TAL TECH

EESTI MEREAKADEEMIA

TALLINNA TEHNIKAÜLIKOOL
EESTI MEREAKADEEMIA
merenduskeskus

Artjom Pilags

Assessing changes in Pakri cliff from 3D models using CloudCompare

Diploma thesis

Supervisor: Associate Professor Inga Zaitseva-Pärnaste
Co-supervisor: Professor Heiko Jens Herrmann

Tallinn, 2022

Hereby I declare, that I have written this thesis independently.

No academic degree has been applied for based on this material. All works, major viewpoints and data of the other authors used in this thesis have been referenced.

Artjom Pilags

(*signed digitally, date in digital signature*)

Student code: 183520VDVR

Student email address: 1artjom.pilags@gmail.com

Supervisor Associate Professor Inga Zaitseva-Pärnaste:

Thesis is in accordance with terms and requirements

(*signed digitally, date in digital signature*)

Chairman of thesis defence commission: Associate Professor Inga Zaitseva-Pärnaste

Accepted for defence

(*signed digitally, date in digital signature*)

Table of Content

Table of Figures

Annotation

The purpose of this thesis is to build 3D models of the Pakri cliff using the OpenDroneMap and Meshroom programs based on images taken in 2015 and 2018, as well as their subsequent comparison using the CloudCompare program. The main method for work is photogrammetry, and the object of study is the Pakri cliff, which is subject to abnormally rapid transgression and is gradually being destroyed. Since the Pakri cliff is a natural monument and the most destroyed part of the North Estonian Clint, it is this place that requires careful observation and collection of all kinds of data to prevent accidents and destruction of historical monuments, for example, the old lighthouse, which was built by Peter the Great and is located at the moment on the edge of the cliff.

In the thesis, the student divided the study into theoretical and practical parts. In the theoretical part, the student got acquainted with the area under study, the method for building 3D models, as well as with the work and description of the programs that he uses in the practical part.

In the practical part, the student proceeded to install programs and build 3D models. During the study, an additional comparison of the author's computer and the TalTech cluster was made to identify the advantages and disadvantages of each of the devices. During the work, minor applications, which were necessary to open the main programs, were installed and described.

As a result of the study, the author obtained four 3D models and compared them with each other, and based on the results of the comparison, he concluded that within three years two strong collapses occurred in the Pakri cliff area, the maximum length of the collapsed rock was 26 centimeters relative to the surface. The author also compared the quality of 3D models that were built using different photogrammetric programs, this study did not show strong differences and the maximum difference between the compared reconstructions was 1.5 centimeters, that is, insignificant.

The purpose of the dissertation was achieved and as a result the author made all the necessary comparisons, and also made an additional comparison between the two devices in the course of the work.

Keywords: *Pakri cliff, 3D models, CloudCompare, Meshroom, OpenDroneMap, Photogrammetry, Docker.*

Abbreviations

ODM	OpenDroneMap
RAM	Random Access Memory
GPU	Graphics processing unit
CPU	Central processing unit
HPC	High-Performance Computing
SLURM	Simple Linus Utility for Resource Management
SSH	Secure Socket Shell
OBJ	Object
ICP	Iterative Closest Point
IT	Information technology

Introduction

The purpose of this dissertation is to compare and measure 3D models of the Pakri cliff, created in different years and with different programs, using the CloudCompare program, in order to study the differences between them.

Pakri Rock is located in the north-east of Estonia and is a natural monument, nature reserve and the most destroyed part of the North Estonian Clint[1].

It has always been interesting not only to tourists, but also to researchers, since the coastline in this place curves at an abnormally fast speed. To predict collapses, as well as prevent accidents, the Pakri cliff requires constant monitoring, as well as the collection of data and its comparison.

The main method of the work is photogrammetry, that is, a discipline that deals with determining the characteristics of objects from images. Thanks to this method the program, that the author uses in this dissertation, will work.

Two open source 3D modeling programs were taken to be compared with each other:

- OpenDroneMap
- Meshroom

These softwares were chosen for comparison, because although they perform the function of recreating an object in 3D format, they are built on different platforms, have a different interface, have a different number of tools and settings, and, accordingly, the final 3D models built by these programs one by one and the same images may differ from each other. In this dissertation, the author will compare the results of both programs and draw a conclusion about the advantages or disadvantages of each.

The 3D models built by these programs will be compared using the CloudCompare program, because although there are many programs for creating 3D models, Cloudcompare has always been and remains the best software for comparing them.

Also, the following years will be taken as the subject of study of 3D models of the Pakri cliff:

- 2015
- 2018

---

[1] Geological formation formed by sedimentary rocks.

1 Theory

1.1 Pakri Cliff

The Pakri peninsula is one of the most famous sights of the city of Paldiski. The length of the peninsula is 11 kilometers, and its average width is 4.5 kilometers. The entire peninsula covers an area of about 40 square kilometers.

The glint of the Pakri Peninsula is protected by the state and is of international importance, as it is considered the only coastal cliff of its kind in Europe due to the outcrop of the Paleozoic layers. The height of the clint reaches 25 meters and consists of several layers of different rocks. These layers are very colorful and each layer has its special color and strength. The lower part of the cliff consists of loose Cambrian and Lower Ordovician sandstone and clay, and the upper part of hard rocks of Ordovician limestone. The glint is gradually destroyed under the influence of wind, frost, storm waves, and other natural factors. (Einasto)

The last collapse of the coastal cliff occurred on 22/04/2021, in the afternoon near the old lighthouse, next to the path along which people walk. It is believed that this is the largest collapse of the clint in recent years, but in 2008 there was a similar collapse of the rock, which could be heard and felt even in the city.

For tourists who come here to admire the beautiful scenery, a car park and an observation deck were built, from where you can enjoy the open spaces of the sea. However, this should be done with caution, because the rocky soil is unreliable and can collapse at any moment. (Nizametdinov, 2021)

There is also a lighthouse located on the northwest coast, which stands on the natural elevation of the peninsula on the edge of a high limestone cliff. It is considered one of the oldest lighthouses in the Baltic and was built by the order of Peter the Great in 1722, who personally chose the place for its construction. At the moment, the lighthouse is not functioning, as due to the natural collapse of the rock the old structure was too close to the cliff. However, 80 meters from the old lighthouse, another one was built, back in 1889, and stands there to this day.

The height of the Lighthouse is 52.3 meters, the height above sea level is 73 meters, and the distance from the edge of the cliff to the lighthouse tower is 143 meters. It indicates the route along the northern coastline on a very important sea route. The Pakri lighthouse is equipped with lamps

that are powered by solar panels that are controlled by a computer. Also, during dense fog, the lighthouse is able to emit sound signals that attract the attention of sailors. (Jartour)

1.2 Photogrammetry

Photogrammetry is a scientific and technical discipline that allows you to determine the size, shape, position and type of objects in space from their images. This method of measuring three-dimensional coordinates uses photographs as the main means of measurement, and the main principle for this is triangulation.

There are currently two main types of photogrammetry:

1) An aerial that uses images captured by a camera in the air.

2) Terrestrial, which uses images taken with a camera in hand or on a tripod. Also, if the distance to the object is less than 200 meters, then this will be called short-range photogrammetry.

In this thesis, the aerial method of photogrammetry will be used, since the images which will be used to build the 3D models were made using a drone. (Geostart)

1.3 Open Source software

Open source programs allow any user to participate in the development of the program, make their own corrections, additions and updates. Thanks to this feature, the software is continuously improved by the developer community.

Currently, open source software is used almost everywhere, as about 95% of IT enterprises use it to modernize infrastructure and develop applications.

The main advantages are high speed of implementation and flexibility in adding the requested functions, ease of scaling and cost efficiency. The tasks assigned to developers can be divided into teams or groups, which ensures flexibility, productivity and speed of work, and in case of complex problems, high-level specialists can pay attention to the project, and do not need to wait until the developer gives access to make changes to the project.

Such software saves money and provides a number of other financial benefits as the cost of continuous software development is shared among the entire community. (Hewlett Packard Enterprise)

2 Software

2.1 OpenDroneMap

One of the programs used in this thesis is OpenDroneMap, which was launched in 2013 and is an open source suite of image processing tools.

This software converts images taken with a conventional camera into 2D and 3D geographic data. In a nutshell, it is a program that takes images as input and creates various geo-referenced resources such as maps and 3D models as output. (Figure 1)

OpenDroneMap is a command line-based application that is one of the most successful open source programs in the field.

The application can also be used in the browser, which is another benefit as it makes collecting data from the drone more mobile and does not tie the user to the desktop. (Mapscaping)
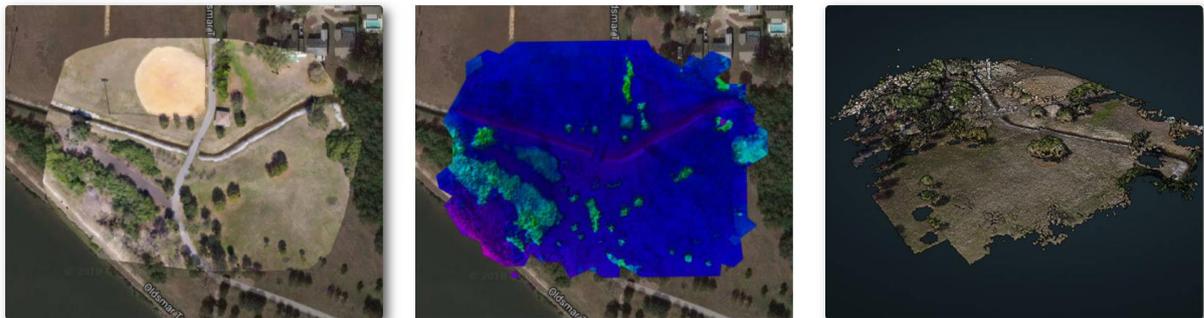
Figure 1. OpenDroneMap 3D models

(OpenDroneMap)

Another advantage of ODM is that it does not require large hardware costs, all that is required to use the program and create a serious project is free disk space and 16 GB of RAM, also at the moment OpenDroneMap does not require the use of a GPU, so all work can be done using only one central processor.

