

# 3D Virtual Fish Population World for Learning and Training Purposes

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## Abstract

This paper presents the potential use of the 3D virtual world of fish population for training and educational purposes, especially for who are new to fish farming industry. Virtual Reality is the proven technology which is emerging everyday with new methods and implementation. We simulate the fish swimming behavior based on the social rules that are derived from flocking behavior of birds. The simple relation we proposed to represent fish birth and death resembles the biological ecosystem of fish in the sea. The experiment results from different case studies we carried out shows the realistic fish population dynamics. The system user interface gives the users the ability to change the system parameters for different cases to see the real-time effect. Through different case studies carried, our framework can be used to simulate different environments.

*Keywords: 3D, virtual reality, fish farming, virtual world*

## 1 Introduction

Technology is emerging and becoming more advanced with the time span. With the development of technology, more and more resources are easy to access from home and school. The distance-learning concept is now proven technology and accepted worldwide. The teaching methodology in school, training and learning methods have been changing in large scale with the use of new technology. One of the most popular technology, which have very great scope in the coming days is to adapt virtual worlds in many sectors including learning and educational sectors. 3D Virtual World (VW), which provides realistic three-dimensional environments and offer engaging, interactive and immersive experiences, creates new opportunities for teaching and learning (Sampson, 2011). These opportunities are related to the realism of the educational activities representation within 3D VWs and to the enhanced aspects of interactivity provided within them. In the recent years, different researchers have recognized the educational and training potential of 3D VWs due to their unique features, such as the recreation of the sense of presence, their immediateness, the real world simulations provided, and the new experiences that

may not be possible, non-cost effective and even dangerous to represent in the real world (Molka-Danielsen and Mats, 2009).

In the adult sector large multinationals companies are using virtual worlds to educate their employees, and hospitals (e.g. St George's London), Governments (e.g. Canadian Border Security) and the Military (e.g. USAF MyBase in Second Life and TRADOC in Active Worlds being just two of many examples) are also exploring the use of this technology (Dalen.co.uk, 2010). The need of training simulator is demanding due to cost, safety and environmental purposes. We can use virtual world simulators to model any complex modules in which we can test any danger situation without affecting the life of human and physical damages. Innovative use of virtual reality technologies for the education and training offer new opportunities that can address needs for modular design that are adaptive, safe, flexible and reusable. There have been already another study on the reliability and potential of virtual fish farming as discussed on this paper (Hiemstra, 2015).

This study is primarily for education and training purposes especially in fishing industry. Aalesund is the capital city of fishing industry in Norway. Most of the people are engaged in this business and are willing to do. There are many stages, which needs to be finished in order to step into this industry. People are required to go through several training courses in order to start their fishing business of their own. It is well known that a real life training that involves experiment with alive fish, ocean and environment is quite impractical and not suitable. The testing for training such as what makes the breeding of fish faster, what may cause death of fish, what will happen to the fish environment if we change the parameters of sea (light, quality of ocean water, pollution, ship traffic) will be quite complex and nearly impossible in real life. Our project gives the complete framework to cope with this kind of problems for the fish farmers who are willing to start their own business. The virtual world we have made is completely immersive which plays a great role for giving real feeling to the trainers. In virtual world, they can experiment any parameters and see the effect directly. After going through several hours on training, they will achieve the professional skills which help them to start working in the fish industry.

Our model provides the framework for completely immersive training simulator for fish farmers. The framework uses mathematical modeling such as fish breeding rate, death rate and external factors in terms of mathematical modeling. Steering behaviors of fish such as following leader, changing the heading towards coworkers, maintain the speed of flocks is used to show the movement of fish in a realistic manner (Reynolds, 1999). In this paper, we use the term boids (Boids are bird-like objects that were developed in 1980s to model flocking behavior) to represent the flock of fish. 3D models are used to represent fish, environment, ocean, rocks and other objects to get a virtual world similar to the real life. The materials are used for 3D models, lighting and camera effects to add more realism to the model. In addition, the important part is User Interface (UI) that gives the user easy access to change any parameter such as fish death rate, birth rate, velocity and others that will show direct effect on our simulation. Also, we can add, modify for other complex scenario based on the requirements. Our framework is quite flexible, cost effective and easy to start.

