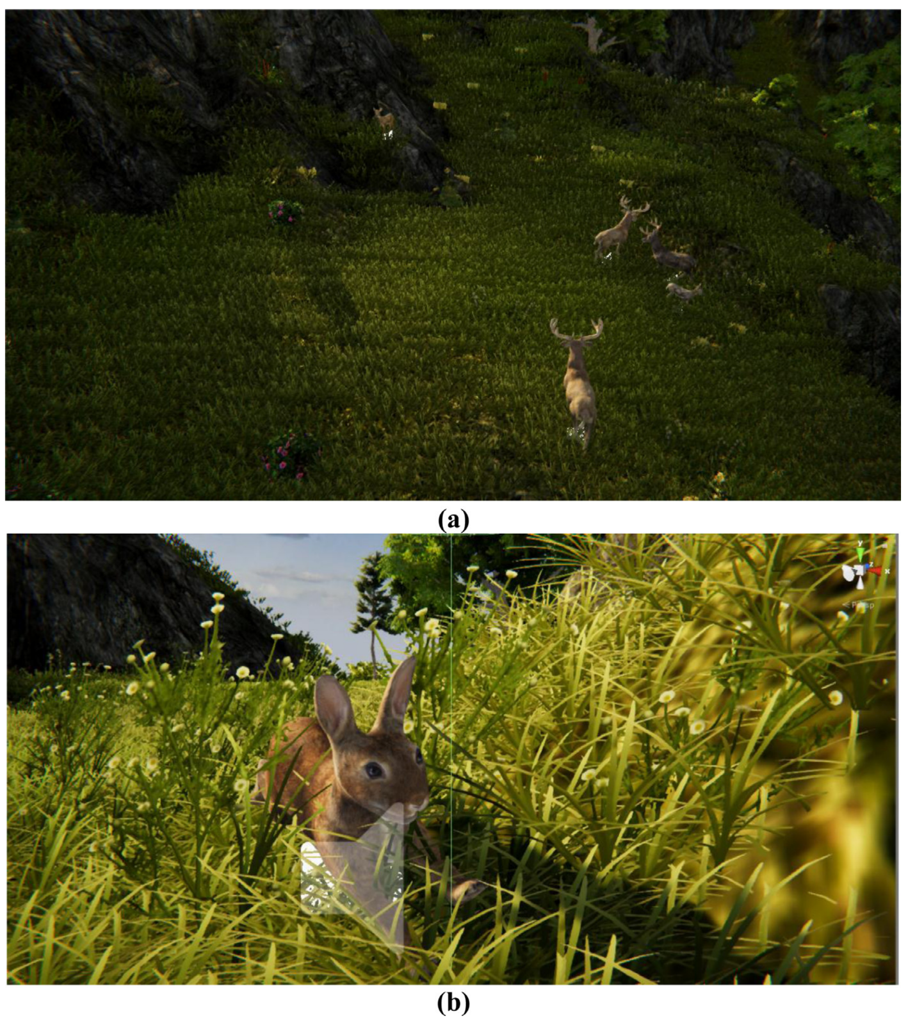


Fig. 6. AI implemented (a) deer family and (b) rabbits.

they cover a larger field of discourse" [37].

There was no mathematically meaningful method to measure uncertainty and imprecision until fuzzy logic was presented [36]. Fuzzy Systems are similar to human decisions in terms of the ability to solve problems and produce precise solutions. In fuzzy systems, the uncertainties of the real world are met more appropriately due to the formation of soft or vague boundaries instead of crisp boundaries [38].

Although fuzzy logic theory contains many theories and methods, it mainly relies on three concepts: fuzzy sets, membership functions and fuzzy linguistic rules.

3.1. Fuzzy sets

Fuzzy sets are used to describe uncertainty in the conceptual or mathematical models of empirical phenomena. Fuzzy sets theory is a generalized form of classical set theory, and all elements of fuzzy set belong to the set with some degree of membership. The membership of a set can be represented by μ. Assuming that $X = \{x\}$ is a finite set of points, a fuzzy subset A of X is defined with μA which takes a value in the range of [0,1] as can be given Eq. (1).

Table 1
Description of behavior changes in various confidence levels.