OpenDroneMap is used directly in engineering and agricultural work, and also helps in global emergencies such as flooding, dam failure or coastline disturbance. (Zingfeld, 2022)

2.2 Meshroom

Meshroom is the second software chosen by the author for 3D model comparison in this thesis. This is another free and open source 3D reconstruction application based on the AliceVision platform.

AliceVision is a photogrammetric computer vision platform that provides 3D reconstruction and camera tracking algorithms. The application offers a powerful programming environment and state-of-the-art algorithms that can be tested and analysed and then reused.
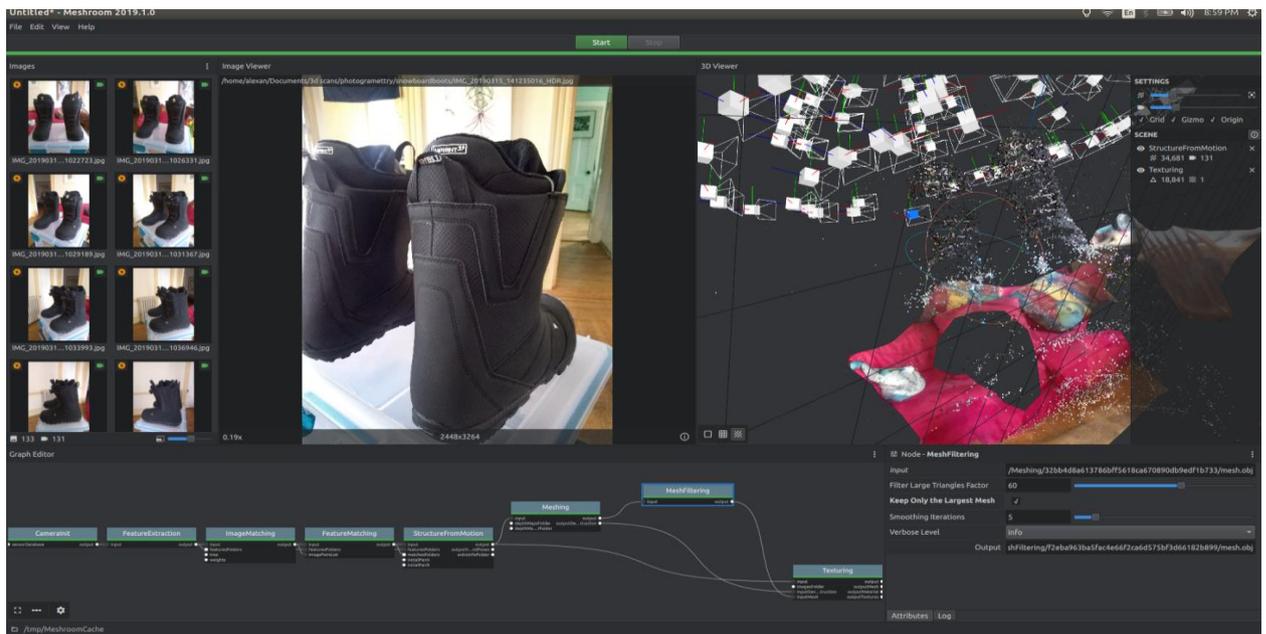
Figure 2. Meshroom interface

(Github, 2019)

A characteristic difference from other programs is the combination of a large number of modules to create a 3D model, while in other similar applications these modules must be activated and configured.

This program is easy to learn and suitable for both beginners and professionals, probably due to the user-friendly interface (Figure 2) and a large selection of free plugins in the application itself. (Uptodown)

2.3 CloudCompare

CloudCompare is the software that will be used to compare 3D models in this research paper. This application was originally designed to compare two dense 3D point clouds or between a point cloud and a triangular mesh, the comparison is done using a specific point in an octree dedicated to this task. CloudCompare has now been extended to more general point processing software and also includes many advanced algorithms:

- Registration,
- Resampling,
- Working with colored/normal/scalar fields,
- Calculation of statistics
- Sensor management,
- Interactive or automatic segmentation,
- Improving the display.

This software combines high performance and data loading speed. Thanks to some technical solutions taken by CloudCompare, the program can store about 90 million empty points per gigabyte of memory. (CloudCompare, 2016)

3 3D Models creation

3.1 Preparation of data

3.1.1 Access to cluster

In order to start working with the above programs and start building 3D models, as well as to make their further comparison, it was needed to get photos of the Pakri cliff, which were taken by a student of the Estonian Maritime Academy in 2015, as well as photos of the Pakri cliff in 2018 taken using a drone. To do this, it is needed to go to the Taltech High Performance Computing Center, which develops and manages computing resources for scientific purposes of the Tallinn University of Technology.

The access to the cluster[2] requires permission to be added to the HPC Users group.

Hello,

I have added your account to base.hpc.taltech.ee. You can now log in with your Uni-ID username and password over ssh.

Figure 3. Getting permission

The author got access to the base.hpc.taltech.ee hpc2 cluster (Figure 3) , which is the latest computing cluster installed at TalTech in 2019. This cluster processes jobs using the SLURM cluster manager and also has 32 nodes, each of which has the following characteristics:

- 2 x Intel Xeon Gold 6148 2.40 GHz (40 cores, 80 threads per node)
- 96 GB RAM
- Ethernet 25 Gb/s
- 800 GB of local workspaces

3.1.2 Images downloading

After accessing the cluster, the author needed to download the WinSCP program to simplify the work.

---

[2] A group of servers and other resources that act like a single system

WinSCP is a free graphical client with which you can establish a remote connection between the user's computer and the server to which you want to connect (Figure 4) . The program features include all basic file operations - copying, deleting, etc., and also supports the SSH network protocol, which is needed to connect to the TalTech cluster. (Chron)
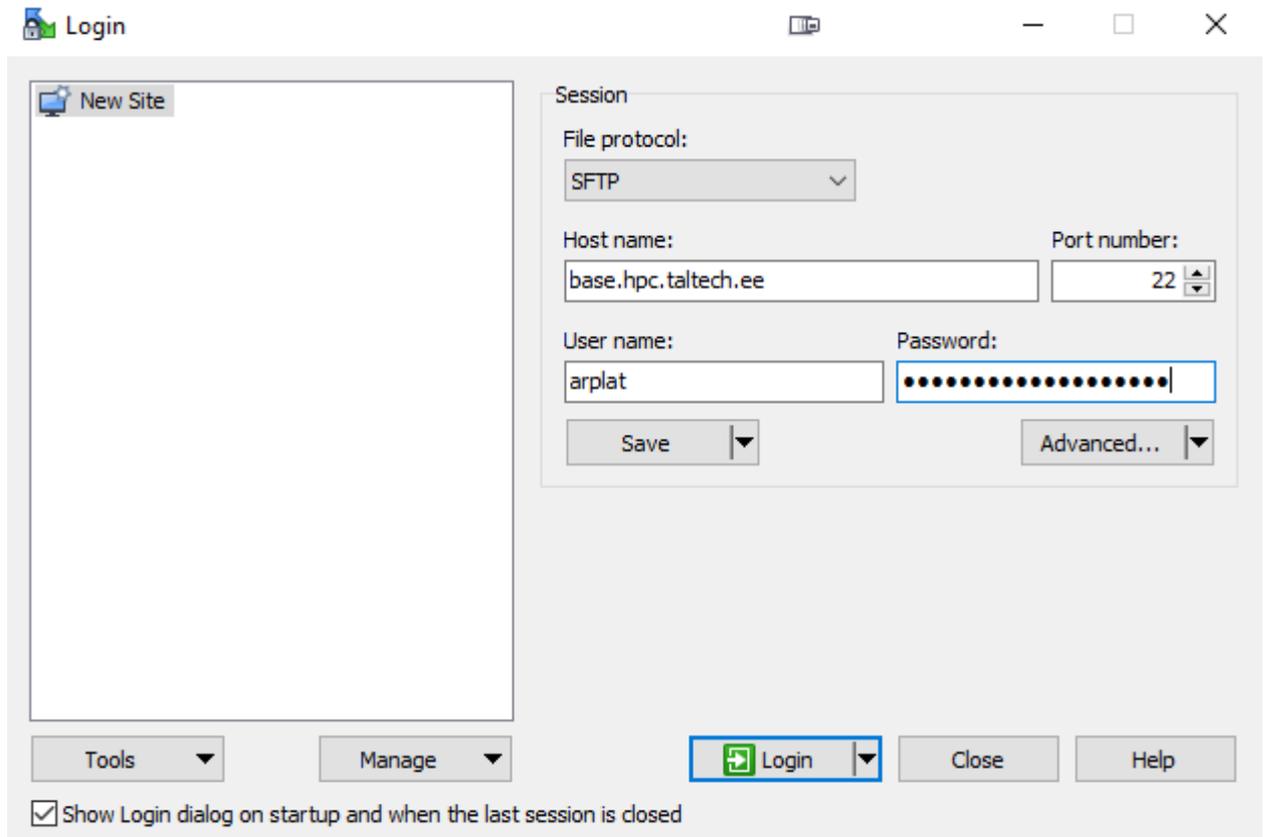

Figure 4. Images uploading

As a result, the 2015 photo folder contained 447 images, while the 2018 photo folder was smaller and contained only 78 images.