## 2 Related Work

Virtual Reality (VR) has been studying for many years and is implemented successfully in many different sectors. The first practical use of VR was done by William Winn in 1993 (Youngblut, 1998). Winn discussed the importance of immersive VR technology in three different aspects which are not available in the real world (Winn, 1993). The three aspects he suggested are size, transduction, and reification. In 1994 Jonassen proposed that learners construct their own reality, or at least interpret it based on their perceptions of experiences, so an individual's knowledge is a function of one's prior experiences (Jonassen, 1994). There are plenty of works accomplished on VR in many areas. Some of them are discussed in this section.

Sandra Tan and Russell Waugh mentioned the use of VR in teaching and learning Molecular Biology. She discussed that her project helps students to give a better understanding in visualization for example (DNA) instead of drawing, models and other molecular dynamics on the board. It was easier for students to understand the transcription process in molecular biology (Sandra Tan, 2003).

The company called "minecraftedu" has already implemented Virtual learning in school. They believed this helped kids to explore planets and historical place (Miller, 2012).

Damian Schofield have discussed on effectiveness of advanced three-dimensional (3D) VR technology in chemical engineering and simulates the configuration and operation of a polymerization plant (Schofield, 2012).

Chih-Kai Huang and his co-authors discussed the implementation of a Virtual Fishing System. They mentioned how the user can incorporate a boat simulator, an interactive fishing rod, and virtual reality fishing scenes. This system creates a spontaneous and interactive environment, and offers the thrill and fun of sea fishing at home or at the amusement park (Chih-Kai *et al*, 2004).

Seungho Park has discussed in his article about the virtual fishing system through digital image sensing. He proposed the system that simulates fishing in a virtual space with changing baits (Park, 2003).

## 3 Modeling

This section is the core of the whole scheme. It bridges the gap between user interaction and the simulation result directly, which gives the users completely immersive to their result to understand the effect of what they want to simulate.

We have implemented individual agent based system. According to Yndestad (Yndestad, 2015), System is composed of a set of partners collaborating on a common purpose. Agents are related to the landscape. System model in terms of agent-based model can be represented by

$$S(t)=\{A(t), L(t), N(t)\} \quad (1)$$

where,  $A(t)$  represents a set of agents,  $L(t)$  is a landscape and  $N(t)$  is the relationships between the agents them self and between them and the landscape. Yndestad represents the individual agents in his system model as

$$S(\text{Agent}, t) = \{A(\text{Arc}, t), A(\text{Dyn}, t), A(\text{Eti}, t), A(\text{Lea}, t)\} \quad (2)$$

where  $A(\text{Arc}, t)$  represents the agent's architecture,  $A(\text{Dyn}, t)$  is the agent's dynamics,  $A(\text{Eti}, t)$  is the agent's ethics and  $A(\text{Lea}, t)$  is the agent's learning.

In our framework, we assumed each fish as an individual agent, ocean as the environment and dynamics such as birth, death, and scaling rates are used to formulate the relations. The agent learning means each fish can adapt its swimming behavior by following steering behavior rules that will be discussed in this chapter in section 3.3. We will describe the model in details in the following sections.

### 3.1 Fish Modeling

We have divided fish model into fish model and shark model. Also made seven assumptions as in Algorithm I.

### 3.2 Environmental Modeling

The environment model is very important to give a good realistic system and to simulate the effects of changing the environment parameters on the fish behavior. Some parts of the environment are fixed; others can be changed in the UI directly, while the remainders are changing by simple dynamics equations. We have added trees, bushes and rocks to our model. We have assumed the trees, bushes growing, and decay. In addition, the shifting of rocks is also added. We have defined some rates that are function of time for trees, bushes and rocks objects similar like we defined in the fish model. Besides, we generate a random number and check if this number is less than the rate we define, and then we assume objects are decaying, growing or shifting of rocks.