Confidence type	Cautious	Passive	Aggressive
Cowardly	When it encounters a target in the defined area, it flees.	When it is attacked, it wanders around and run away.	Can't set to coward, automatically start on brave.
Brave	When a possible target enters its radius area, the AI will be triggered. If the target does not leave the radius area within the predefined time, the AI will attack to the target. And also, it will attempt to flee when its health reaches to defined value.	It wanders around. It attacks other animals only when attacked. And also, it will attempt to flee when its health reaches to defined value.	It fights with any animals in its radius area. However, it will attempt to escape when its health reduces to the defined limit.
Overbold	When a possible target enters its radius area, the AI will be triggered. If the target does not leave the radius area within the predefined time, the AI will attack to the target. It never escapes and continues to fight until it dies or the target leaves radius.	It wanders around. It attacks other animals only when attacked. It never escapes and continues to fight until it dies or the target leaves radius.	It attacks animals in sight. It never escapes and continues to fight until it dies or the target leaves radius.

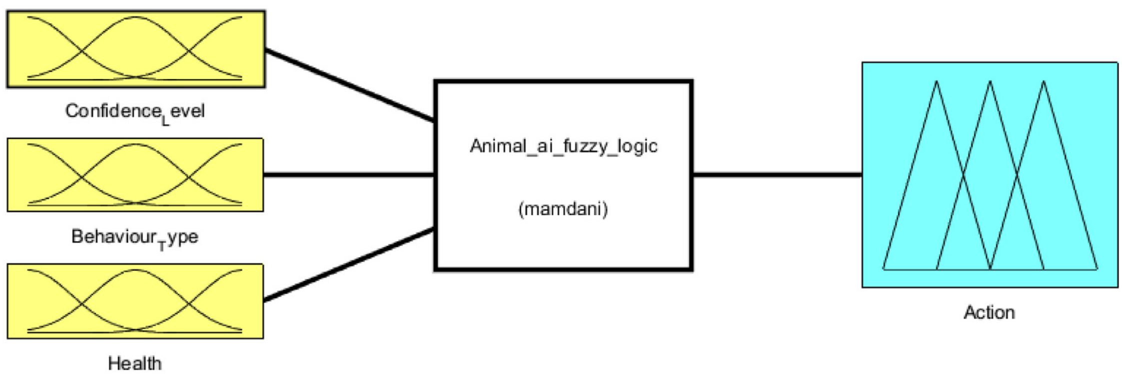


Fig. 7. Overview of the Fuzzy Logic System.

$$\mu_A(x) \in [0, 1] \tag{1}$$

A fuzzy subset is characterized by the membership function which defines the membership degrees of fuzzy elements in the sequential pairs including of the elements and their membership degrees. Therefore, the fuzzy subset A in X can be defined as a set of sequential pairs of a generic element x, and its degree of membership function as follows;

$$A = \{(x, \mu_A(x))\} \text{ for each } x \in X \tag{2}$$

To all fuzzy subsets of A, Eq. (3) is written as;

$$A = x_1, \mu_A(x_1) + x_2, \mu_A(x_2) + \ldots + x_n, \mu_A(x_n) \tag{3}$$

If $\mu B(x)$ which is a degree of membership of x in B is added to fuzzy set as a new subset, the fuzzy union and fuzzy intersection set are defined in Eqs. (4) and (5).

$$A \cup B = \{x, \max(\mu_A(x), \mu_B(x)) | x \in X\} \tag{4}$$

$$A \cap B = \{x, \min(\mu_A(x), \mu_B(x)) | x \in X\} \tag{5}$$

3.2. Membership functions

After the selection of fuzzy sets to be used, the assignment of membership functions of the fuzzy sets is performed. A fuzzy membership function is an expression that indicates the belongingness degree of membership of x in fuzzy subset A. This membership degree $\mu_A(x)$ is any value between 0 and 1. If the $\mu_A(x) = 0$, x does not belong to subset A. On the other hand, if the $\mu_A(x) = 1$, x belongs to subset A completely. And, the feature that differentiates fuzzy logic from crisp logic, if $\mu_A(x)$ is between 0 and 1, x belongs to the subset A with partial membership.

In the membership functions, a connected set of possible values in which each possible value has its own weight between 0 and 1 is defined by fuzzy numbers [39]. A fuzzy number is a generalization of the real numbers characterized by a probability distribution. From this perspective, fuzzy numbers for fuzzy logic play a similar role as ordinary numbers of classical mathematics [36]. Triangular, Trapezoidal and Gaussian fuzzy numbers are the most commonly used and most basic fuzzy numbers. Their membership functions and their calculations on fuzzy sets are illustrated in Fig. 5 respectively.

