ILLUSTRATIVE 3D VISUALIZATION OF NETWORKED VEHICLE SYSTEMS

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Illustrative 3D visualization of Networked Vehicles Systems

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Abstract

Nowadays, with the development of the robotic vehicles it became possible to perform various tasks in the air, water, land and even space. They are utilized as fundamental data-gathering tools for environmental monitoring, marine and atmospheric plume detection and localization, allowing greater understanding of the planet and its environmental processes.

The main objective of the present work is to create three-dimensional illustrative visualization in a form of animation to convey the concept of real missions executed by means of robotic vehicles to the technical and non-technical audience. In this thesis, the motivated visualization scenario is based on the Rapid Environment Picture (REP-15) annual exercise co-organized by the Underwater Systems and Technology Laboratory (LSTS) from the Faculty of Engineering, University of Porto (FEUP) with the Portuguese Navy.

The tool used to create the visualization is the open source animation software Blender. Visualization of the phase I of the REP-15 is presented by the detection of the underwater mine scenario and the communication between an Autonomous Underwater Vehicle (AUV) and an Unmanned Aerial Vehicle (UAV). The phase II includes the cetaceans tracking, hydrographic conductivity, temperature and depth (CTD) survey, locating of the underwater vehicle by passive listening and aerial survey by the UAV.

One of the important objectives is to include real data in animation. Real trajectories of the vehicles were obtained by means of using of the location data that were stored on-board of the vehicles during the missions' execution. Use of bathymetric data allowed obtaining the seabed mesh of the surveyed area in Blender. The three-dimensional scenes of the created animation have a potential to be used for the visualization of other missions and in the simulation software for the development of the vehicle systems.
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<td>Two-dimensional</td>
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<td>3D</td>
<td>Three-dimensional</td>
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<td>AUV</td>
<td>Autonomous underwater vehicle</td>
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<td>CSV</td>
<td>Comma-separated values</td>
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<td>CTD</td>
<td>Conductivity, temperature and depth</td>
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<td>DUNE</td>
<td>Unified Navigation Environment</td>
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<td>GPU</td>
<td>Graphics Processing Unit</td>
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<td>IMC</td>
<td>Inter-Module Communication</td>
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<td>IP</td>
<td>Internet Protocol</td>
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<td>LAUV</td>
<td>Light autonomous underwater vehicle</td>
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<td>PNG</td>
<td>Portable Network Graphics</td>
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<td>REP</td>
<td>Rapid Environment Picture</td>
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<td>RHIB</td>
<td>Rigid-hulled inflatable boat</td>
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<tr>
<td>ROV</td>
<td>Remotely operated vehicle</td>
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<tr>
<td>TCP</td>
<td>Transmission control protocol</td>
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<tr>
<td>UAV</td>
<td>Unmanned aerial vehicle</td>
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Chapter 1

Introduction

Nowadays, visualization is applicable almost in all areas of human activity. Using visualization technics it is possible to convey the complex idea in a simplified view. The invention of computer graphics is an important step in visualization. Using of computer graphics gives possibility of representing any sort of data, information or processes in a better form for perception and understanding.

People have tried to portray the effect of motion since ancient times. At the present day, it is possible to create a vivid and interesting animation movie. Three-dimensional computer graphics allows artists to create images and virtual scenes that can barely be distinguished from the real.

The successful development of the unmanned robots is giving promising results in various problems solving. They can perform different tasks under the water, in the air, on the surface of Earth and other planets.

As an example, by means of autonomous underwater robots it is possible not only to explore the ocean floor, but also search the shipwrecks and other sunken objects, provide the port security and surveillance of subsea pipelines. Unmanned aerial vehicles are deployed for a number of military and civil applications such as reconnaissance, inspection of above-ground pipelines, firefighting, scientific research, surveying and policing. Networking offers new opportunities in use of vehicles systems.

Visualization of networked vehicle systems can be used as a unique tool to convey the idea and disseminate the achievements of these systems.
1.1 Motivation

The old saying, “a picture is worth a thousand words,” still remains true in every field of human knowledge. Dozens of text pages with explanations can be replaced by several minutes of an animation that can convey the same idea, but in more illustrative way.

The major motivation of the work is to create a visualization of real missions that took place during the phase I and II of the Rapid Environment Picture (REP-15) annual exercise to technical and non-technical audience by means of three-dimensional animation. REP-15 was co-organized by the Underwater Systems and Technology Laboratory (LSTS) from the Faculty of Engineering, University of Porto (FEUP) with the Portuguese Navy.

Visualization of real missions gives the opportunity to obtain the larger view of the executed projects and to recreate the necessary scenes of the missions. It also gives the possibility to disseminate the new achievements in the development of the robotic vehicles in an interesting illustrative way.

A non-technical audience may have better understanding of autonomous vehicles by means of visualization.

1.2 Objectives

This work addresses the following main objectives:

- to understand the concepts of robotic vehicle systems and visualization;
- to master skills of creating 3D animation;
- to find out whether it is possible to include the real paths of the vehicles in animation;
- to find out what other data from the real missions can be used for visualization;
- to choose the optimal quality of rendering;
- to create the visualization of the missions that took place during the REP-15;
- to consider the further use of the work.
1.3 Thesis structure

This work is organized as follows.

Chapter 2 is dedicated to the theoretical part of the work. The overview of visualization is presented in Section 2.1. Section 2.2 describes the basics of 3D animation which was used in this work. Networked vehicles systems are described in Section 2.3. Section 2.4 is presented by the examples of the related works.

Chapter 3 is a main chapter of the work. Section 3.1 presents the overview of the REP-15 and visualization scenario. Section 3.2 describes the software used to achieve the goals of the work. Section 3.3 provides the achievements of obtaining of the real trajectories of the vehicles and the seabed meshes in Blender. Section 3.4 describes the creation of the visualization for the Phase I of the REP-15. Visualization of the Phase II is presented in section 3.5. Section 3.6 contains the information about rendering of the animation.

Chapter 4 presents the conclusions and future work.
Chapter 2

Background and Related work

This chapter provides a brief overview of visualization and networked vehicle systems. Section 2.1 describes the notion “visualization” and fields of its application. Section 2.2 is devoted to the steps of 3D animation creation which was used in this work. Overview of the networked vehicle systems, networking concept, review of the vehicle systems of the Underwater Systems and Technology Laboratory are presented in Section 2.3. The examples of the related works are described in Section 2.4.

2.1 Visualization

The term visualization can be found in different contexts. Visualization can be a technique of the mental picture creation in a person’s mind in psychology, can be a sketch or a table representing some data, but mostly it denotes the general name of the presentation methods of numerical information, physical phenomena or some processes in a from convenient for visual perception and analysis.

There is no single generally accepted classification of visualization. Some of the approaches to visualization taxonomies are based on the type of data and graphical perception models [1, 2], other approaches based on the visualization algorithms and not the data itself [3, 4], and another approach is focused on the interactivity of visualizations [5].

An important goal in many applications is to present certain data in the form that is the best for the human perception. In fact, the method of presentation depends on the type of the data and objectives. Some data is better to present in the form of the
diagram, but other is convenient to perceive in the table form. Information visualization evolved as an approach to make large quantities of complex information intelligible [6].

With the invention of the computer graphics visualization is becoming increasingly common. Visualization can be found almost in every field of the human knowledge. Today visualization finds application in various fields as science, education, medicine, architecture, engineering, business and multimedia. Visualization in computer graphics is any technique for creating diagrams, images or animation to convey the information for further use.

Scientific visualization is the transformation, selection and representation of the data from the experiments or simulations. It allows understanding, exploring, analyzing and communicating the scientific data. A scientific storytelling using visualization is presented in [7]. Educational visualization is used in the teaching to give the idea of something that is difficult to see or to explain in words [8]. In architecture [9], visualization is a graphical display of the projected buildings and constructions. In medicine, visualization is used to study the relationship of anatomic structure to biologic functions and to detect and treat diseases and traumas which disturb or threaten normal life processes [10, 11]. Product visualization is an important aspect in the product development and its manufacturing.