3.1.3 Computer selection

First, 3D models of the Pakri cliff will be built using the OpenDroneMap program.

The author needs to choose on which computer to create 3D models

It was decided to create the first model using the author's computer, and the second one using the TalTech cluster, this solution will help determine which method is easier and more convenient for the average user, it will also be possible to compare the speed of processing photos and the resource intensity of this process on each of the devices.

17

3.2 ODM 3D model creating using author's PC

3.2.1 Author PC hardware specifications

To create the first 3D model, 78 images need to be processed, so firstly it is needed to make sure that the power of the author's computer is enough to get started.

- Intel(R) Core(TM) i5-9600K 3.70GHz (6 hyperthreads)
- 16 GB RAM
- 1TB disk space
- Ethernet 58 Mbps

Required specifications and RAM:

- Latest generation CPU
- 100GB disk space
- 16GB RAM

Minimum RAM needed for N images

Number of images	RAM or RAM + Swap
40	4
250	16
500	32
1500	64
2500	128
3500	192
5000	256

Figure 5. Required RAM

(OpenDroneMap)

The computer's settings allow to process 78 images without any problems, so author can proceed to the next step.

3.2.2 Docker

Docker is an open source platform for managing, building and deploying containerized applications. This program allows the user to package applications into "containers", that is, into standardized executable components that combine the application's source code with operating system libraries and dependencies necessary to run this code in any environment. (Education, 2021)

"Containers" allow to package an application and all of its dependencies into a single image that runs in an isolated environment that does not affect the main operating system.

3.2.3 Virtualization enabling

Docker requires the processor to enable a feature called virtualization. To enable this feature, open a PowerShell[3] console as an administrator and enter the following command:

- Enable-WindowsOptionalFeature -Online -FeatureName Microsoft-Hyper-V –All

To complete the installation, you need to restart a computer and continue working.

3.2.4 Oracle VM VirtualBox

Oracle VM VirtualBox is a virtualization software that allows to allocate the right amount of RAM and processors to process a 3D model.

When program is turned on, the virtual machine runs by default, so in order to set the necessary settings, it is needed to suspend its work. Now, by clicking on the "System" panel in the settings, you need to increase the amount of allocated memory to 60-70%, and also add 50% of the available processors. (Figure 6)

---

[3] A cross-platform task automation solution made up of a command-line shell
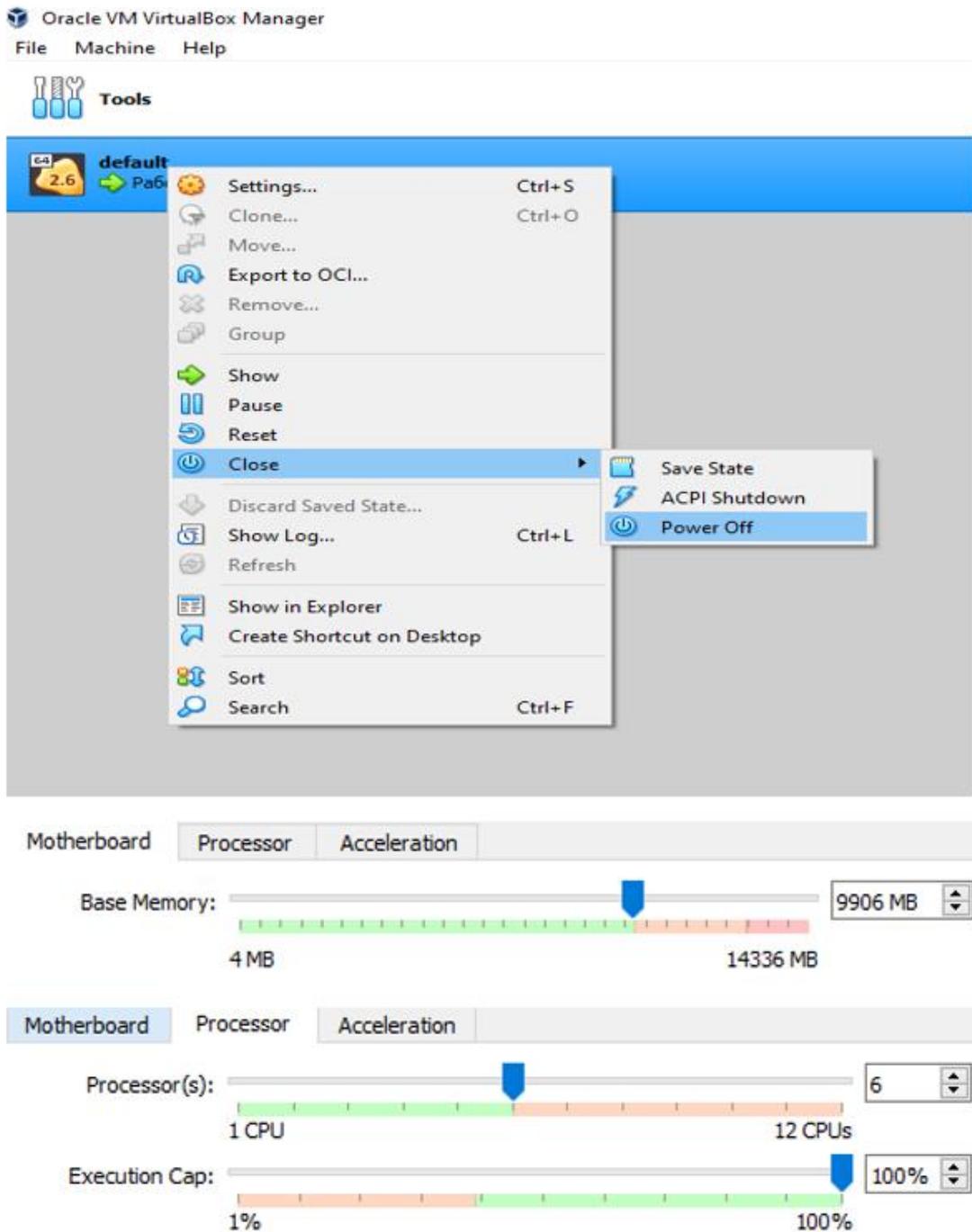
Figure 6. Memory and processor settings

In this case, the author increased the RAM to 9906MB and allocated 6 processors for work, after which he launched the virtual machine.

3.2.5 Git Gui

The last step before installing the ODM is to download the Git Gui program.

This application allows to download open source programs and run them on your device. It is the moment when the author will be able to download and run OpenDroneMap and start building a 3D model.

Open the Git Gui program and click "clone an existing repository", then paste a link to the ODM location, and also choose a place to save the program on the computer. (Figure 7)
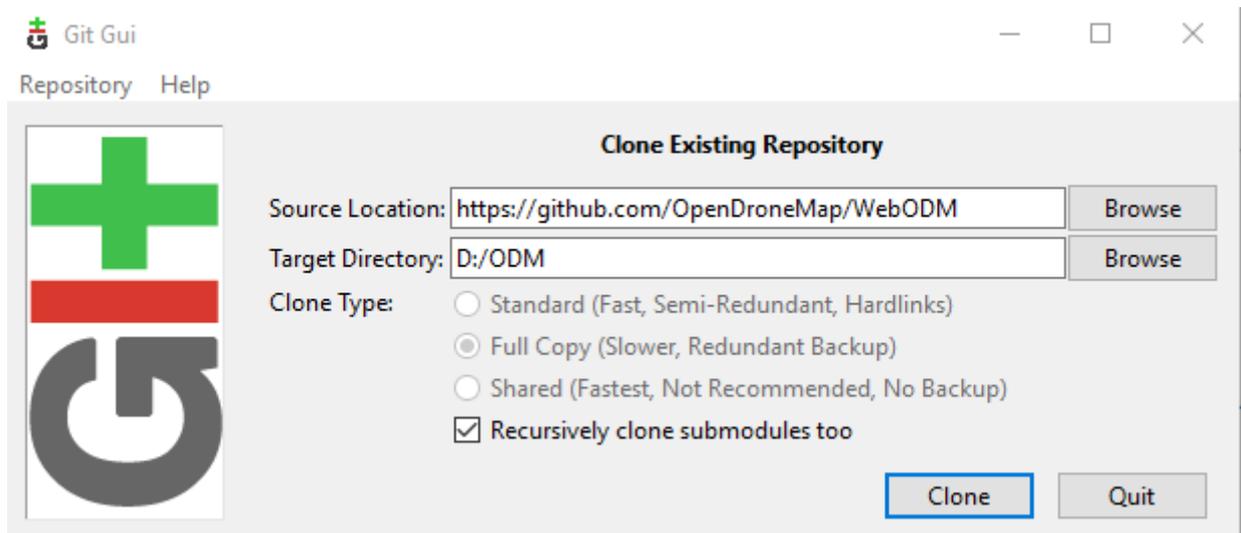

Figure 7. Git Gui

Pressing the "Clone" button will install the ODM program on the computer and in order to run it, it remains to go to the "Repository" menu, then click on the Git Bash button.