3.3. Fuzzy linguistic rules

In daily life, people use linguistic phrases to express numerical quantities. For example, when talking about the air temperature, it is much easier to use expressions such as HOT, COLD or VERY COLD, rather than to say the exact numerical temperature of the air. It is particularly true that the numerical values are hard to determine [40]. In such cases, fuzzy set concept is a convenient way of expressing inaccurate statements.

Fuzzy linguistic rules transform given set of input linguistic variables to the output variables by using linguistic IF-THEN structure [24]. The general form of a linguistic rule is written as “IF A THEN B” where A and B are suggestion collections including linguistic variables [41]. Fuzzy linguistic rules are written to describe output variables by using each combination of input variables, and they are pooled in a rule table. This table provides output values for all possible input values in a Fuzzy Logic based system.

4. Fuzzy logic based animal behaviors

In the proposed FL-based virtual environment, a deer family and rabbits seen in Fig. 6(a) and (b) have been modeled with artificial intelligence to act independently and to increase interaction with the user. In order to ensure in-game interaction of the user also, a flying eagle representing the player has been modeled, and the user movements have been transferred to the eagle with developed arduino-gyro based system. The animals modeled by AI act according to the behavior

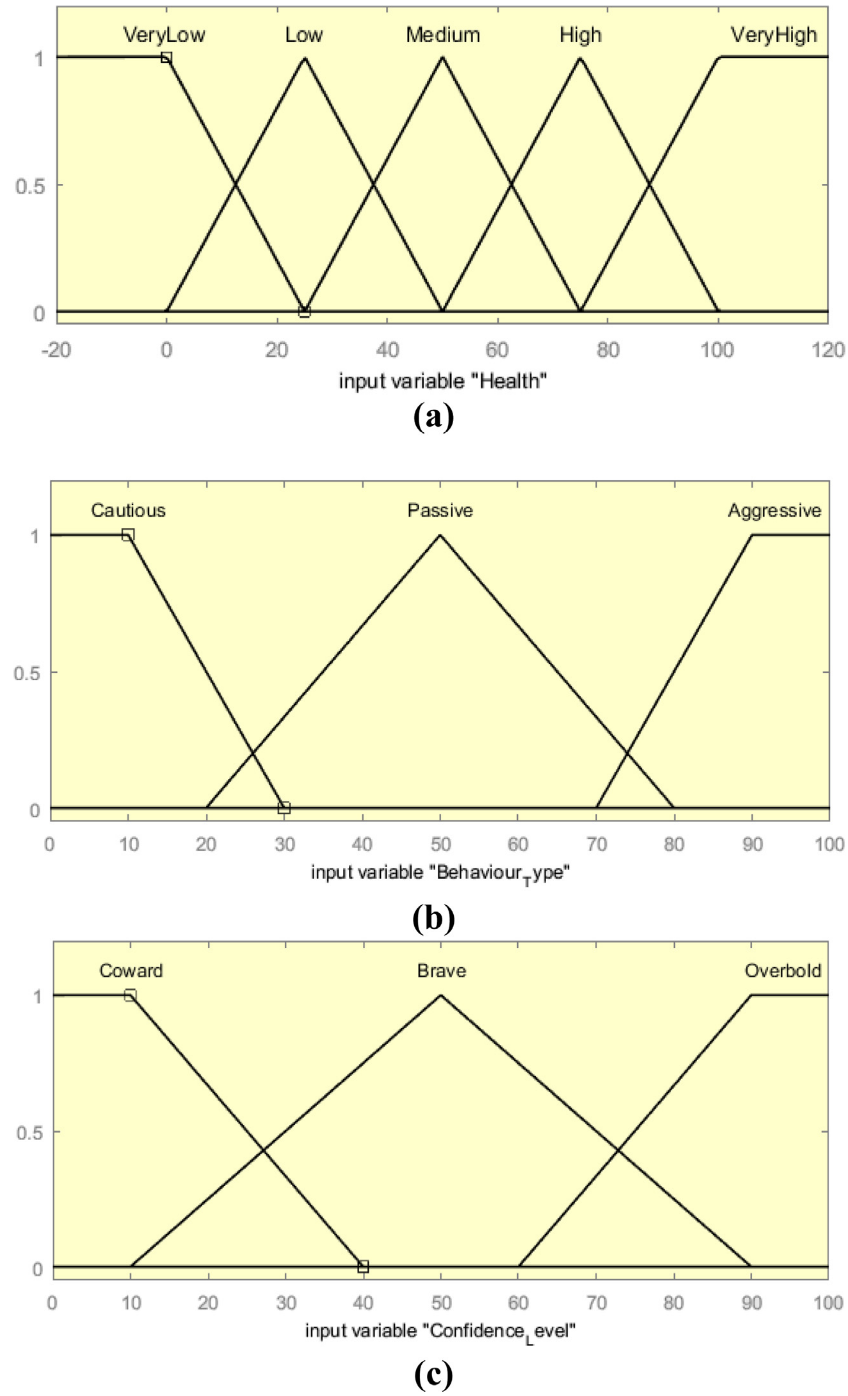


Fig. 8. Membership sets for (a) health (b) behavior type and (c) confidence level.