Visualization in robotics helps to illustrate robot manipulator modelling, trajectories, robot collisions, and provides invaluable contribution in robotics education [12]. Moreover, visualization in robotics can be used as an interactive tool that gives possibility not only to observe, but also to interact with created robot in virtual reality. Very often, visualization is used coupled with simulation for grasping research in robotics [13].

Sometimes it is necessary to explain how things look and work, their internal structure, how behave some complex processes or to convey some concepts. In these cases is used illustrative visualization. 3D animation is a vivid and illustrative way of visualization. For this work it was decided to use a 3D animation as a tool for visualization.

2.2 Basics of 3D animation

The earliest attempts to show the phenomena of the motion may have begun with the cave painting. People and animals were depicted repeatedly in superimposed positions, clearly trying to convey the perception of motion. Figure 2.1 shows the example of the attempt to depict the movement of the lions at Chauvet cave in the south of France approximately 30000 years ago.
Background and Related work

Figure 2.1 - Cave painting depicting the motion (image source: [14])

Animation is the process of displaying static images that minimally differ from each other in a rapid sequence to create the illusion of the motion and the shape change.

Creation of the 3D project, as surely as creation of the real movie, consist of several mandatory and consecutive stages. These stages are the same and do not depend neither on the software used for creation, nor on the type of project (whether it is feature-length movie or short promotional video).

During the filming of the real movie must be selected the actors, selected the place where the movie will be shot and if necessary created a scenery. Then, the filming location had to be equipped with cameras and illumination, actors should be prepared for shooting (clothing, make-up). Once the positions of the cameras were chosen and light was installed, movie is ready for shooting. The final stage is editing and obtaining the final product.

3D-artists, during the creation of their works, are repeating the same steps. They are creating the scenery, three-dimensional models (objects, characters), they are making them move and speak, installing the lighting and choosing the cameras positions. Besides, artists are making the scene look realistic. This step is similar to the applying make-up and choosing the clothing for the artists. Compositing is a final modification of the project. Thereby, the steps of creating 3D animation are analogous to the steps of creating the movie.

Therefore, the process of the animation creation can be represented in the following steps:
- Modeling;
- Texturing;
- Animation;
- Lighting;
2.2 Basics of 3D animation

- Camera positioning;
- Rendering;
- Compositing.

2.2.1 Modeling

Creation of the three-dimensional model of the objects called modelling. Artist can create everything that he wants: 3D models of characters, trees, buildings, mountains and any other object. The process of modelling can take different amount of time. Usually, it depends of the object complexity. Thus, it is possible to create a simple box for several minutes and creation of the human head takes several days or weeks.

2.2.2 Textures and materials

All the objects that we see in the real world differ from each other in appearance. Since we know how should look the objects created from the different materials, we can easily distinguish them: milk from water, glass from plastic, gold from copper.

At the stage of modelling, objects created in the three-dimensional space, differ from each other only in shape. To make the 3D-model look like the real object, it is not enough only to replicate accurately its shape, but also to “dress” it properly.

Textures and materials can be considered as one of the most important tools during the animation creation. A superb model will look like grey plastic toy without any textures. At the same time, accurate and well thought-out textures and materials can make the scene look like the reality.

2.2.3 Animation

Animatimg is one of the most important steps in animation creation. At this stage, 3D-artists are enlivening 3D models by making the objects change their position, orientation, size, deforming them, making them move by means of the movement of the another object.

2.2.4 Lighting

Lighting is another important step of the animation creation. To simulate the lighting in three-dimensional graphics are used the special objects - the light sources. To make the 3D scene look like real it is important to take into account various factors as what
type of the light source should be used, where it should be located, energy and direction of the light.

2.2.5 Camera positioning

During the watching of the movie or some television show it is noticeable that camera angle is always changing. As an example, in the beginning of the football game is shown the stadium from the bird’s-eye view, after camera focused on the players and coaches or the ball. It would not be interesting to watch the match, if it was shown only from the one point, without changing the camera positions and using other cameras located in different places of the stadium.

In fact, the final product of the three-dimensional animation is the video that can be “filmed” from different angles. For instance, an object can be shown from the distance and in this case it is possible to see it whole, or it is important to show only particular part of it. In the second case is possible to use the camera zoom. In short, the choice of the camera angles in 3D animation is as important as in the movies or television. In 3D animation are used virtual cameras. As real cameras, virtual can be moved from one location to another. Moreover, it is possible to switch from one camera to another in the process of animation. Thus, first fifty frames of animation can be observed from the first camera and then switch to a view from the second one. Virtual cameras may have the same properties as the real. As an example, they can simulate the effect of the depth of the field or can capture the image from the different angles.

3D-artist, working on the animation creation, has to be able to choose the right location of the cameras and think over how to move the cameras to have the best view.

2.2.6 Rendering

The sequence of the previous steps can be different. But without rendering all those steps will not have the sense, because the work will be incomplete. Visualization is a synonym of rendering. Rendering is a final result or product from the previous steps: generated image or video.

2.2.7 Compositing

Compositing implies the assembling and improving of the rendered images or movies. Frequently after the first rendering they are not perfect and need minor modifications.
Compositing gives the required and completed output as well as possibility to combine separate elements into single one.

2.3 Networked vehicle systems

2.3.1 Underwater Systems and Technology Laboratory (LSTS)

This work was based on the provided information by the team of the LSTS. LSTS or Underwater Systems and Technology Laboratory [15] is an interdisciplinary research laboratory established in 1997 at the Faculty of Engineering of the University of Porto. Specialization of the laboratory is design, construction and operation of the autonomous underwater, aerial and surface vehicles. Researches from the laboratory are working on the development of the tools and technologies for the deployment of networked vehicle systems.

The autonomous vehicles were successfully applied and tested in different projects in the Mediterranean Sea, the Atlantic and Pacific oceans by the researchers from LSTS during the last fifteen years.

2.3.2 Networking concept

Autonomous or unmanned vehicles can perform important, difficult, dangerous and monotonous tasks in different environments, such as air, space, ocean and land. Multiple vehicles can be more effective than single one. The time that takes to perform a certain operation by single vehicle can be reduced by using several vehicles, and at the same time an area of the exploration can be increased.

Communication between the vehicles, interaction between the human operators and vehicles, real-time decision making are giving opportunities and advantages for the different operations execution. Accordingly, networking of the systems offers new possibilities to the operation of the unmanned vehicles.

Networked vehicle system is a system where human operators, heterogeneous autonomous vehicles and various sensing devices interact through communication networks [16]. These networks have a dynamic topology. Both unmanned vehicles and human operators may have a dynamical physical position. Vehicles, during a mission, can operate as mobile communication and sensing tools, obtain the data from the remote locations, and moreover, work as data mules. Figure 2.2 shows the LSTS concept of the networked vehicle systems. A communications hub, depicted as a cloud, is used for the data dissemination and global situation awareness.
In [17] it was considered an example of the conceptual deployment of a networked vehicle system. In the assumed scenario, there are two human operators connected to the network. Other operators can join to the mission at any moment. The goal of one of the operator is to obtain underwater side-scan survey at some remote location. This goal should be specified to the system and the network should automatically adapt to perform the objective. At first, should be found the vehicles that are capable to obtain the required data. Then, the selected vehicles have to perform the location survey. Lastly, obtained data should be relayed back to the station.

Considering the presented example, one of the unmanned aerial vehicles could get the list of tasks from the base station. After it could fly to the device that provides wireless as well as acoustic underwater communications and transmit the tasks to it. Further, this device had to select the underwater vehicles that able to perform the survey and relay the tasks to them. After completing the survey, obtained data could be delivered back to the base station using the same communication way as before. The example of the deployment of a networked vehicle system is shown in Figure 2.3.
2.3 Networked vehicle systems

To manage and control these networked vehicle systems it was necessary to develop software and protocols that can be applied across various devices for cooperative and single tasks. To solve this problem, the LSTS researchers have developed on-board software DUNE, command and control software Neptus and the IMC communications protocol [18].