A command prompt, where you need to enter the command, will open:

- $ ./webodm.sh start &

OpenDroneMap is up and running, and now opening a web browser at http://localhost:8000 takes the user to the WebODM[4] main page, from where it is possible to start processing images and building a 3D model.

---

[4] OpenDroneMap browser version

3.2.6 WebODM

The next task is to select images for processing and the parameters we need. To build the 2015 3D Model, it was chosen to use the –auto-boundary option, which automatically sets the boundaries using camera locations to limit the reconstruction area. This can help remove distant background artifacts. The -dsm option is also used, which creates a digital surface model, ground + objects, using a progressive morphological filter.

The same parameters will be used to build both 3D models.
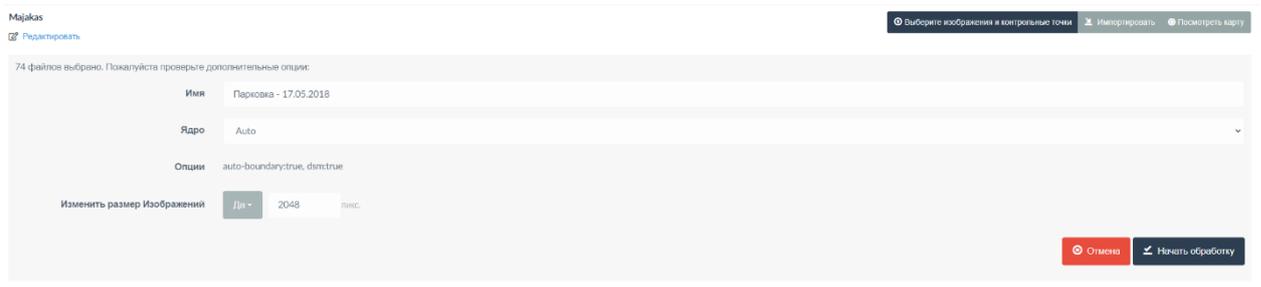

Figure 8. WebODM
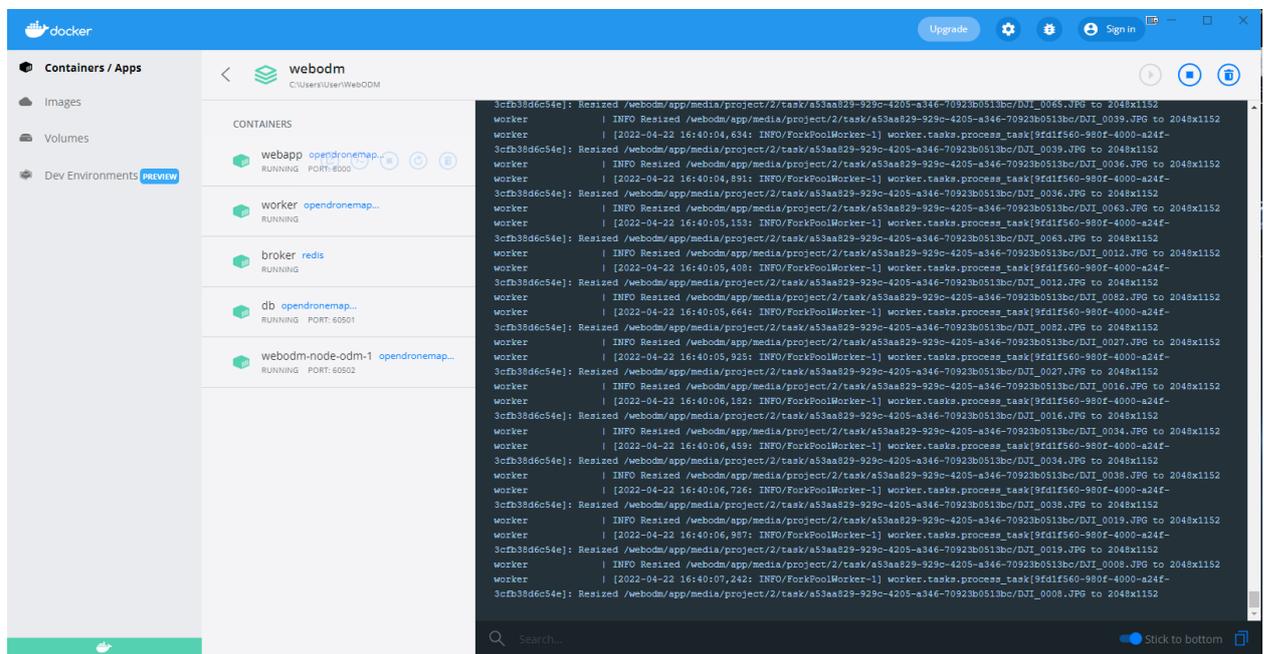
Figure 9. Docker process

Once the task is started, automatic image processing in Docker starts.
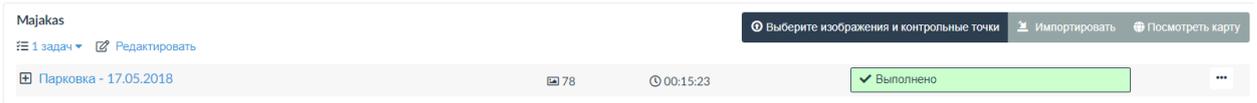
Figure 10. Completed model in WebODM

The job was successfully completed and the entire processing took 15 minutes and 23 seconds.

3.3 ODM 3D model creating using the TalTech cluster

The next 3D model will be built using the TalTech cluster, for this it is firstly needed to download the PuTTY program.

PuTTY is a client for working with remote access protocols, it will allow to establish a secure connection to the cluster and manage it from the user's computer, while all the work will be done on the server side. (US)
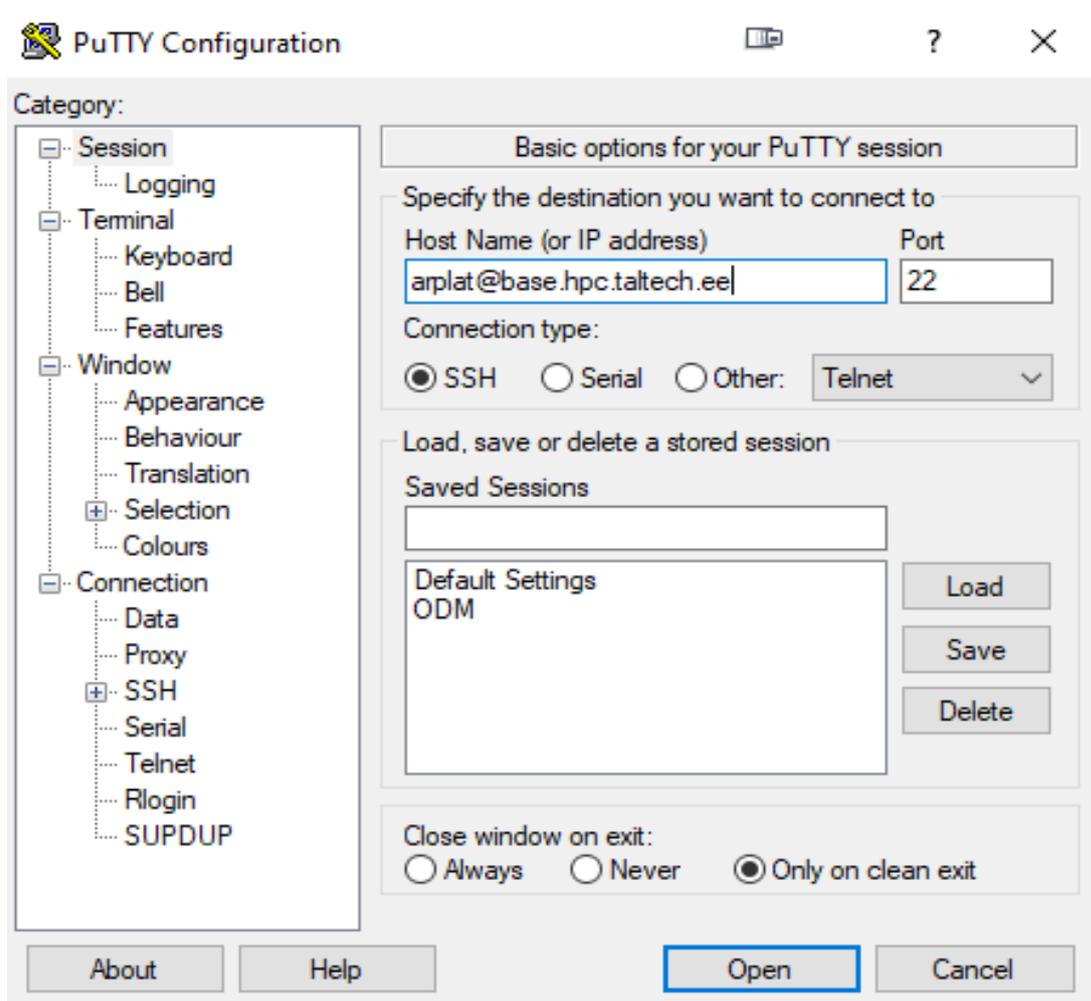

Figure 11. PuTTY login and configuration

To start working in the client, you need to log in, that is, enter the uni-ID of the user, as well as the name of the host to which you want to connect. It is important to select the type of connection, in this case it is a connection using SSH.