of the players.

4.1. Behavior types

An AI temperament controls various settings of how an AI will behave to targets or how to interact with the environment or other intelligent/dummy animals around it. In this project, this is facilitated by three predetermined behaviors that AI can follow.

- *Passive:* In passive AI, animals do not attack. Basically, they just walk around and watch. If they're attacked, they react according to confidence levels.
- *Cautious:* In the cautious AI, animals may escape or move depending on events occurring according to confidence levels. Any animal with this behavior may also act to protect the territory if the level of confidence is brave or higher.
- *Aggressive:* In such AIs, animals will attack any animal species in their target. Such animals are expected to have a great sense of confidence.

4.2. Confidence levels

The AI behaves according to its confidence level on its behavior type. So, each confidence type is categorized by behavior types. Description of behavior changes in various confidence levels are given in Table 1.

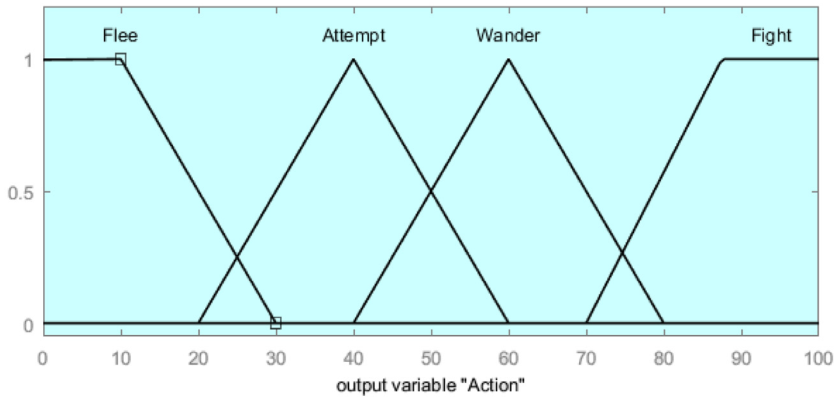


Fig. 9. Fuzzy logic system output.

Table 2
The rule table.

Confidence	Behavior type	Health				
		Very low	Low	Medium	High	Very high
Coward	Cautious	Flee	Flee	Flee	Flee	Flee
	Passive	Flee	Flee	Attempt	Wander	Wander
	Aggressive	–	–	–	–	–
Brave	Cautious	Flee	Attempt	Wander	Fight	Fight
	Passive	Attempt	Wander	Wander	Fight	Fight
	Aggressive	Attempt	Wander	Fight	Fight	Fight
Overbold	Cautious	Fight	Fight	Fight	Fight	Fight
	Passive	Fight	Fight	Fight	Fight	Fight
	Aggressive	Fight	Fight	Fight	Fight	Fight