DUNE or Unified Navigational Enviroment is the on-board software running on the vehicle. DUNE is responsible for navigation, control, task execution, maneuvering, communications and vehicle supervision, as well as interaction with sensors, actuators and payload.

Neptus [19] is the command and control software used by human operators to interact with networked vehicle systems. Neptus is responsible for the mission planning, simulation, execution, review and analysis.

The Inter-Module Communication (IMC) protocol is a message-oriented protocol. Purpose of the IMC is communication among human operators, heterogeneous vehicles and sensors.

2.3.3 Review of some vehicles and support systems at the LSTS

The main vehicles and systems at the laboratory include:

- autonomous underwater vehicles (lightweight);
- unmanned aerial vehicles;
communication gateways;
- wavy drifter buoys.

**Light Autonomous Underwater Vehicles (LAUV)**

The LAUV is a lightweight version of the ordinary autonomous underwater vehicles. LAUV can be easily operated, launched and recovered. Managing of the vehicle does not require comprehensive training of the operators. It is low-priced and affordable. The vehicle is aimed at standalone or networked operations for control, safety, hydrographic and oceanographic exploration. LAUV has not only a basic functional system that includes communications, computational system and basic navigation sensors, but also capability of adding optional payload modules. Figure 2.4 shows examples of the lightweight underwater vehicles.

![Image of LAUVs](image-source-[20])

**Figure 2.4 - Autonomous underwater vehicles (image source: [20])**

**Features of LAUVs:**
- performs underwater observation and exploration using echo sounders, sonars, cameras and other sensors;
- gathers data as temperature, turbidity, salinity or dissolved oxygen;
- maps areas with sonar for searching shipwrecks, archaeological sites and other sunken objects;
- creates 2D and 3D maps.

**Unmanned aerial vehicle (UAV)**

The X8 Skywalker is a low-priced aerial vehicle modified at the LSTS designed for surveillance missions, fast algorithm testing and terrain mapping. The X8 aerial vehicle
2.3 Networked vehicle systems

can be easily launched and quickly recovered. The example of the X8 is shown in Figure 2.5.

![Unmanned aerial vehicle X8 Skywalker](image-source.jpg)

**Figure 2.5** - Unmanned aerial vehicle X8 Skywalker (image source: [20])

**Features:**
- capable of carrying a small digital HD video camera;
- capable of performing video reconnaissance up to 3 kilometers with constant Wi-Fi connectivity;
- capable of real time video transmitting to the operation station, as well as of storing of it on the board for the later analysis;
- capable of extending the Wi-Fi network for field operation by means of the on-board Wi-Fi modem;
- capable of autonomous launching from catapult;
- capable of creating a map of the operation area through image mosaicking.

**Manta communications gateway**

The communications gateway gives possibility of controlling and monitoring multiple vehicles to multiple operators in a networked environment over different platforms. The gateway has waterproof enclosure and can be installed in a buoy, supports wireless and acoustic communications. An example of the gateway is shown in Figure 2.6.
Background and Related work

Figure 2.6 - Communication gateway Manta (image source: [20])

Features:
- creates the local wireless networks using Wi-Fi and acoustic modems;
- creates the mobile networking infrastructure;
- capable of connecting the local network to the Internet using 3G and 4G networks;
- capable of bridging the heterogeneous networks and data exchanging between acoustic, TCP/IP and satellite links.

Wavy drifter buoy

Wavy is a simple and low-cost drifter buoy equipped with the necessary devices to measure, log and report its own position even under rough sea conditions. Figure 2.7 shows the example of the wavy drifter buoy available at the LSTS.

Figure 2.7 - Wavy drifter buoy (image source: [20])
Features:
- constant GPS signal;
- simple interface;
- long battery life;
- light and resistant;
- easily trackable.

2.4 Visualization and simulators

2.4.1 Simulation

Carrying out the experiments with the underwater robots requires a high number of resources, costs and logistics. The testing of the robots can be carried out in water tanks or open environments, such as the sea and the ocean. Water tank requires significant space and maintenance. Testing in the ocean usually involves planning, transportation and costs. Experimental validation of these robots is quite laborious and difficult. To save time and cost, one way to test something before applying it in a real case is to simulate it.

Simulation is used in many contexts. In three-dimensional computer graphics the notion “simulation” can be used for creating the simulation of the real physical phenomena, such as smoke, rain, dust, cloth and water.

Mainly, simulation is the imitation of the operation of a real-world system or process over time [21]. To perform the act of simulating first it is necessary to develop the model that represents the key characteristics or functions of the selected system or process (that can be real or abstract). The model represents the process itself, while the simulation represents the operation of the process over time. Virtual environment, interactivity, observation of the simulated system or the process can be provided by means of the visualization.

Computer simulation found its application in various areas. A few of them:
- training;
- medicine;
- manufacturing;
- emergency management;
- education and learning;
- decision support;
- entertainment;
Visualization and simulation are closely related to each other. One example for underwater robots is the visualization the results from simulation of the work of remotely operated vehicles (ROVs) with different type of manipulators. Simulation of the aerial vehicles mostly presented as a training software for the vehicle’s operator.

Simulator systems allow facilitating the development of the underwater robots. By using a simulator it is possible to test and develop the systems before they are deployed as well as to supervise a real underwater mission where developers do not have a direct view.

The work in [22] provides a description and the features of several virtual simulators developed for autonomous underwater vehicles. Most of these simulators are outdated or are very specific to a particular project. There are also commercial simulators, such as ROVsims [23], DeepWorks [24] and Vortex [25], but basically they are designed for the ROV operator training. At the LSTS, it has been tested the work of the publicly available simulator UnderWater SIMulator (UWSIM) [26].

UWSIM is an open-source tool developed for simulation and visualization of underwater robotic missions [27]. UWSIM visualizes an underwater virtual scenario and can be used in the following cases:
- validate perception and control algorithms;
- supervision/playback of a survey;
- simulation of a vehicle dynamics.

UWSIM supports virtual cameras. It is possible to simulate the real condition applying the vision-based algorithms on virtual images.

**Figure 2.8** - UWSIM screenshots
2.4 Visualization and simulators

In Figure 2.8 (left image), UWSIM renders a scenario where an underwater vehicle performing the grasping of the object from the seabed and publishes the images captured from the virtual camera. The right image of the Figure 2.8 shows the reproduction of a survey in UWSIM from the dataset captured during the real survey. In this way, UWSIM gives possibility to obtain a playback and supervision of the real missions.

To simulate dynamic behavior of the vehicles in UWSIM it is necessary to use external software such as MATLAB.

Unfortunately, UWSIM has not found its application at the LSTS. This is explained due to the non-compatibility of the simulator with DUNE.

2.4.2 Visualization of manipulators

Development of the manipulator arms, robotic hands and different grasping mechanisms can be improved by use of simulation and visualization. A large number of grasping simulators are based on the attempt to emulate the human hand because of its proven capabilities. Figure 2.9 shows a screenshot from visualization of the publicly available simulator Graspit! [28] designed for grasping research.

![Graspit! Simulator Screenshot](image-source: [28])

The work in [29] is focused on the development of a visualization tool for manipulator arm, Raptor, built for underwater operations. The main objective of the tool is to decrease the risk of failures, such as collisions, unexpected obstacles and damages, and also to improve the operator's situation awareness. The interface of the developed tool is shown in Figure 2.10.
2.4.3 Autonomous vehicles visualization examples

In [30] there is a 3D animation describing the features and capabilities of the Bluefin-21, an autonomous underwater vehicle of Bluefin Robotics. Bluefin Robotics is an American company which develops, builds and operates autonomous underwater vehicles. Figure 2.11 shows a screenshot from the animation that shows the replacing of the vehicle’s batteries.