Access to the base.hpc.taltech.ee cluster login node can be obtained using SSH, to do this we enter the ssh uni-ID@base.hpc.taltech.ee command, as well as the user password, and get access to the server.

Figure 12. Connected to HPC base

At this stage, it is needed to create a file - odm.slurm, the contents of which are as follows:

#!/bin/bash

#SBATCH --nodes 1 #Request to use one computer core

#SBATCH --ntasks 1 #Number of tasks to execute

#SBATCH --time 12:30:00 #Maximum running time

#SBATCH --partition gpu # partition that has computers with GPU

#SBATCH --mem=128G #Request to use 128GB of computer memory

module use /illukas/software/modules/

module load Singularity/3.7.3 #Container solution

export PROJECTDIR=/gpfs/mariana/home/arplat/Paldiski-Data/20180517-mavic/

#Path that shows where the images are to be processed

singularity run --nv --bind $PROJECTDIR:/datasets/code docker://opendronemap/odm --project-path /datasets --dsm --auto-boundary

#Starting the OpenDroneMap program and the parameters for which you want to build a 3D model.

Now start the task using the command - sbatch dronemap.slurm, which starts the task as soon as the resources for this are available.

The job queue can be checked with the command squeue -u $USER

Figure 13. Submitted job

Figure 14. Job partition

As a result, the task took 10 hours 51 minutes and 44 seconds to complete, and the 3D model of the Pakri cliff in 2018 was done.

3.4 PC-s comparison

The author made two 3D models in OpenDroneMap, the first using his computer, and the second using the TalTech cluster. As a result, both models were successfully created, but if to compare the complexity of the work, then completing the task in the Taltech cluster was much easier, mainly due to the fact that all programs or their analogues that needed to be installed on the author's

computer were already loaded into the cluster, so the main work was to write a task to start 3D modeling and explore the basic commands to run.

3.5 Getting started with Meshroom

The next program in which the author will create 3D models is the Meshroom program, so you need to start by installing this program.

Unlike OpenDroneMap, Meshroom is easier to install and has its own user-friendly user interface, which makes it easy to work with and allows even a beginner to quickly understand the use of this program.

The program is downloaded from the official website of AliceVision, where user can choose a convenient download option. In this case, it is needed to select the version for Windows.
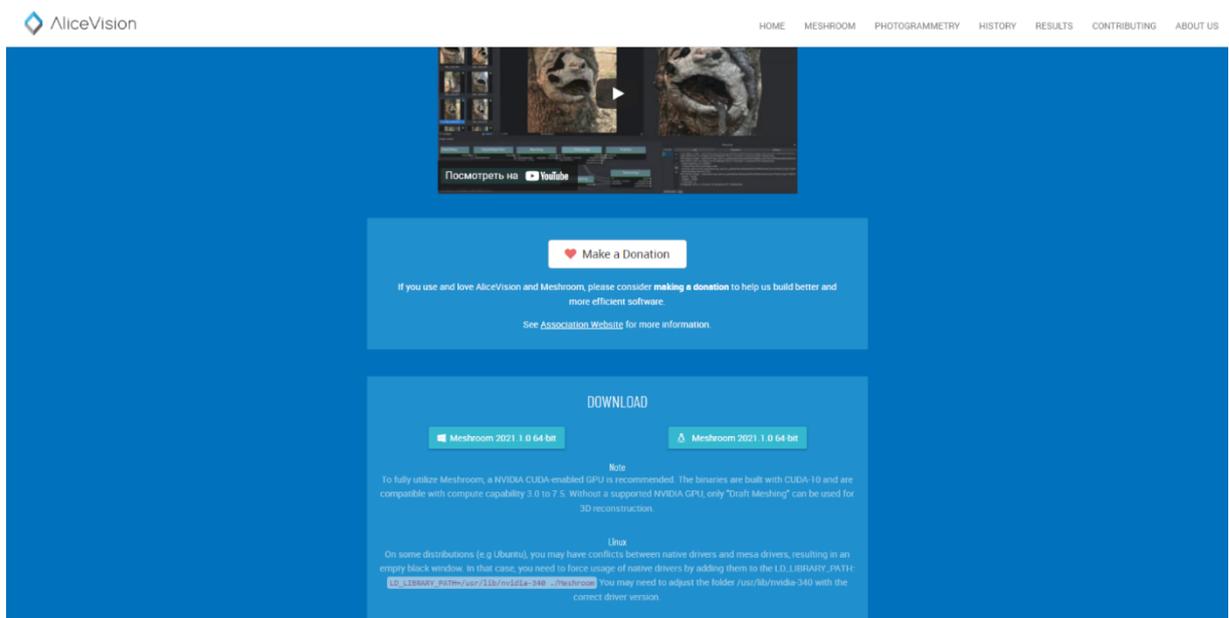
Figure 15. Meshroom uploading
(Alicevision)

After installing and running Meshroom, the main program interface appears, in which you can do everything what is need to build a 3D model.
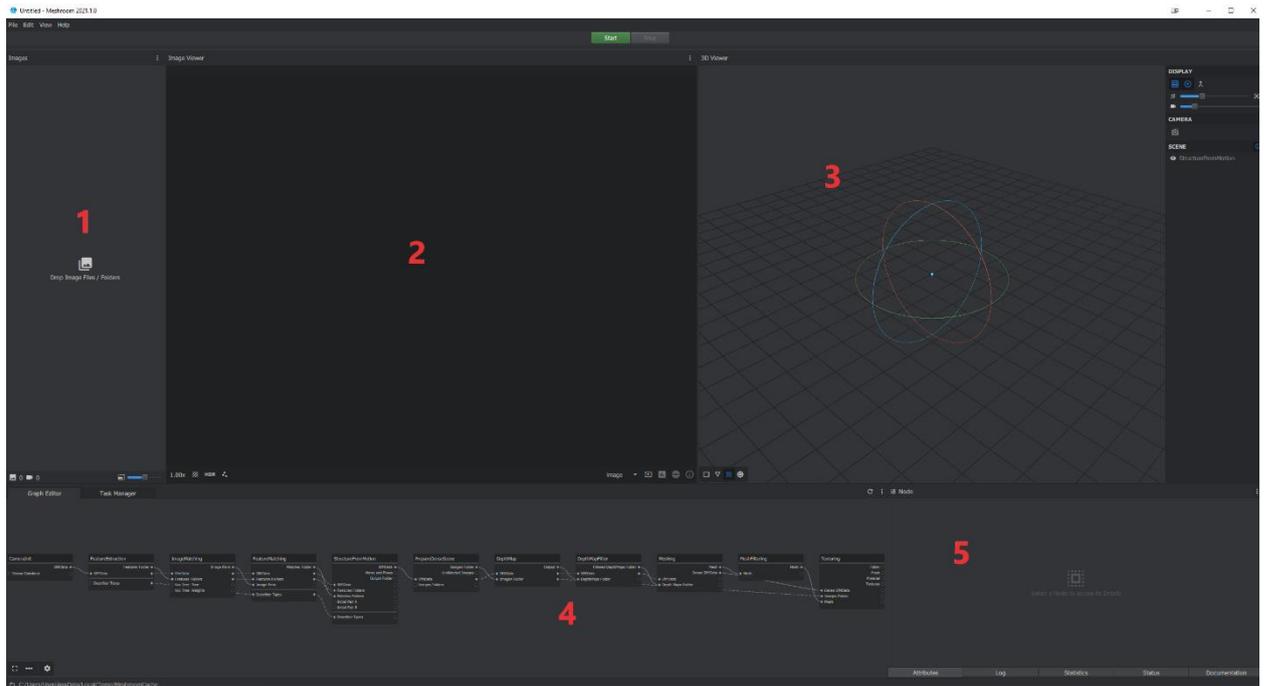
Figure 16. Meshroom interface

Brief description of the interface: (Figure 16)

1. Compartment in which the photos required for processing are placed.
2. Preview window of uploaded user images.
3. After starting the simulation, this section will display the process of building a 3D model, it can be viewed from different angles during the process.
4. Graph Editor - a window for displaying a pipeline of processes, here all photos go through certain stages set by the user. Each stage is a separate node for processing, which is responsible for certain processing. After passing through all the nodes, the final 3D model of the object appears.
5. The Node window allows you to change the parameters of each individual node, as well as see a report on the current process.

Now the author can start uploading photos and start recreating the 3D model of the Pakri cliff. It was decided to start by uploading photos from 2018.

The node parameters are already set by default and the author does not need to change them to others without the need.