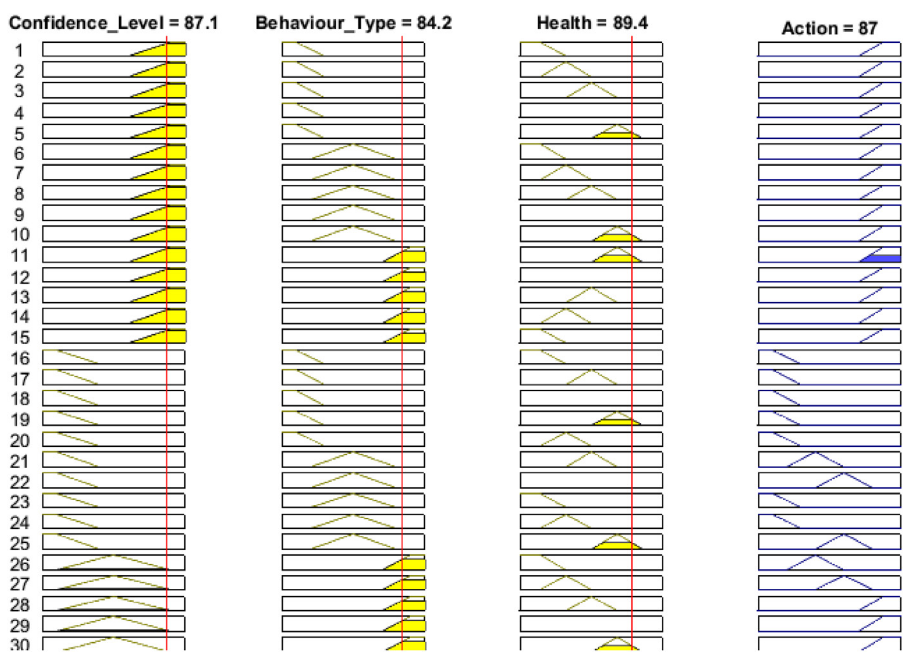


Fig. 10. Effects on outputs made by inputs.

4.3. Modeling of fuzzy logic system

In this work, health, behavior type and confidence level have been defined as inputs of the fuzzy logic based virtual environment, and action states have been computed as outputs. The model of the system is given in Fig. 7. The model firstly was developed with MATLAB software to see to what extend the FL method can evaluate the model. MATLAB is a menu-driven software that enables easy application of fuzzy constructs such as membership functions and decision rules. There are different fuzzy logic methods such as Mamdani [42], Tagaki-Sugeno [43] and Tsukamoto [44]. In this work, Mamdani's minimum operator has been selected to model causal relationship between fuzzy variables. The Mamdani method is extensively accepted method for identifying expert knowledge. It allows to define experience in a more intuitive and more human way. One of the most important reasons why the Mamdani has been preferred instead of the Sugeno in this work is the production method of the crisp output obtained from the fuzzy inputs. Mamdani method uses the defuzzification process for a fuzzy output. On the other

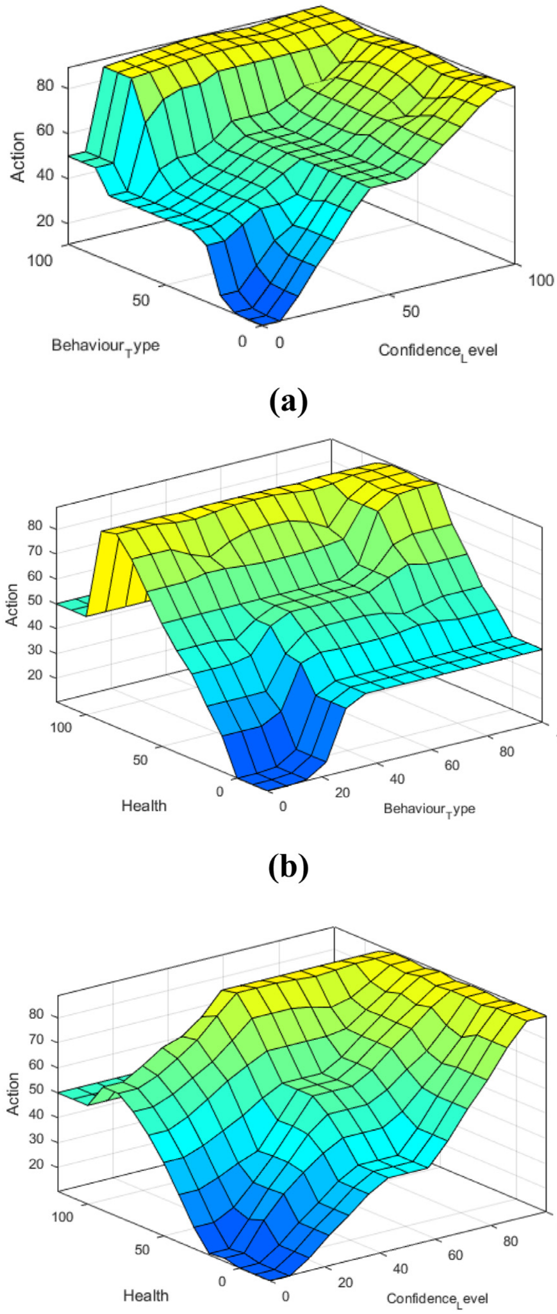


Fig. 11. The output values in surface diagram (a) behavior type-confidence level, (b) health-behavior type and (c) health-confidence level.

hand, Sugeno method uses weighted average. So, the expressive power and interpretability of Mamdani output is lost in the Sugeno [45].