The yearly exercise REP-13 [31] was aimed at collecting data about the sunfish habits and its habitat. There is a short simple animation [32] which lasts 42 seconds showing the sunfish tracking scenario. Figure 2.12 shows a screenshot of the animation, where an aerial vehicle is detecting the sunfish.
2.4 Visualization and simulators

Figure 2.12 - Sunfish tracking (image source: [32])

For REMUS 6000, an autonomous underwater vehicle of the Norwegian company KONGSBERG, there was created an animation [33] describing its features and capabilities. This visualization and visualization of Bluefin-21 AUV are very similar and probably they are both were created for the commercial purposes. Figure 2.13 shows a screenshot of the animation.

Figure 2.13 - REMUS 6000 animation (image source: [33])
Chapter 3

Visualization of Networked Vehicle Systems

This chapter concludes the main part of the work. Section 3.1 describes the visualization scenario and overview of the annual exercise REP-15. Section 3.2 presents the overview of the software used in this work. Real data from the missions executed by the vehicles and used in animation are presented in Section 3.3. Section 3.4 describes the process of the visualization creation for the Phase I of the REP-15. Section 3.5 presents the steps of the visualization creation for the Phase II. Section 3.6 provides the information about rendering of the animation.

3.1 REP-15 and animation scenario

To accomplish the main goal of the thesis, it has been decided to create a 3D animation of the several real scenes of the yearly exercise of the Underwater Systems and Technology Laboratory (LSTS), called REP-15 [34], which took place in July 2015.

REP-15 has been co-organized by the LSTS with the Portuguese Navy. The annual exercises allow to the researchers to check the work and new achievements in the development of networked vehicle systems. The REP-15 was divided in three phases and took place nearby the Azores islands. During the first phase, operations took place on shore and near the shore. Open water operations took place during the second phase. The last phase has the goal to map the shallow vents between Faial and Pico islands.
3.2 Blender

During the first phase of the REP-15 there were executed the military exercise in the interests of the Portuguese Navy, particularly the detection of the underwater mine using the underwater vehicles. Another important part of the phase was to test the communication between the underwater and aerial vehicles. Thereby, to show the two main actions of the first phase it was necessary to create at least two scenes showing the detection of the underwater mine and communication between AUV and UAV.

The second phase was aimed to collect some data of the environment of cetaceans using AUVs and UAVs. This phase took place offshore. To spot the cetaceans a small rigid-hulled inflatable boat (RHIB) was used. Aerial vehicle was launched from the ship of the Portuguese Navy, NRP Almirante Gago Coutinho. CTD surveys were performed by two AUVs simultaneously. Moreover, it was tested the locating of the underwater vehicle by the passive listening.

During the last phase there were performed the mapping of the shallow vents. The last phase has not been included in the animation, since all the data of the phase were not available till the beginning of September.

3.2 Blender

To accomplish the goals of the thesis was used Blender 2.74. Blender is a free and open source 3D creation software. It supports modeling, rigging, texturing, animation, simulation, rendering, compositing, motion tracking, scripting, video editing and even game creation. Using Blender is possible to create from simple basic 3D model to complete animation movie [35].

To learn and quickly understand the principles and ideas of the animation creation, to understand the work of necessary features of Blender was used Blender Reference Manual that available on the main website of Blender [36] and number of tutorials available on the Internet. Figure 3.1 shows the main window of Blender 2.74.

3D models of the objects can be created using the basic meshes in Blender. Mesh is a collection of vertices, edges and faces that defines the shape of the object. The shape of the basic meshes in Blender can be changed by using the Edit mode of the object.

The actions of the animation are defined by the key frames. Key frames are used to set the values of properties which define the starting and ending points of any action. In Blender almost all properties can be key framed.
3.3 Real data

3.3.1 Trajectory of the vehicles

One of the objectives of the thesis was to use the real data from the vehicles for animation creation. A path that vehicle have to follow to explore some certain area can be set by an operator. During completing the mission the vehicle is saving all the data including its own locations along the path. Thereby, it is possible to get all the coordinates such as northing, easting, altitude and other values as rotation angles of the vehicles. A negative value of the altitude has meaning that the vehicle is located under the water. For unmanned aerial vehicles these values are always positive.

To complete the objective it was necessary to find out how to import these data into Blender and create the real trajectory of the vehicle. The first step was to search all the possible methods of importing the positions into Blender.

In Blender it is possible to use Python scripts that allow having new features and options that do not exist in Blender by default. The name of the script that enables new functionality in Blender is Add-on. It is possible not only to enable Add-ons that available in Blender, but also to install them from the external sources. This option allows using scripts that was written even by your own. Figure 3.2 shows the window of Blender that allows to enable available Add-ons or to install the new one.
3.3 Real data

There is a community of the artists that are using Blender for creation of their artworks [37]. On the forum of the Blender artists [38] it was found a script “CSV F-curve Importer” of one of the Blender artists, Mr. Hans P.G. That script according to the description had possibility to accomplish the goal of the importing of the real path data of the vehicles into Blender. Purpose of the script was to import CSV file into Blender and to create f-curves.

CSV or “comma-separated values” is a file that stores basic database-style information in a simple format as plain text. Each line of the file is a data record that consists of several fields. The fields are separated between each other by some delimiter, such as comma. Thereby, to use this script, it was created CSV file with all positions of the vehicle. The line of the file with the following data ‘0.24,1.39,-0.05’ has meaning that the vehicle was at the certain moment of time at the certain point with coordinates of the northing, easting and altitude equal to ‘X=0.24,Y=1.39,Z=-0.05’. F-curve is an animation curve with a set of key frames which are represented as points. In this case trajectory of the vehicle during some task execution is presented as the f-curve in Blender.

Since the script was written in 2011 emerged a problem of the script’s outdating. It was not working with the latest Blender version 2.74 that was used for the animation creation. It was created for the versions 2.5x. Developer of the script, Mr. Hans P.G., was notified of the problem and afterwards it was solved.
With the help of the script it was obtained the curves for each of the axes. The figure 3.3 shows the graph editor of Blender that shows f-curves created using CSV F-curve Importer.

![F-curves obtained using CSV F-curve Importer](image)

**Figure 3.3 - F-curves obtained using CSV F-curve Importer**

Since the amount of the positions of the vehicle was quite big (more than 2600 coordinates), during the preview of the animation it was quite hard to follow the movement of the vehicle. This happened due to the fact that an area explored by the vehicle was quite large and amount of the location coordinates was considerable.

This lead to the idea that is it is necessary to see the line of the vehicle trajectory. For this purpose it was found another script of Mr. Hans P.G., CSV Mesh Importer.

CSV Mesh Importer is a script that allows to import a CSV file into Blender and to create meshes, such as edges, vertices and faces. The figure 3.4 shows the view of the importer.

![CSV Mesh Importer](image)

**Figure 3.4 - CSV Mesh Importer**
3.3 Real data

The use of CSV Mesh Importer is quite similar to the use of CSV F-curve Importer. Was used the same CSV file with the coordinates of the location of the autonomous underwater vehicle. The import command sequence is following:

- Choose the type of CSV file;
- Specify the path to the file location;
- Choose the delimiter of the CSV file;
- Choose the type (creation of the vertices only or creation of the vertices and edges);
- Specify the columns;
- Complete the import.

Due to CSV Mesh Importer was successfully obtained the real trajectory of the vehicle in Blender. Figure 3.5 shows the trajectory of the autonomous underwater vehicle during the real mission execution.

![Figure 3.5 - Real trajectory imported into Blender](image)

Illustration of the trajectory is giving a clear idea of how the vehicle was moving under the water during the mission execution.

Moreover, it is possible to get the trajectory from the simulation of the missions. For the phase II of the REP-15 there were simulated trajectories of the AUVs to perform hydrographic survey in case of the detection of the cetaceans in the ocean. It was assumed that there were two underwater vehicles at that moment. Figure 3.6 shows top view (left) and side view (right) of the simulated trajectories. Side view shows that trajectory of the vehicles is not a straight line, but a sequence of immersion and emersion.
When the phase II was completed there were obtained the real trajectories from the missions that took place on the 19th of July. During this day there were involved the unmanned aerial vehicle X8 and two underwater vehicles XPLORE. Figure 3.7 shows the imported real trajectories of the vehicles into Blender.