Pressing the start button starts the process, the duration of which depends on the characteristics of the user's computer.
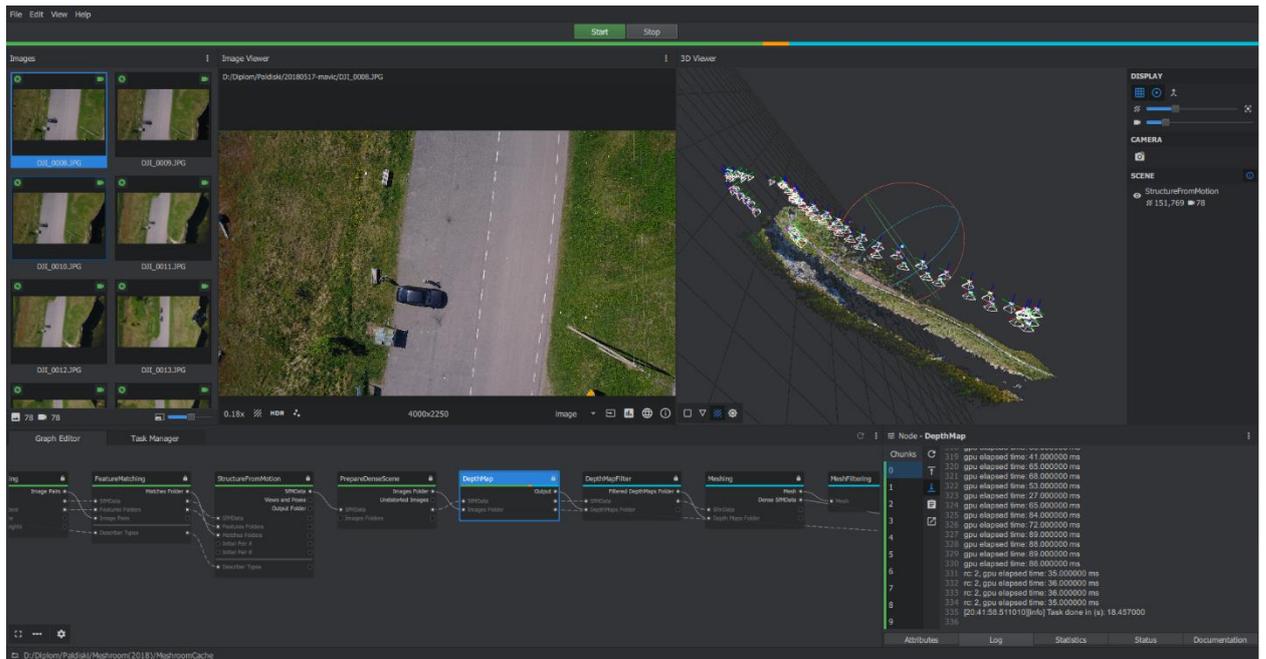
Figure 17. Meshroom process

In the image (Figure 17), the processing is running and more than half of the work is already done, and the program interface allows the author to see how the 3D model is being built, how many percent of the work is already done, and a report on all actions and possible errors in the Node window.

The work was completed successfully and as a result, the author received a high-quality 3D model of the Pakri cliff in 2018. Now it is possible to start recreating the 2015 model using the same parameters and then compare them in CloudCompare.

4 Comparison of 3D models in CloudCompare

At this stage, the author proceeds to comparison of the obtained 3D models in the CloudCompare program.

Installing the program is not difficult, since the CloudCompare download utility is available on the official website of this application.

After installation, the author studied the tools available in CloudCompare and got acquainted with the instructions for using the application, as well as received theoretical knowledge on how to compare two 3D models with each other.

4.1 ODM 3D models

To start with, two 3D models that were built using the OpenDroneMap program will be compared with each other.

When opening CloudCompare, you need to add 3D models from the path where they were saved after reconstruction and find the object in .OBJ format. This is a file format used for a 3D object containing 3D coordinates (polygon lines and points), texture maps, and other information about the object. (ReviverSoft)
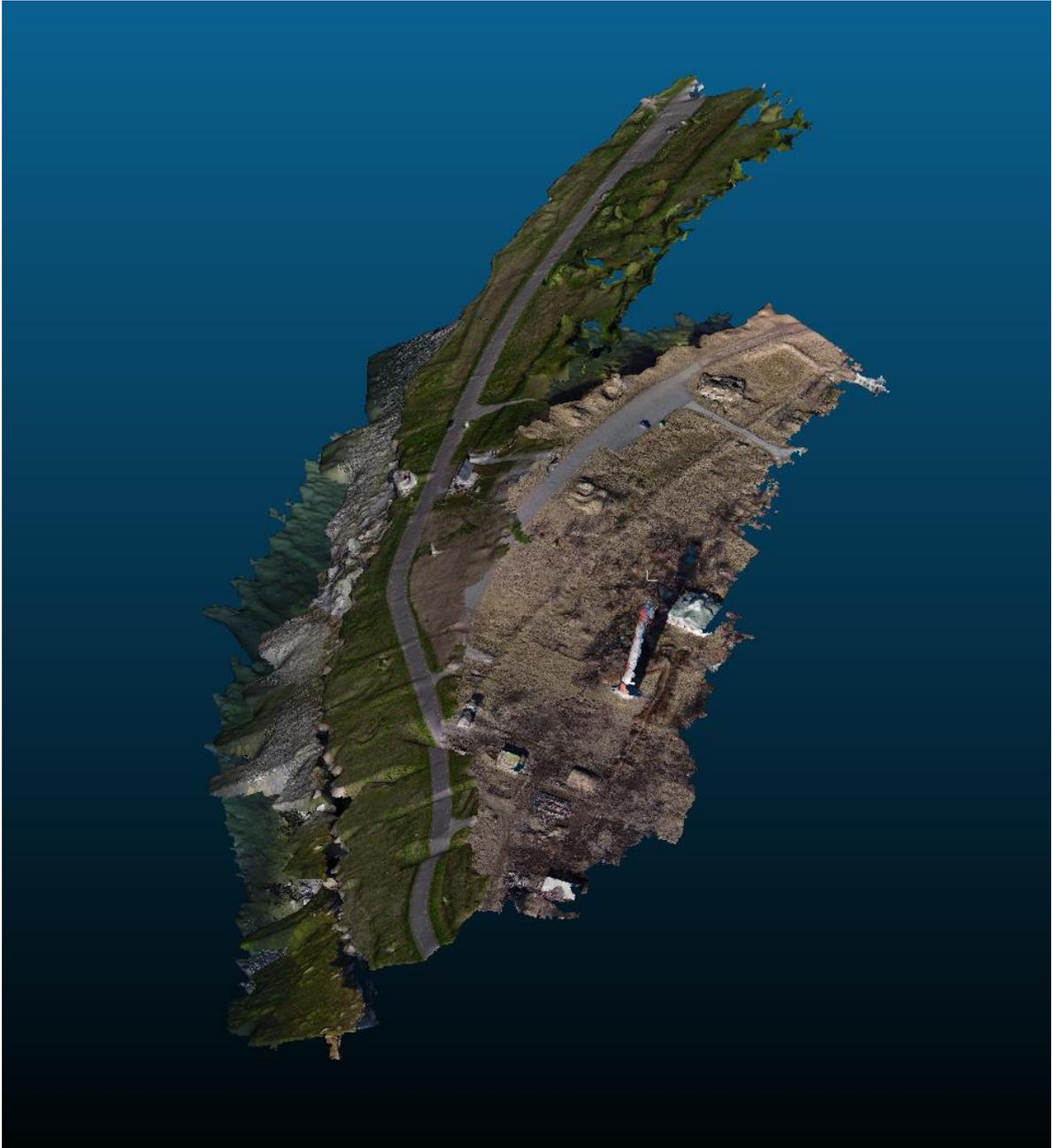
Figure 18. ODM created 3D models in CloudCompare

After adding the models, they are in different positions in space and also have different sizes. Before starting the comparison, it is needed to edit and change their position in space, size, and also cut off unnecessary parts of objects that do not require comparison, such as: part of the 3D model that is located behind the road, a new lighthouse and speckles that arose in the process of reconstructions and are the objects separated from the overall picture.

For this process, the author will need tools such as:

- Translate/Rotate - the tool will allow the author to move selected objects relative to others.

- Segment - this tool allows the user to independently segment the objects he has selected. The process can be repeated several times, each time changing the orientation of the objects in order to correctly segment the objects in 3D.

- Point Picking - This tool allows the user to select points for which they would like to receive information. In this case, you do not need to know the distance between the points that will be fixed at the same place on both 3D models. Power line poles with several supports were chosen as such points, since the location of these objects could not change regardless of time. The distance between the supports on the 2015 model was 3.69 meters, and on the 2018 model 4.08 meters.