The fuzzification of the input parameters are given in Fig. 8(a)–(c). In addition to heuristic knowledge and expert experience, literature data were used to describe membership functions. The limits and form of each subset are generally recommended by experts. According to Fig. 8(a)–(c), triangular membership function has been selected in the study because it can only be specified with three parameters, and this accelerates the learning process when the membership function is too general. This responsiveness is particularly important in virtual environment applications requiring user satisfaction [18]. The following fuzzy subsets have been selected to fuzzify the input variable Confidence Level: Coward, Brave and Overbold. Similarly, the other input variable behavior Type also have three fuzzy subsets: cautious, passive and aggressive. And, health status as the last input variable have five fuzzy subsets: very high, high, medium, low and very low. On the other hand, output variable given in Fig. 9 has been defined with four fuzzy subsets: flee, attempt to flee, wander and fight. All these outputs are computed by the fuzzy logic system according to intensity of the states. For example; braver confidence, higher health and more aggressive behavior types means that actions are more concentrated on fight. In adverse situation, the actions are more concentrated on flee.

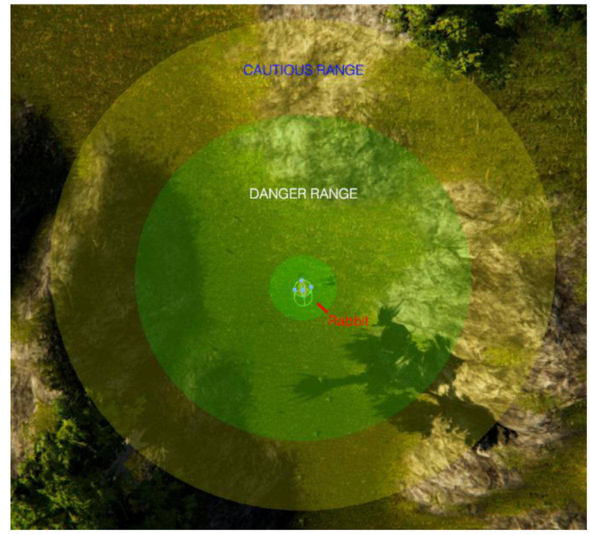


Fig. 12. Colored range demonstration on rabbit example.

4.4. Generating rules

For the responsiveness of the fuzzy system, it is vital to create rules that contain all the possibilities relative to the input sets. If there are any missing rules, no output will be generated by the system.

The way of creating the rules is to use if-then statements. 3 membership sets were defined for two of the input variables (behavior and confidence level), and 5 membership sets were used for the other input variable (health status). Accordingly, the total number of rules is $3 \times 3 \times 5 = 45$. Since it is unreasonable to have aggressive behavior for cowardly animals, it is restricted in the system to construct animals as both cowardly and aggressive at the same time. Thus, the number of rules is reduced to 40. Some rules that are written for the fuzzy system are given below:

(i) *If (Confidence Level Is Overbold) And (Behavior Type Is Cautious) And (Health Is Very Low) Then (Action Is Fight)*
(ii) *If (Confidence Level Is Coward) And (Behavior Type Is Passive) And (Health Is Medium) Then (Action Is Attempt To Flee)*
(iii) *If (Confidence Level Is Brave) And (Behavior Type Is Passive) And (Health Is Medium) Then (Action Is Wander)*
(iv) *If (Confidence Level Is Brave) And (Behavior Type Is Aggressive) And (Health Is Very High) Then (Action Is Fight)*
(v) *If (Confidence Level Is Coward) And (Behavior Type Is Cautious) And (Health Is Low) Then (Action Is Flee)*

These rules have been properly converted to search table format as shown in Table 2. In the Table 2, confidence and behavior type sets are located on left side of the table, and health sets are located on top. For instance, if confidence level is brave, behavior type is passive and health level is medium, the rule "wander" for action state of the computer controlled character in virtual island. As is clearly seen in the rule table, as the confidence level and health degree increases, the output value that determines the AI-based animal behavior in the system also goes into the Fight state. On the other hand, the decrease in these input values brings the animal behavior closer to the Flee state. However,

(a)

(b)

Fig. 13. Fleeing deer herd (a) scene-1 (b) scene-2.

there is a third factor affecting the output. The more aggressive the behaviors, the greater the tendency of outputs to become aggressive.