To distinguish the trajectories from each other it was applied different coloration: the trajectory of X8 is red, XPLORE-1 is blue and XPLORE-2 is green. The fact of obtaining the real trajectories in Blender is very important since it gives an overview of the whole mission assigned for the vehicles. It also gives possibility to recreate all the scenarios of the executed tasks. Table 3.1 shows top view of all the trajectories separately.
### 3.3 Real data

**Table 3.1 - Trajectories of the vehicles**

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Trajectory</th>
</tr>
</thead>
<tbody>
<tr>
<td>X8</td>
<td><img src="image1" alt="X8 Trajectory" /></td>
</tr>
<tr>
<td>XPLORE-1</td>
<td><img src="image2" alt="XPLORE-1 Trajectory" /></td>
</tr>
<tr>
<td>XPLORE-2</td>
<td><img src="image3" alt="XPLORE-2 Trajectory" /></td>
</tr>
</tbody>
</table>

Since two XPLOREs were performing the tasks simultaneously there is a reason to show their trajectories together (Figure 3.8).
3.3.2 Bathymetric meshes

Using the autonomous underwater vehicles it is also possible to obtain the data from bathymetric surveys. Bathymetry is the measurement of the depth of water in the oceans, lakes, rivers or seas. By virtue of bathymetry it is possible to obtain the shape of the underwater terrain. Further, this data can be used for the creation of the shape of the surveyed seabed. To use the real shape in Blender it was necessary to find a way how to import this data into Blender. Thus, it was necessary to create a mesh from bathymetric data, export it from the software used at the LSTS in a format that can be imported into Blender.

One of the REP-15 phase III operations was to survey coastal areas of the Azores. Figure 3.9 shows the selected area marked by a red rectangle.
3.3 Real data

One way to check the attainability of the objective was using of the DUNE simulation. Figure 3.10 shows the area from the red rectangle of the image before. On the image below are shown numbers that define the depth value at the certain point. Next to the islands these values equal to 53 and 70 meters, further from the coast this number is increasing to 229. The depth of the area in the lower left corner is reaching to 405 meters.

![Figure 3.10 - Coastal area of the Azores](image)

Due to the simulation was obtained the mesh of the specified area. This mesh was exported in a format supported by Blender. The next step was to import this file into Blender. Import was performed successfully, however the size of the mesh was enormous and caused problems in the work with the mesh in Blender. But this can be explained by the fact that during the simulation was used the real data. Thus, the size of the obtained mesh was reduced for the convenience of use. Figure 3.11 shows top view of the mesh imported into Blender.

![Figure 3.11 - Imported mesh of the seabed](image)
Looking at the image before and obtained mesh it is possible to see that flat part of the mesh is the smooth surface of the islands and another part is uneven surface of the seabed.

As it was described previously the maximum value of the water depth was 405 meters. Figure 3.12 shows the gradual increasing of depth with the increasing of the distance from the coast.

![Side view of the mesh](image)

**Figure 3.12** - Side view of the mesh

In this way, it is possible to use the bathymetric data for creation of the real shape of the seabed of the surveyed area.

One of the common ways to represent the bathymetric data is to present it in the form of the bathymetric chart. To illustrate it in Blender as multicolored chart it was necessary to find a texture that can provide the desired result.

Blend is one of the most frequently used procedural textures in Blender. Using this texture it is possible to create a sequence of colors with a smooth transition from one to another.

Figure 3.13 shows the result of applying the created texture for the seabed mesh obtained before.

![Texturing result for the smooth mesh](image)

**Figure 3.13** - Texturing result for the smooth mesh
Since the shape of the mesh is mostly smooth, the same texture was applied for the mesh with another shape. It was interesting to know what result will be achieved with this texture for curved and uneven surface. Figure 3.14 shows that the same texture can be successfully applied for the different shapes of the meshes, and probably even more illustrative for uneven shapes.

![Texturing result for the uneven mesh](image)

This was planned to use for the visualization of the phase III, but unfortunately all the obtained data was not available till the beginning of September. However, the possibility of the obtaining the seabed mesh for visualization was proved.

3.4 Phase I

The idea of the phase I was briefly described before. The first step of the animation creation is to define what you want to show to the audience and how to attract the attention and at the same time to convey the idea. The first phase was divided for 2 main actions: the detection of the underwater mine by the underwater vehicle and communication between the underwater and aerial vehicles. Thereby, it was necessary to create two scenes: the underwater scene and the scene above the water.

3.4.1 3D models

At first it was necessary to define and create 3D models that will build the “skeleton” of the actions, particularly for the phase I: underwater vehicle, aerial vehicle, underwater mine, seafloor and water surface.

During the military exercise was used particular model of the underwater vehicle, Iver [39]. The goal of the illustrative visualization is not to show the exact copy of the
models and to show the real images, but to convey the main idea illustratively. Nevertheless, for this work all the models and scenes are close enough for the real ones. Iver AUV is shown in Figure 3.15.

![Iver AUV](image-source: [34])

**Figure 3.15 - Iver (white) underwater vehicle (image source: [34])**

Generally, the process of 3D modelling can take different amount of time, which depends on the object’s complexity. Some objects can have simple shapes and they do not require a lot of hours for their creation, but other objects can have a lot of little details. Modelling of such objects can take from several hours till several days. If it is necessary to create the particular 3D model and to show only the model of the object, in this case it is important to pay attention to all the little details. While during the creation of the 3D animation the most important part is the action and little details of the models can be omitted.

At the LSTS there were available two 3D model of the vehicles:

- AUV;
- UAV.

It was possible to use these models for creation of this work. Models are shown in Figure 3.16.
Basing on the real image of the Iver and the AUV model of the LSTS there were created 3D model of the Iver shown in Figure 3.17.

The main external difference of the Iver AUV from the vehicles developed at the LSTS is the “head” of the vehicle and colors. Table 3.2 shows the screenshots of the model from the different orthographic views (top, right and front).

3D viewport of Blender supports two types of projection: orthographic and perspective. Our eyes are used to perspective viewing in which distant objects appear smaller. In orthographic projection objects stay the same size independent of their distance. It seems odd at first, but it is more convenient for work.
Table 3.2 - Iver AUV

<table>
<thead>
<tr>
<th>Orthographic view</th>
<th>Screenshot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top</td>
<td><img src="image1" alt="Top View" /></td>
</tr>
<tr>
<td>Right</td>
<td><img src="image2" alt="Right View" /></td>
</tr>
<tr>
<td>Front</td>
<td><img src="image3" alt="Front View" /></td>
</tr>
</tbody>
</table>

Since the Iver has the white color, it was decided to use the UAV model from the LSTS. In this way both aerial and underwater vehicles will have the same color range.

The next step of the underwater scene creation for the phase I was to create the underwater mine. The underwater mine has the shape of the sphere and in most cases it
is symmetric. A chain or steel cable connecting the mine to an anchor on the seabed are used to prevent the mine drifting away.

To model the mine in Blender used two types of meshes were used: sphere and cylinder. Since the shape of it can be symmetric it was possible to use the mirror modifier available in Blender. The Mirror modifier mirrors created mesh along local axis (X, Y or Z), across the center of the object. Assuming that the mine consists of the eight equal symmetric parts, it is possible to recreate the entire model having at least one eighth part of it. Table 3.3 shows the steps of the mirror modifier application.

The final model of the mine itself is shown below in Figure 3.18. It was necessary to change the bottom of it to model the junction part of the mine to the chain.