- Scale/multiply - a tool that allows you to scale the desired user 3D object. Since the author has learned the distances, now we need to find the factor by which we need to multiply the smaller model in order to get the same dimensions. Dividing 3.69 by 4.08 gives a result of 1.1. It was by this coefficient that the author multiplied the 3D model of 2015, after which both objects became the same size. (CloudCompare, 2018)
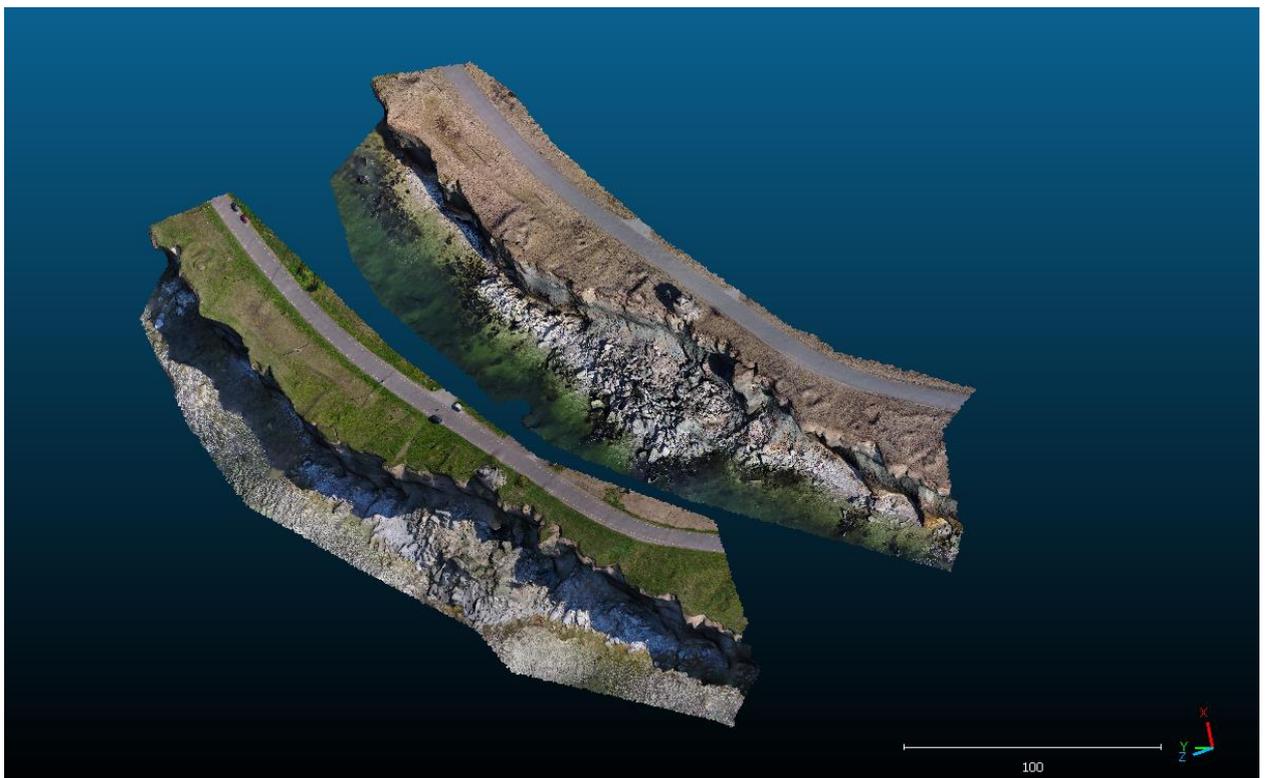

Figure 19. Edited ODM created 3D models in CloudCompare

After the editing process, you can see that both models are now in the same plane, have the same dimensions and outlines.

31

Now the author proceeds to comparison of the two objects, two tools are used for this process:

- Fine Registration (ICP) is a tool that can register two objects with automatic accuracy, that is, connecting the common points of the clouds into one. This process requires two conditions to be met. Firstly, the objects for registration should already be in approximately the same position and space, so using the Translate / Rotate tool, the author superimposes one model on another and aligns them as much as possible. Secondly, both objects must represent the same model, in this case two 3D models of the Pakri cliff are used, with a difference of three years, so the main points of the clouds are in the same places, which allows this condition to be met.

- Compute Cloud/Mesh distance - the tool will allow the author to calculate the distances between two models. The 2015 model will be taken as a basis, it will be used as a reference and the distances will be calculated in accordance to its polygons. In the comparison parameters, the author set the maximum distance between the models to one meter in order to reduce the possible calculation time

The process took about five minutes, but required a heavy load on the processor, after the end of the comparison, a color scale was added that showed the distances between the compared objects. In blue there are places that existed in 2015, and in red, the ones which were not present in 2015, taking this into account we can conclude that the red areas are the places of collapses.
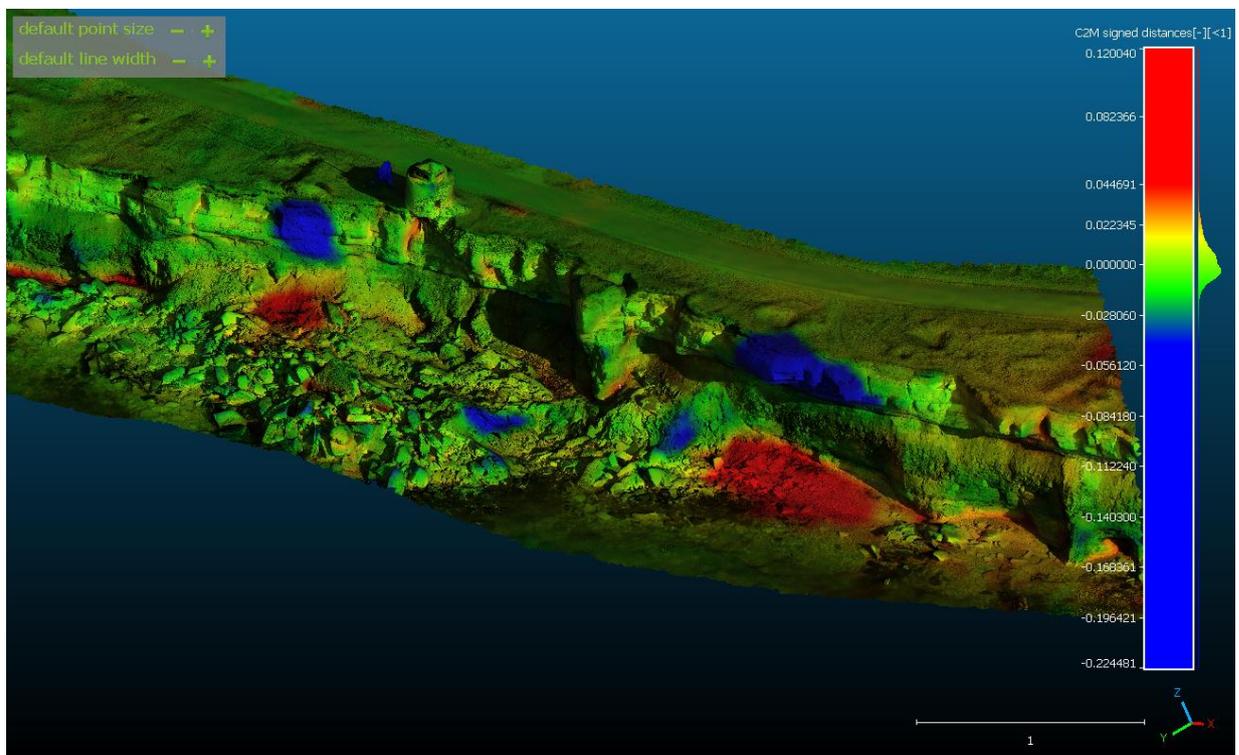
Figure 20. Compared ODM 3D models

The comparison was successfully completed, and as a result, it became possible to see in which places there were collapses in three years. Also, it is very important to clean the object from unnecessary speckles, since when calculating the distances between points, they are also counted and this leads to an incorrect result.
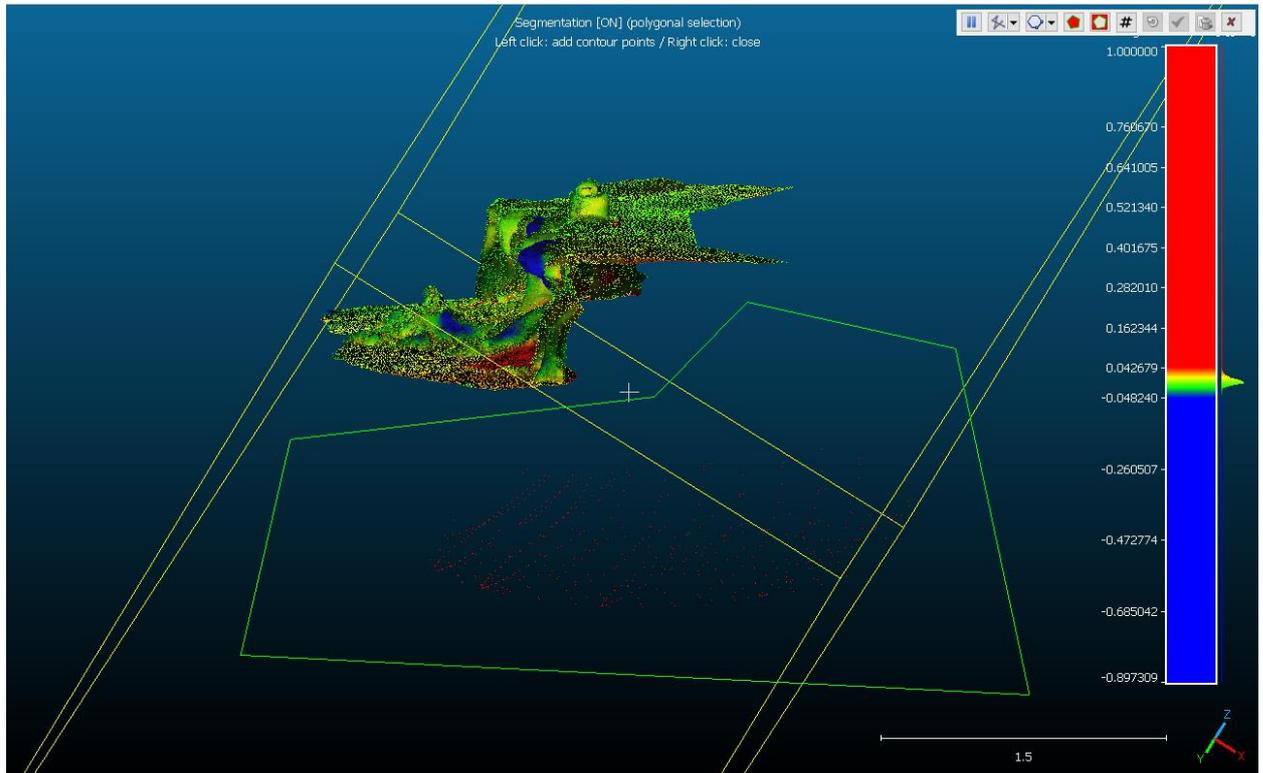
Figure 21. Noise cleaning