5. Results

The computer controlled AI-based animals use the calculated output value based on confidence, behavior, and health levels to show the appropriate behavior.

The crisp output for the system is calculated with center of gravity method (COG). The sample results from the system have been shown in Fig. 10. As seen in Fig. 10, if the input parameters become such as confidence level = 87.1, behavior type = 84.2 and health = 89.4, the output Action State value was calculated as 87. In another sample, for confidence level = 23.2, behavior type = 38.8 and health = 6.65, Action state is 32.3. The types of behaviors that correspond to these values are performed by looking at the rule table.

The effects of the inputs on outputs explicitly shown in the Fig. 11(a)–(c). In the context of Fig. 11(a)–(c), the output values in 3D surfaces can be seen according to behavior type, confidence level and health.

The system designed according to input parameters in Matlab environment was transferred to Unity 3D platform by using C# language and FL algorithms for rabbit, deer and some bird characters. After coding of fuzzy logic algorithms, the Virtual Island has been tested, and behavioral movements of AI-based animals were observed. The computer controlled AI-based animals are successful in aims of this work. The decision-making characteristics of an animal with AI are not triggered without the following information; did other animals enter the radius area as given in Fig. 12 and what are their behavior types? That is, if there is an animal coming to the deer fastly and entered into the radius area that the deer can notice, a trigger signal is sent to the AI interface in the software. This trigger signal operates the AI mechanism which determines how the animal decides. In this decision-making phase, the animal uses the health, behavior type and confidence level features to escape or attack other animals. For example, If the eagle controlling by user quickly and directly approaches the rabbit, the rabbit tries to find an escape route away from the eagle and other possible dangers, if any. The rabbit changes its behavior according to the warning interval and the danger interval . In addition, if the animals are not predators, they can interact closely with each other in a real ecological environment.

In another test result is presented in Fig. 13(a) and (b). It shows that the behavior of the AI-based deer herd against the eagle character which is controlled by user with developed hardware. Here, a deer herd grazing in the meadow has perceived the eagle character approaching him, and the deers decided on them own behaviors according to the behavior of the eagle. As the eagle has approached the deer herd in danger boundaries, the deer herd has showed the escape behavior against the eagle character. Similar behavioral interactions were established among other AI-based animals living within the Virtual Island. So, a habitat similar to the real world has been created.

6. Conclusion

The purpose of this study is to design a virtual island that includes AI capable animals to increase the level of experience of users. For this purpose, the island of Chios was modeled on the Unity3D platform and free moving characters were added to the island. In addition, a gyroscopic equipment was developed for the users visiting the island to fly from the point of view of an eagle. The confidence level, behavior type and healthy variables for each animals are chosen as the input data of the system to determine how animals behave in the environment and in their interaction with the user. The model firstly was designed with MATLAB software to understand what extend the FL method can estimate the action states of the animal characters. Then, the model is transferred to Unity 3D platform by using C # language and FL algorithms.

As demonstrated by the results of the study, it is possible to easily design AI-based animals with fuzzy logic in a virtual environment. The rules used in this study give AI-based animals a chance to think about their environmental conditions and decide on their own how to behave in different situations. The results of the study have proven that the virtual environment consisting AI-based animals has a good performance in terms of animal-user interactions and provided satisfactory results in run time.

The main difference of this study from other studies is that the AI-based animals in VE interact not only with the user but also with each other and provide a more realistic experience to users. However, when developing FL-based characters, the use of more input and output values to create more complex behaviors will increase the realism. It is also clear that the use of a proper membership function and its subsets will lead to the development of more sensitive animals.

Declaration of Competing Interest

None.

Acknowledgments

We would like to thank Reo-Tek Simulation, Interactive Presentations and Exhibition Design Co. for its help in this work.

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