*Algorithm 1.* Fish and shark modeling.

```

Foreach fish and shark agent
  Initialize {fish birth rate {k1}, fish death rate (k2), fish scaling rate
    (k3), shark birth rate (k4), shark death rate (k5), shark scaling rate
    (k6), shark eating fish rate (k7) }
  Calculate probabilities
  {
    Prob. of fish birth ( $p_{k1}$ ) =  $1/k1$ 
    Prob. of fish death ( $p_{k2}$ ) =  $0.00001 * k2$ 
    Prob. of fish scaling ( $p_{k3}$ ) =  $0.00001 * k3$ 
    Prob. of shark birth ( $p_{k4}$ ) =  $1/k4$ 
    Prob. of shark death ( $p_{k5}$ ) =  $0.00001 * k5$ 
    Prob. of shark scaling ( $p_{k6}$ ) =  $0.00001 * k6$ 
  }
End Foreach

Do
  Generate random number (R)
  Foreach fish agent
    If  $R < p_{k1}$ 
      New fish is added
    End If
    If  $R < p_{k2}$ 
      Fish is treated as dead and removed from the world
    End If
    If  $R < p_{k3}$ 
      The size (length, breadth and height) of fish is increased
    End If
  End Foreach
  Foreach shark agent
    If  $R < p_{k4}$ 
      New shark is added
    End If
    If  $R < p_{k5}$ 
      Shark is treated as dead and removed from the world
    End If
    If  $R < p_{k6}$ 
      The size (length, breadth and height) of shark is increased
    End If
  End Foreach
  Foreach fish and shark
    If  $R < k7$ 
      Fish is killed by shark and fish is removed
      New shark is born
    End If
  End Foreach
  While user halt the program.

```

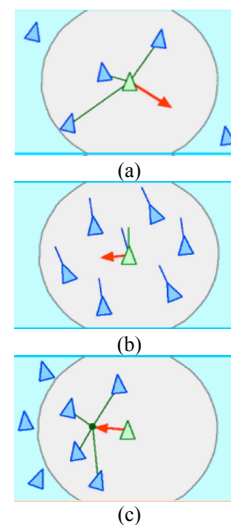
### 3.3 Steering Behavior Rules

Craig Reynolds proposed the famous steering behavior rules to represent the social behavior movement models in 1996. The basic flocking model consists of three simple social steering behavior rules that describe how an individual boid maneuvers based on the positions and velocities its nearby flock mates (Reynolds, 1999). The three main parameters are summarized below.

**Separation:** Steer to avoid crowding local flock mates (Figure 1 (a)).

**Alignment:** Steer towards the average heading of local flock mates (Figure 1 (b)).

**Cohesion:** Steer to move toward the average position of local flock mates (Figure 1 (c)).



**Separation:** Steer to avoid crowding local flock mates.

**Alignment:** Steer towards the average heading of local flock mates.

**Cohesion:** Steer to move toward the average position of local flock mates

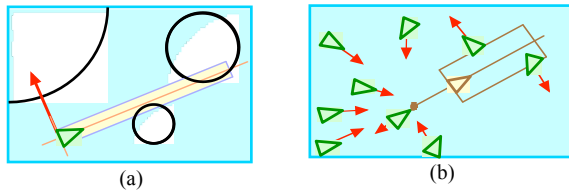
**Figure 1.** The Reynolds steering behavior rules (Reynolds, 1999).

The proposed steering behavior rules are not enough to adapt the complex environment. Therefore, Reynolds proposed adding individual based rules which will help each individual to adjust steering behaviors even in a complex dynamic environment (Reynolds, 1999). This will eventually help boids to finish specific task. The two important methods he included are:

- Obstacle avoidance (Figure 2(a)): This behavior allows boids to find path against obstacle in cluttered environment situation.
- Leader following (Figure 2(b)): Boids will adapt this behavior to follow the leader for specific task.

We have implemented the steering behavior rules proposed by Reynolds in Unity3D. The program is written in MonoDevelop Unity – C# (www.unity3d.com). The main reason behind implementing this model is to simulate the behavior for

the school of fish. Five rules are implemented in our model (Alaliyat et al, 2014).



**Figure 2.** The Reynolds extended steering behavior rules (a) obstacle avoidance (b) leader following (Reynolds, 1999).