![Figure 3.18 - 3D model of the underwater mine](image)

The final step for the underwater mine was creation of the chain that connects the mine to the anchor on the seabed. A chain is a series of connected links. To create the link of the chain it was used a mesh called torus. Torus has the shape of the doughnut. An amount of the torus segments can be easily adjusted. Using edit mode of the torus it was possible to model easily the link of the chain. The next step was to duplicate the link and rotate it by 90 degrees. Table 3.4 shows all the steps of the chain creation.
Table 3.3 - Mirror modifier for the underwater mine

<table>
<thead>
<tr>
<th>Axis</th>
<th>Right orthographic view</th>
<th>Top orthographic view</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td><img src="X.png" alt="Image" /></td>
<td><img src="X.png" alt="Image" /></td>
</tr>
<tr>
<td>X, Y</td>
<td><img src="X_Y.png" alt="Image" /></td>
<td><img src="X_Y.png" alt="Image" /></td>
</tr>
<tr>
<td>X, Y, Z</td>
<td><img src="X_Y_Z.png" alt="Image" /></td>
<td><img src="X_Y_Z.png" alt="Image" /></td>
</tr>
</tbody>
</table>
### Table 3.4 - Creation of the chain for the underwater mine

<table>
<thead>
<tr>
<th>Creation sequence of the chain</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Creation sequence" /></td>
</tr>
<tr>
<td><img src="image2" alt="Creation sequence" /></td>
</tr>
<tr>
<td><img src="image3" alt="Creation sequence" /></td>
</tr>
<tr>
<td><img src="image4" alt="Creation sequence" /></td>
</tr>
<tr>
<td><img src="image5" alt="Creation sequence" /></td>
</tr>
<tr>
<td><img src="image6" alt="Creation sequence" /></td>
</tr>
</tbody>
</table>

3.4 Phase I
Final 3D model of the underwater mine with the chain is shown in Figure 3.19.

![Figure 3.19 - final 3D model of the underwater mine with the chain](image)

The mine detection was executed by the side scan sonar. Side scan sonar is a technique of the seafloor imaging. A sonar device emits conical or fan-shaped pulses down towards the seabed across the wide angle perpendicular to the path of the sensor through the water. For the underwater scene of the phase I it was necessary to show that the vehicle is not just following some path, but that it is imaging the seafloor to detect the mine location. For that purpose it was created a simple model shown in Figure 3.20.

![Figure 3.20 - Iver and side scan sonar](image)
3.4 Phase I

3D models of the seafloor and the surface of the ocean were created by using the basic mesh object of Blender, called plane. It is a standard plane which contains four vertices, four edges and one face. Since the surface of the seafloor is not flat it was necessary to deform the plane to make the surface look more realistically. One way to do it is to subdivide the plane into desired amount of the segments and after to deform it by changing of the location of the certain vertices as shown in Figure 3.21 (a). Another interesting way to deform the plane is a combination of the applied Displace modifier and Clouds texture. The Displace modifier displace vertices in a mesh based on the intensity of a texture. The result is shown in Figure 3.21 (b) that can be improved by the adjusting of the properties and settings.

\[ \text{Figure 3.21 - Deformation of the plane} \]

The plane for the ocean surface does not require its deformation. The most important for it is to set such properties of the materials and textures that can give the desired result and make the plane look like a water surface.

3.4.2 Underwater scene (mine hunting)

Having all the necessary 3D models it is possible to start the creation of the animation itself. The first step is to locate all the models and to think over all the actions. It is necessary to think where to locate the cameras and where the action will start.
At first it was necessary to create the movement of the vehicle. The real trajectories of the vehicles were not available since the surveys were executed by the vehicles not from the LSTS. In Blender it is possible to set a “Follow path” constraint for any mesh and create the path for the mesh. This constraint places its owner onto a curve target object (the path) and makes it move along this curve. The velocity of the movement is defined by the “Evaluation time” property of the path animation. It is necessary to key frame the starting and ending point of the movement. Edit mode of the path is shown in Figure 3.22. Vertices of the orange line define the shape of the curve. Black curve is the path itself. Little black arrows show the direction of the movement.

![Figure 3.22 - Edit mode of the path](image)

In this way it was created the path for the Iver and the vehicle was moving along this path.

To make the seafloor look like sand it was necessary to set the properties for the Material and Texture tabs. The effect of sand was obtained by using of the “Noise” texture with enabled and adjusted properties of the Influence panel.

To obtain the effect of water and waves it was not enough just to set the blue color for the plane. The effect of moving water was obtained by application of the “Clouds” texture, adjusting of the Influence panel, and the most important part was key framing of the “Size” property of the texture. The bigger difference in the values of the key frames, the faster “movement” of the texture. It is important to mention that the plane should be slightly transparent. Therefore it was necessary to enable the “Transparency” property in the Material tab. Moreover, water is reflecting the objects. By enabling the “Mirror” property it was possible to obtain the reflectivity. However, for the underwater scene this property should be disabled. The visibility under the water is getting worse
with the distance. This effect can be obtained by enabling the “Mist” property of the “World” tab. It can take a lot of time to obtain the desired result by adjusting of the properties.

The last step for the underwater scene was camera positioning. In Blender, locations of the camera can also be key framed. The first frame shows moving Iver from the certain distance (Figure 3.23).

![Figure 3.23 - First frame of the underwater scene](image)

Since the vehicle is not just moving under the water, after some seconds it was necessary to show that it is performing survey of the seafloor using sonar. In Blender it is possible to restrict the rendering of the certain objects. Restrict rendering is used when it is necessary to show some objects in the certain frames and to hide them in other. Green disabled icon of camera (Figure 3.24) in front of the “sonar” title means that during rendering of this frame the mesh “sonar” will be invisible.

![Figure 3.24 - Restrict rendering](image)

In this way it was possible to enable rendering of the mesh which imitates the sonar’s pulses. Since the vehicle follows the path it was necessary to relocate the camera and to key frame its current position (Figure 3.25).
Figure 3.25 - Iver performing the survey

The next crucial frames show the detection of the underwater mine. In this frames camera was located straight in front of the action as shown in Figure 3.26. The path of the vehicle was located above the mine.

Figure 3.26 - Detection of the underwater mine

When the goal of the exercise was reached the vehicle can float up to the surface and transmit the obtained data. The frame shown in Figure 3.27 illustrates Iver floating up to the water surface. Position of the camera was changed according to the movement of the vehicle.
3.4 Phase I

Figure 3.27 - One of the final frames of the underwater scene

3.4.3 Communication scene

To make the smooth transition from the underwater scene to the scene showing the communication between the vehicles, it was decided to show the smooth emersion of the camera focused on the underwater vehicle (Figure 3.28).

Figure 3.28 - Transition from the underwater scene to the communication scene

Table 3.5 shows the principle of the communication between the vehicles from the different orthographic views.
Table 3.5 - Communication between the vehicles

<table>
<thead>
<tr>
<th>Orthographic view</th>
<th>Screenshot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top</td>
<td><img src="image1" alt="Top View" /></td>
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<td>Right</td>
<td><img src="image2" alt="Right View" /></td>
</tr>
<tr>
<td>Front</td>
<td><img src="image3" alt="Front View" /></td>
</tr>
</tbody>
</table>

Assuming that the underwater vehicle is a green rectangle and a blue mesh is the aerial vehicle that flying above the water and trying to establish the communication. One of the vehicle is static and another is moving all the time. An orange curve is the path of the aerial vehicle.
The communication between the vehicles can be visualized as a signal which was transmitted from one vehicle towards another and backwards. This signal can be modeled from a number of the identical spheres as shown in Table 3.5. If two vehicles were static it is possible to create the movement of the signal by means of key framing the locations of the spheres. But the aerial vehicle is not static and therefore it was necessary to find another solution.

To solve that problem it was used a “Hook” tool for the path available in Blender. First step was creation of the path that will be used for transmitting the signal between the vehicles. The next step was to delete all the vertices of the curve except of two. After it was necessary to select each vertex of the curve and to call the “Hook to the new object” command. These steps will create two new null objects at each vertex, called empties. By setting the vehicle as a parent object to the empty it is possible to obtain the “flexible” path between the vehicles which is shown as a black straight line between the vehicles.