**Cohesion:** This rule is responsible for fish agent to get closer to the center of neighbor fish. Hence the school of fish are formed. This rule can be seen as attraction rule i.e. acts opposite of separation rule. Assume cohesion of boid ( $b_i$ ) as ( $Coh_i$ ). It can be calculated in two steps. First we calculate the center of flock ( $f$ ) represented as ( $\vec{F_c}$ ), which can be obtained by

$$\vec{F_c} = \sum_{vbj \in f} \frac{\vec{p_j}}{N} \quad (3)$$

where,  $j$  is the position of boid  $j$  and  $N$  is the total number of boids. Then, the gravity of boids to lean toward the center of density of the flock is called as cohesion displacement vector as indicated by

$$\vec{Coh_i} = \vec{F_c} - \vec{p_i} \quad (4)$$

**Alignment:** This is the rule for boids (fish) to steer towards the same direction with neighboring fishes. There is a certain range of threshold distance of alignment for the fish which are counted as neighbors and average of their velocities are calculated. We can calculate alignment ( $Ali_i$ ) in two steps. First we find the average velocity vector of neighboring fishes ( $\vec{Fv_1}$ ) by

$$\vec{Fv_1} = \sum_{vbj \in f} \frac{\vec{v_j}}{N} \quad (5)$$

Then displacement vector of Alignment ( $Ali_i$ ) can be calculated by

$$\vec{Ali_i} = \vec{Fv_1} - \vec{v_i} \quad (6)$$

where  $\vec{v_i}$  is the velocity vector of boid  $i$  without this rule there will be no formation of nice flocking behavior of fish rather than bouncing each other randomly.

**Separation:** This is the rule for boids to make some distance from neighboring fish. The rule can be seen as type of repulsion rule. It's important to note that the

distance from which the boids start to avoid each other must be less than the distance from which the boids attract each other (due to the cohesion rule). Otherwise no flocks would be formed. We have implemented separation ( $Sep_i$ ) rule by (7). The self-position of boid  $b_i$  and neighboring visible boid  $b_j$  vectors are summed together. Then separation steer ( $\vec{Sep_i}$ ) can be calculated by

$$\vec{Sep_i} = \sum_{vbj \in f} (\vec{p_i} - \vec{p_j}) \quad (7)$$

**Leader following:** This is the rule to follow nearby moving boid chosen as leader ( $p_l$ ). The leader following ( $Led_i$ ) is calculated by

$$\vec{Led_i} = L * (\vec{p_l} - \vec{p_i}) \quad (8)$$

where  $L$  is a leading strength factor. (Note: the moving vector (velocity) has limits, minimum and maximum.

**Random movement:** This rule is to add some disturbance in the movement of fish to make realistic. Random number generator of Unity is used for this purpose. The random movement ( $Rand_i$ ) is calculated by

$$\vec{Rand_i} = -f \text{ factor} * \vec{r} \quad (9)$$

where  $r$  is a unit sphere random vector and  $f$  factor is a flock random strength factor.

Then the moving vector ( $V_i$ ) is for boid ( $b_i$ ) is calculated by combining all the steering behavior vectors as by

$$\vec{V_i} = w_1 + \vec{Coh_i} + w_2 \vec{Ali_i} + w_3 \vec{Sep_i} + w_4 \vec{Led_i} + w_5 \vec{Rand_i} \quad (10)$$

where  $w_i$  are the coefficients describing influences of each steering rule and used to balance the five rules.

The simulations of fish with all these rules are implemented in Unity3D game engine. The choice of game engine has been more important due to its better visual representation. We imported the 3D model fish, shark and other sea materials from third party instead of wasting time on building 3D models in which we are not interested. The animation such as movement of fish tail and fins make more realistic. All the 3D models are rigid solid object with dynamics of physics. This is important to keep away from collision of objects. We have used box collider and cylinder collider of game engine according to the necessity.



## 4 3D Modeling and Visualizations

3D model is the presentation of object used in VW which is similar in real life. The basic components of 3D models are cubes, polygons, sphere, cylinder and so on (Cudworth, 2014).

We can model, build, or create whatever we can visualize if that visualization is based on careful, complete observations of what you see in the real world. With scripting, we can change the size, position, color, texture, and visibility of any 3D models and transform them as they are approached and viewed, a great way to keep the experience fresh and interesting.

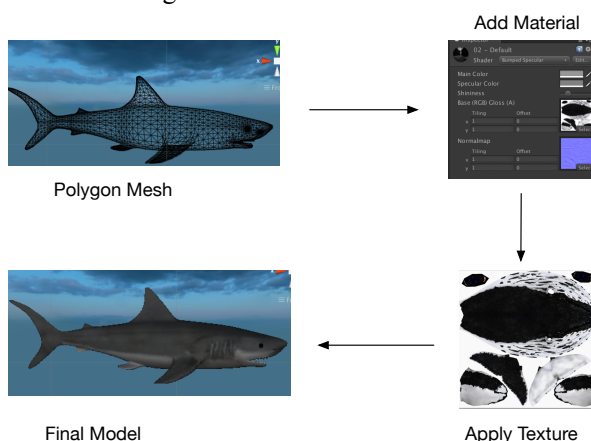
In the real physical world, we perceived 3D objects and their relationship to each other in space through a variety of “depth cues”. Our brains observe the relative size of two objects, and we often assume the larger one is closer to our position in space. By using the time-honored technique of forced perspective by building objects some distance away in a smaller scale, or diminishing these objects in actual scale as they progressively become distant, we can fool the brain into thinking these objects are even farther away (Cudworth, 2014). The 3D models used in our framework are:

### 4.1 Fish

The 3D model of fish is made of polygon meshes. The fish model has meshes defined with name “fish” and several joints are merged to make one solid 3D fish. It holds the information of animation of fish, i.e. waving the fins when they move. The general procedure of making 3D model fish is similar to shark as shown in Figure 3.

### 4.2 Shark

The shark model is also a collection of polygons formed in meshes. The mesh information is stored in “humpback” as mesh. The shade used for shark is Bumped Specular. The steps for the formation of shark are shown in Figure 3.



**Figure 3.** Steps involve in making 3D model of shark.

### 4.3 Other Models

The other objects models that we have used in our project are:

- Rocks
- Water bubbles
- Water creatures like crab, trees.

### 4.4 Lighting

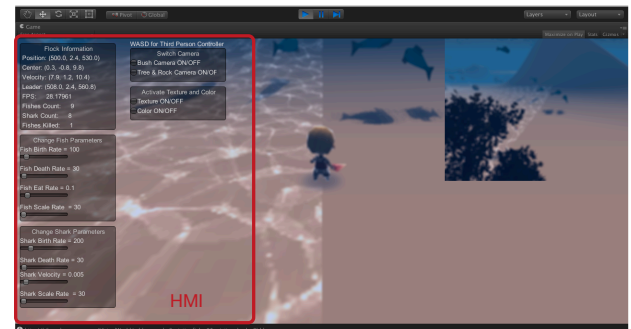
There are three basic things that lighting should do within a virtual environment and they are (Cudworth, 2014)

- Illuminate the meaning (or purpose) of this environment
- Support the mood(s)
- Augment the visual style Abbreviations and Acronyms

Even though we have nice textures and structures if there is no light that is meaningless. We have used point light, directional light and spot light.

### 4.5 Viewing

A Unity scene is created by arranging and moving objects in a three-dimensional space. Since the viewer’s screen is two-dimensional, there needs to be a way to capture a view and “flatten” it for display. This is accomplished using Cameras (Unity3d.com, 2016). We have installed several cameras in different areas in the scene, a camera to follow the leader, a camera to visualize the dynamic behavior of trees and rocks and a camera for bushes.



**Figure 4.** Human Machine Interaction.

### 4.6 Human Machine Interaction (HMI)

HMI as shown in Figure 4, is necessary to facilitate the user to select various parameters such fish birth rate, death rate, camera selection and so on to see the real time effect on the scene. We have used different types of controlling mechanism for the scene which are as below.