The final step was to show the signal (data) transmitted from the AUV to UAV. It was achieved by using of the “Duplication” property of the mesh and by the key framing of the “Start” and “End” values of the frames. These values indicate where to start duplicate the mesh along the path and where to finish the duplication.

The path for the aerial vehicle was created in the same way as it was described before for the underwater vehicle. The result of rendering for the communication is shown in Figure 3.29.

![Figure 3.29 - Transition from the underwater scene to the communication scene](image-url)
Accordingly, Iver has performed the survey to detect the location of the underwater mine and transmitted the obtained data to the aerial vehicle. The logical conclusion of the scene should be the returning of the UAV to the base station with obtained data. For this purpose was created the scene shown in Figure 3.30.

![Figure 3.30 - The final scene of the phase I](image)

It is important to mention that propellers of the both vehicles also were animated for the created scenes. The effect of real sky was achieved by the adjusting of the properties in the “World” tab.

### 3.5 Phase II

#### 3.5.1 3D models

To create the visualization for the phase II it was necessary to have the following 3D models:

- UAV;
- Models of XPLORE and NOPTILUS LAUVs;
- RHIB;
- Model imitating the NRP Almirante Gago Coutinho;
- Whale.

The real images of the robotic vehicles used during the phase II were shown previously in Figure 3.15 (section 3.3). 3D models provided by the LSTS were used for creation of the necessary models. Real image of the ship of the Portuguese Navy, NRP Almirante Gago Coutinho, is shown in Figure 3.31.
Modeling of the ship with such complexity could take a huge amount of time. Therefore it was decided to find a free 3D model available on the Internet and to remodel it. A website [40] has a big gallery of 3D models available in the different formats. On this website, it was found a model of the ship (image a) which was imported into Blender afterwards and remodeled as shown in Figure 3.32 (image b).

Table 3.6 shows the model from the different orthographic views.
The AUVs NOPTILUS and XPLORE are vehicles developed at the LSTS. The main external difference of the vehicles is the color: NOPTILUS is orange and XPLORE is yellow. The aerial vehicle X8 has an orange-black coloration. Table 3.7 shows the obtained 3D models of the vehicles.
Table 3.7 - 3D models of the vehicles

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>3D model</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOPTILUS</td>
<td><img src="image1" alt="NOPTILUS 3D model" /></td>
</tr>
<tr>
<td>XPLORE</td>
<td><img src="image2" alt="XPLORE 3D model" /></td>
</tr>
<tr>
<td>X8</td>
<td><img src="image3" alt="X8 3D model" /></td>
</tr>
</tbody>
</table>

Table 3.8 shows NOPTILUS LAUV from the different orthographic views.
Table 3.8 - NOPTILUS LAUV

<table>
<thead>
<tr>
<th>Orthographic view</th>
<th>Screenshot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top</td>
<td><img src="image" alt="Top View" /></td>
</tr>
<tr>
<td>Right</td>
<td><img src="image" alt="Right View" /></td>
</tr>
<tr>
<td>Front</td>
<td><img src="image" alt="Front View" /></td>
</tr>
</tbody>
</table>

3D model of the XPLORE underwater vehicle is shown in Table 3.9.
Top, right and front orthographic view of the unmanned aerial vehicle X8 is shown in Table 3.10.
Since during the phase II the cetaceans were spotted using RHIB it was necessary to obtain 3D model of the inflatable boat. Moreover, boat cannot be empty during the action, therefore it was necessary to obtain the model of the sitting man. The models of the boat and man were downloaded from the website [40] mentioned before. Imported models are shown in Figure 3.33.

### Table 3.10 - X8 UAV

<table>
<thead>
<tr>
<th>Orthographic view</th>
<th>Screenshot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top</td>
<td><img src="image1" alt="Screenshot" /></td>
</tr>
<tr>
<td>Right</td>
<td><img src="image2" alt="Screenshot" /></td>
</tr>
<tr>
<td>Front</td>
<td><img src="image3" alt="Screenshot" /></td>
</tr>
</tbody>
</table>
3.5 Phase II

The last required model for the phase II was a model representing the cetaceans. It was decided to use a model of the sperm whale shown in Figure 3.34.

3D model of the human face is considered as the most complex model. Therefore it was decided not to show the face of the man sitting in the boat and show him from the back. Moreover, it was necessary to duplicate and modify the model of the man since it is required more than one man to perform any task. The result of the applied materials and textures to the models is shown in Table 3.11.
**Table 3.11** - RHIB with two men inside

<table>
<thead>
<tr>
<th>Orthographic view</th>
<th>Screenshot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top</td>
<td><img src="image1" alt="Top View" /></td>
</tr>
<tr>
<td>Right</td>
<td><img src="image2" alt="Right View" /></td>
</tr>
<tr>
<td>Front</td>
<td><img src="image3" alt="Front View" /></td>
</tr>
</tbody>
</table>

Table 3.12 shows the final 3D model of the whale from the top, right and front orthographic views.
3.5 Phase II

Table 3.12 - 3D model of the whale

<table>
<thead>
<tr>
<th>Orthographic view</th>
<th>Screenshot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top</td>
<td><img src="image1" alt="Top View" /></td>
</tr>
<tr>
<td>Right</td>
<td><img src="image2" alt="Right View" /></td>
</tr>
<tr>
<td>Front</td>
<td><img src="image3" alt="Front View" /></td>
</tr>
</tbody>
</table>

3.5.2 Cetaceans tracking

All the different scenes of the animation should smoothly transit from one to another. The first scene of the phase II shows the inflatable boat with the men inside floating with the aim to spot the cetaceans (Figure 3.35).
The boat is continuing to float and after some seconds it slows down its movement. The locations of the camera was key framed according to the movement of the boat. During the next frames the movement of the boat is stopping and camera is smoothly descending under the water. In this way the further action takes place under the water. The goal was to show the fact that a whale was spotted under the water.

The underwater scene shows the whale swimming in front of the camera. Sperm whales are not very agile mammals. Therefore it was enough to animate only the tail of the model. To pose or deform the mesh object it is used the process called rigging. The first step of rigging is to attach a skeleton, called armature, to the mesh. This skeleton consists from the “bones” which are used for posing or deformation of the mesh. Figure 3.36 shows the model with the attached armature (image a) and an example of the mesh posing (image b).

To animate the model it is necessary to save all the required poses. For the tail of the whale it was key framed three main poses shown in Table 3.13.
3.5 Phase II

Table 3.13 - Whale posing and animation

<table>
<thead>
<tr>
<th>Pose (tail)</th>
<th>Screenshot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Straight</td>
<td><img src="image" alt="Screenshot of Straight Pose" /></td>
</tr>
<tr>
<td>Down</td>
<td><img src="image" alt="Screenshot of Down Pose" /></td>
</tr>
<tr>
<td>Up</td>
<td><img src="image" alt="Screenshot of Up Pose" /></td>
</tr>
</tbody>
</table>

Key framing only of the main three poses is not giving constant movement of the tail. One way to make the tail move cyclically during the animation is to set the “Repeat”
property of the action. Figure 3.37 shows one of the rendered frames obtained for the underwater scene with whale.

![Image](image1.png)

**Figure 3.37** - The underwater scene with the whale

The next action shows the communication between the RHIB and the big ship imitating the NRP Almirante Gago Coutinho. This scene implies that the researchers on the board of the NRP Almirante Gago Coutinho have been notified about the detection of the whale (Figure 3.38).

![Image](image2.png)

**Figure 3.38** - Communication between the researchers
3.5 Phase II

3.5.3 Aerial survey

The next action of the scene is the launching of the UAV from the Gago Coutinho. Figure 3.39 shows the scene where X8 is executing the task above the water. The trajectories of the launching and returning of the vehicle back to the ship were created in Blender by means of use Path-curves. The trajectory of survey itself is a part of the real trajectory of X8.