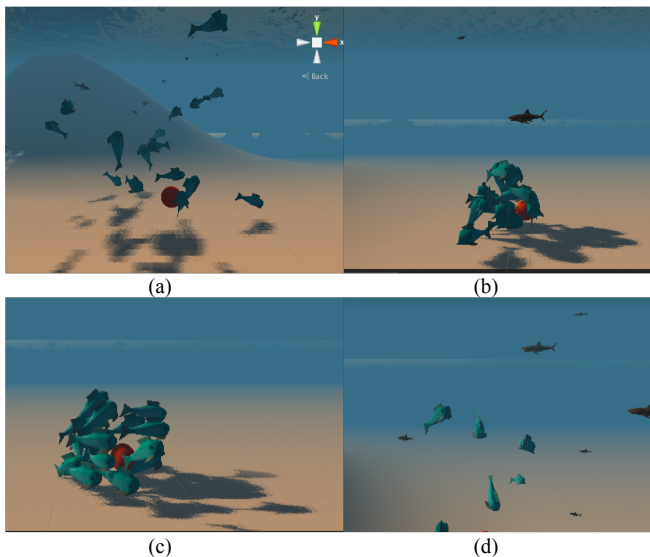
- Label - Display the information related to specific variables.
- Horizontal Slider - Slider has been implemented to facilitate for changing the dynamics of fish and shark populations. It will

easily let the users to change the birth rate, death rate and so on.

- Toggle Button - This is Boolean option for changing the case. It has been implemented for changing the position of camera. For example, the user can easily check the option in the screen to switch the camera from rock area to bushes area or fish flock area.

## 5 Experimental and Simulation Results

For simulation of fish behavior and other dynamics we have made 3D virtual world in Unity3D game engine. We have made a school of fish based on the steering behaviors rules. The movement of fish can be obtained by (10), and the initial number of fish and shark is shown in Table 1. Figure 5(a), Figure 5(b), Figure 5(c) and Figure 5(d) are the simulation results of steering behavior rules respectively for separation, cohesion, alignment and avoidance.



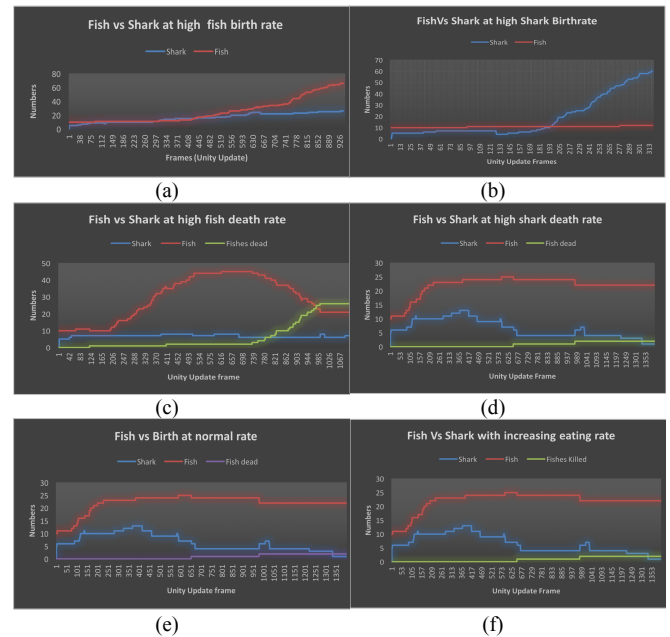
**Figure 5.** Fish movements' rules. a) Separation b) Cohesion c) Alignment d) Avoidance

**Table 1.** Parameter Settings.

Name	Minimum	Maximum	Parameter Value
<b>Fish Birth Rate</b>	10	1000	100
<b>Shark Birth Rate</b>	10	1000	100
<b>Fish Death Rate</b>	1	1000	30
<b>Shark Death Rate</b>	1	1000	30
<b>Fish Initial Number</b>	0	N/A	10
<b>Shark Initial Number</b>	0	N/A	5
<b>Eating Rate</b>	0.05	0.5	0.1
<b>Shark Scale Rate</b>	10	1000	30
<b>Fish Scale Rate</b>	10	1000	30
<b>Shark Velocity</b>	0.001	0.05	0.005

An experiment has been carried on the system we have built to verify the feasibility of the proposed flexible structure. The case studies aim to extract and verify the fish behaviors upon the time changing with some parameter settings. The initial parameters' settings before we run the model are shown in following Table 1.