![Figure 3.39 - AUV performing the task above the water](image)

As soon as the task was completed, the aerial vehicle can return to the ship. For that it should receive the command from the operator. Figure 3.40 shows the communication between the vehicle and the ship.

![Figure 3.40 - Communication between X8 and Gago Countinho](image)

The next scene shows the returning of the AUV on the board of the ship (Figure 3.41). Transparency of the water was slightly increased and it is also possible to notice the
whale swimming under the water. It was done to make the viewer remember about the goal of the action and to smoothly move the scene under the water.

![Image of whale swimming under water]

**Figure 3.41 - Returning of the UAV back to the ship**

### 3.5.4 CTD survey

The underwater scene shows the execution of the CTD survey by two XPLOREs AUVs. A CTD's device primary function is to detect how the conductivity and temperature of the water column changes relative to the depth. Figure 3.42 shows a temperature color map which appears with the movement of the vehicles. The trajectories of the vehicles are parts of the real trajectories of XPLOREs imported in Blender.

![Image of temperature color map]

**Figure 3.42 - Temperature color map**
Emergence of the colors with the movement of the vehicles was achieved by using of the “Dynamic paint” modifier available in Blender. The modifier itself has two types: canvas and brush. The mesh defined as a canvas is receiving the paint. At the same time the mesh defined as a brush is applying paint on the canvas. In this way it was created a plane defined as the canvas and a sphere defined as the brush. To make the brush change its color it was necessary to change and key frame the color value at certain points. The brush was located next to the head of the vehicle and the vehicle was set as a parent of the brush. The rendering of the brush and canvas was restricted. It is important to mention that first should be defined the canvas and only after the brush, since the reverse order does not make the brush apply paint on the canvas. The dynamic paint result was “baked” in form of images (PNG format) that corresponds to each frame. In Blender, “baking” is a process of pre-computing something in order to speed up some other processes (as rendering) later. Further, the baked images were applied as textures for the canvas.

3.5.5 Locating of the vehicle by passive listening

The last scene of the phase II visualizes the locating of the vehicle by passive listening. The main idea of the scene is to show the signal propagation emitted by the autonomous underwater vehicle (Figure 3.43). The signal was depicted as rings around the vehicle with different radiuses. The rings were modeled from the torus mesh mentioned before. The effect of signal propagation was achieved by the sequential rendering enabling/restricting of the rings. A 3D model of the buoy was modeled by using of the sphere and cylinder meshes in Blender.
Moreover, it was created a short visualization of the networking concept. To create this visualization the models and scenes created before were used. Figure 3.44 shows the transmitting of the data from the AUV to UAV. This visualization is aimed to show the communication between the vehicles and operators, dynamism of the network and availability of the data on the cloud. The models of the computers and mobile phone are used to represent the operators. 3D model of the cloud is depicting a communications hub which is used for the global situation awareness and data dissemination.

![Visualization of Networked Vehicle Systems](image)

**Figure 3.44 - Transmitting of the data from the AUV to UAV**

### 3.6 Rendering

As it was described in section 2.2.6, rendering is a process of generating an image or video from the created 3D scenes. One important step before rendering is to set the light for 3D scenes. For this work it was used “Environment lighting” option and “Sun” available in Blender.

Blender includes two render engines: Blender Render and Cycles Render. Render engine is the set of code which defines how the rendered image looks like and how the materials and lighting are used. Cycles Render engine is more new and takes more time for rendering. To work efficiently with Cycles engine it is necessary to have a powerful GPU.

There are two ways of rendering of the animation. First way is to render all the frames in a form of separate images and glue them after by means of video editing. 24 frames form 1 second of the animation. And the second way is to render the animation in a video format. For this work it was decided to use the first way since it is more reliable way of rendering. Also it can be explained due to the fact that if it would be necessary to
3.6 Rendering

change some frames of the animation it is possible to render just the needed frames. In the second case it is necessary to render the whole animation from the beginning.

It is very important to mention that the more complex the 3D scene, the more it takes to render it. The result cannot be seen before rendering and it is possible to obtain the actions more slow/fast than needed. Therefore one way to avoid this is to create the scenes with the simple meshes imitating the real 3D models and render them with low quality. After, it is possible to replace them with the final models.

For this work it was decided to render the images with full HD quality (resolution: 1920x1080).
Chapter 4

Conclusions

4.1 Conclusions

The goal of the presented work was to create 3D illustrative visualization of the networked vehicle systems. Visualization was based on the data of the REP-15.

Primarily, the creation of visualization requires an understanding of the field for which the visualization has to be created. It is very important, since lack of knowledge can lead to mistakes in visualization. Thus, the first step was to understand the idea and purpose of the autonomous vehicles.

Another important step is to define the objectives of visualization. This step defines the most important moments that should be visualized and which should convey the idea in a simple and clear way. To make the visualization simple and understandable it is possible to neglect not crucial moments and to simplify the complicated ones.

To create the visualization of this work it was used an open source animation software Blender. Working with any 3D animation software it is necessary to have a significant practice. At a first glance, it seems that some simple things can be created very easily, but in fact lack of one single step can lead to the wrong result.

It is very important to mention that the same settings can give different results for different objects and different scenes, and it takes a lot of time to obtain the needed result. Working with textures, it is important to consider that they behave differently if the size of the objects was changed. Therefore, each object and each scene of the same project can have different settings.
Conclusions

The strange noise on the picture can be explained by the not proper settings of lighting, but also can appear because of a number of other reasons. In Blender, if the object is duplicated and the duplication is located at the same place it will lead to the noise that can appear after rendering, but will not be noticeable before. Therefore, the creation of visualization is a complicated process which requires an attention to all the details.

Another important objective of the work was including of real data in visualization. It was found a way of importing of the real trajectories of the vehicles from the missions and the seabed meshes that were obtained from the bathymetric surveys. The real trajectories are giving an overview of the executed missions and possibility to see all the paths of the vehicles together and to see the scale of the completed project.

This work was divided in two parts. The first main part of the work was visualization of the phase I of the REP-15. Phase I was consisted from two parts: military exercise (underwater mine detection), communication between AUV and UAV. All the actions of the visualization were created in a way that one is smoothly evolving into another.

The second part of the work was devoted to the phase II. The cetaceans tracking, aerial exploration by UAV, hydrographic (CTD) survey by two AUVs simultaneously and locating of the vehicle by passive listening were the main actions of the visualization for this phase. To create the trajectories of the vehicles the parts of the real trajectories from the missions were used. The reason of using the parts of the trajectories is simple. The full trajectory of the vehicle describes hours of the surveys. To visualize the full scenario requires more time for rendering and also the action can be too monotonous for the viewers. Therefore, it was decided to use only parts of the real trajectories.

Moreover, it was created a short animation showing the concept of networking. Totally, there were rendered 1425 frames for the phase I, 4661 frames for the phase II and 1347 frames for the networking concept. The final video was made by means of video editing software. Render process for this work took more than 7 full days.

This work is a proof that it is possible to recreate and visualize any scenario of the executed missions.

4.2 Future work

As it was mentioned before the data from the phase III of the REP-15 were not available till the September. The possibility of importing the seabed meshes into Blender was proved. Therefore, it is possible to create the visualization of the phase III which is including the multibeam sonar survey of the shallow vents next to the Azores.
Regarding the temperature color map it is important to mention that colors were applied to the canvas approximately. The next step of the work is to check the possibility to apply the certain color to the certain value (given color corresponds to the given value of the depth). The same should be found out for the texture for the bathymetric meshes.

Moreover, it is possible to render the same visualization using the Cycles Render engine and compare the difference. For this purpose it is necessary to set the new materials for the models and set the new lighting for the scenes. It is important to notice that work of the modifiers can also be different from the Blender Render engine.

Another step of the future work is to check the possibility of using of the created scenes for the creation of the other scenarios and in simulation software for the development of the robotic vehicles.
References


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