First, we set the parameters as shown in Table 1, and try different changing in the parameters in control setting of the application. We have done some cases as below:



**Figure 6.** Fish vs Shark on different cases.

Case 1: Changing fish birth rate

We changed the fish birth rate from 100 to 10 making all other parameters constant. The output is shown in Figure 6 (a).

Case 2: Changing shark birth rate

We changed the shark birth rate from 100 to 10 making all other parameters constant. The output is shown in Figure 6 (b).

Case 3: Changing death rate of fish

We increased the population of fish by increasing the fish birth rate and then make fish birth rate very low around 471. The shark birth rate was made low around 921. Later the death rate of fish was shifted from 30 to 926 in slider. We cannot make simulation for very long time due to complexity of scene and rendering freezes. It is shown in Figure 6 (c).

Case 4: Changing death rate of shark

We increase the population of shark by increasing the shark birth rate and then make shark birth rate very

low around 471. The fish birth rate was made constant. Later the death rate of shark was shifted from 30 to 500 in slider. The output is shown in Figure 6 (d).

#### Case 5: Fish and shark at normal rate

The settings for normal rate, which are set at initial parameter settings, are shown in Figure 6 (e).

#### Case 6: Fish and shark with eating rate

The eating rate was changed from 0.01 to 0.3 and the results obtained are shown in Figure 6 (f).

## 6 Conclusions

The inception of VR in education and learning can be tracked back from the 90s. There is lot of potential use of VR in education such as: immersive technology helps student to learn the material, it increases interaction with the world and make feel the user is a part of that world, learners can integrate theoretical ideas by manipulating the 3D object to see how it work. In addition, the learners can create any complex scenario and test them to see the result easily, which is not possible in the real world.

The aim of this paper is to help learners who are interested in fish industry. The learners or students can get a better overview from the system we proposed. The testing of fish behavior in real life is very difficult while it is very simple and easy to understand in 3D virtual worlds by only changing some parameters from the user interface. In addition, learners can get the overview of fish population dynamics based on the setting they have applied in the application with the help of the real time graph. This makes the better understanding when the fish will have high population or less population. Due to the realistic visual representation, users feels completely immersive, which is very important to make the user feel like he is inside a real world.

We have discussed the 3D models we have used in our virtual fish farm, the rules and assumption which we implemented in our system. The simulations of 3D models are extremely helpful for better visual representation and this is facilitating the user correlation with real life. The behavior of fish movement should represent reality which is the main concern of virtual reality as we discussed in the introduction chapter. The overall movement of each individual fish is obtained by summing cohesion, separation, alignment, leader following and random factor as we described in section 3.3 of chapter 3. The fish model such as birth, death, scaling and the probability of getting eaten by shark is another important assumption we implemented in our system in order to understand the ecosystem of fish and shark in the sea. In addition, to make the environment natural-looking; growth function of tree, changing the color of tree to indicate aging and shifting of rock due to sea

waves are also implemented in our system. On top of these models, HMI will give easy access to the user to control all the parameters in the system we have developed and to see the effect instantly. Beside these, we have cameras in different section to switch the environment for the user.

The system we proposed here has the necessary modules for education and training of the people who are interested to pursue the fish farming business. The main advantage of using simulation is that the user can test any complex scenario which has zero impact on physical properties. After spending several hours in testing different scenarios it makes better understanding and will increase confident for farmers to start their business.

The challenge in our system is the need of high computing machine to render complex scenario with lots of 3D models. The rendering of the scene become slow if there are many 3D models such as fish and sharks after continues increase in number. Another challenge is the correct tuning in the parameters to resemble the real scenario such as flock formation, death and birth function. If we have a real life mathematical formulation of death, birth of fish and shark it will add more realism to the system. The use of Genetic Algorithm for self-tuning may help to make the system more robust. In addition, many works have worked on integration of devices like Oculus Rift, Google glass and these are compatible with the Unity 3D.

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