4.2 Meshroom 3D models

The process of comparing 3D models created using the Meshroom program should not differ from the previous one, but after loading the objects into the CloudCompare program, the author encountered a program freeze. The reason for this was that the 3D models built by Meshroom consisted of a much larger number of points and, accordingly, they took more time to process in CloudCompare.
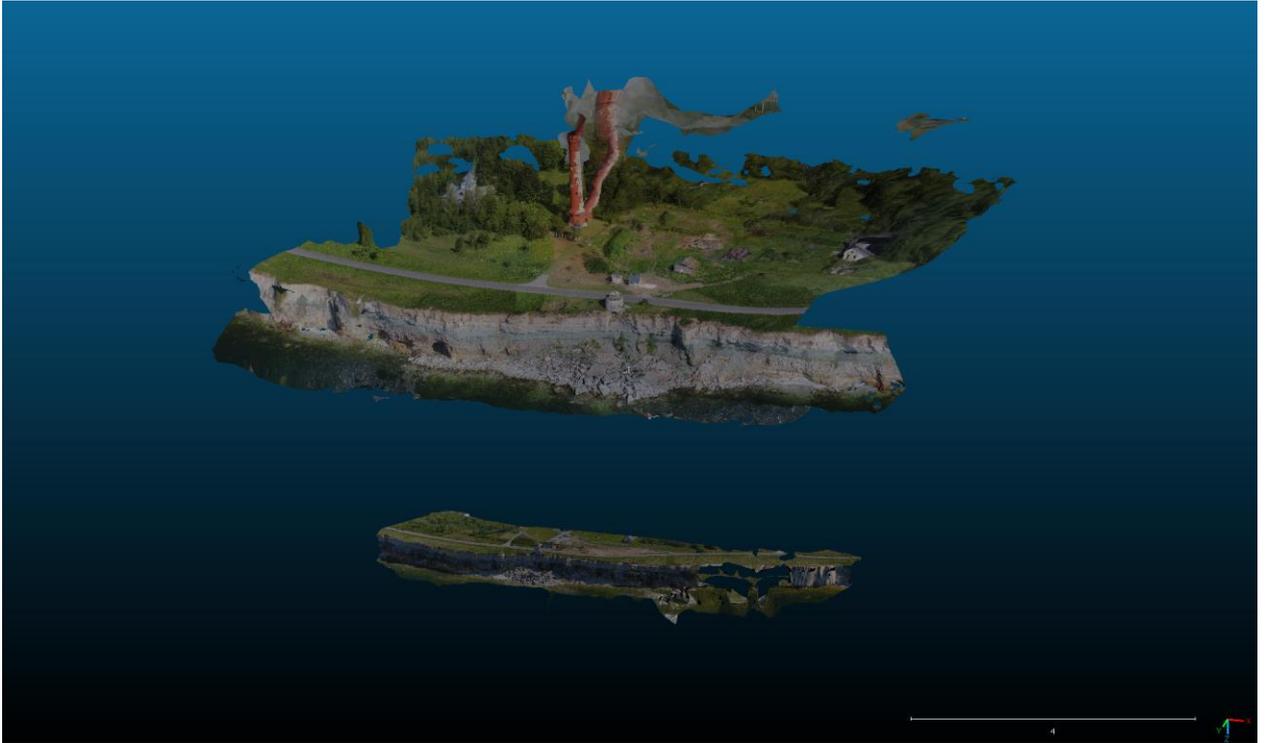
Figure 22. Meshroom created 3D models in CloudCompare

You can also see that the Meshroom program reconstructs not only the object itself, but also its surroundings, so a part of the forest appeared on the 2015 model, which was located behind the lighthouse, and, on the 2018 model, a road that leads west from the place studied by the author was modelled.

The 3D model data has also been edited, unnecessary parts of the models have been trimmed, and the size of the 2018 model has been increased. To measure the distance, the same poles were chosen that were measured in the previous comparison, but this time the distance between the poles on the 2015 model was 0.11 meters, and on the 2018 model 0.48 meters. The coefficient for multiplying the 2015 model was 2.43, after which both models became the same size.

In comparing the two objects, the Fine Registration (ICP) and Compute Cloud/Mesh distance tools were also used, the maximum distance of one meter was set in the parameters.

The comparison process took more time and resulted in about ten minutes, and after adding the color scale, it became clear that the distances between the 3D models coincide with the results of the previous comparison, the collapse areas also did not change.
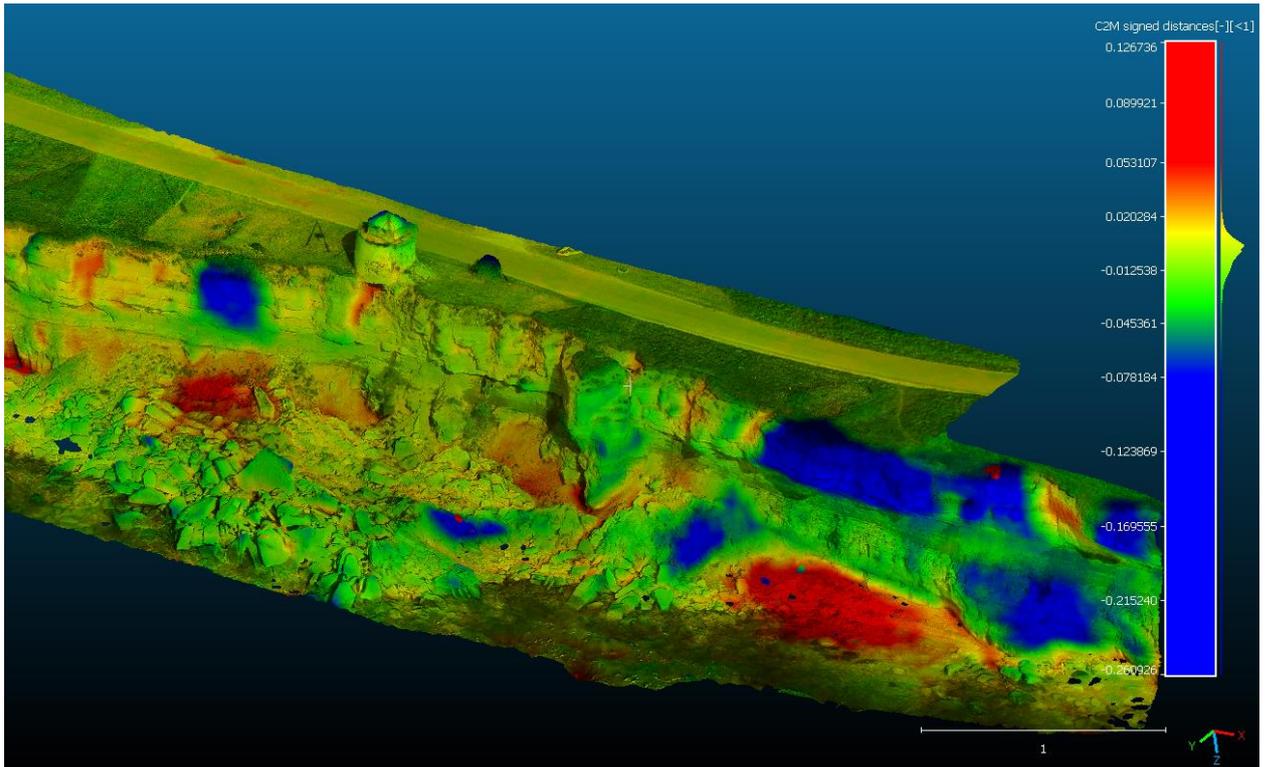
Figure 23. Compared Meshroom 3D models

4.3 Comparing ODM and Meshroom 3D models between themselves

The next step is to compare the results with each other, at the moment you can shorten the step with editing, since the models are already cropped, and only require adjustments to the same size. The distance between the supports of power poles was also taken as the basis for scaling. The OpenDroneMap model had this distance of 1.03 meters and the Meshroom model 0.11, so the Meshroom model was multiplied by a factor of 8.99 to get the same size for both models.

Next comes the comparison process, it remains the same as in previous times, the author uses the "Fine Registration (ICP)" tool, and then "Compute Cloud / Mesh distance", adds a color scale and gets the following result, by which you can determine what that the maximum difference between the models is 1.5 cm.
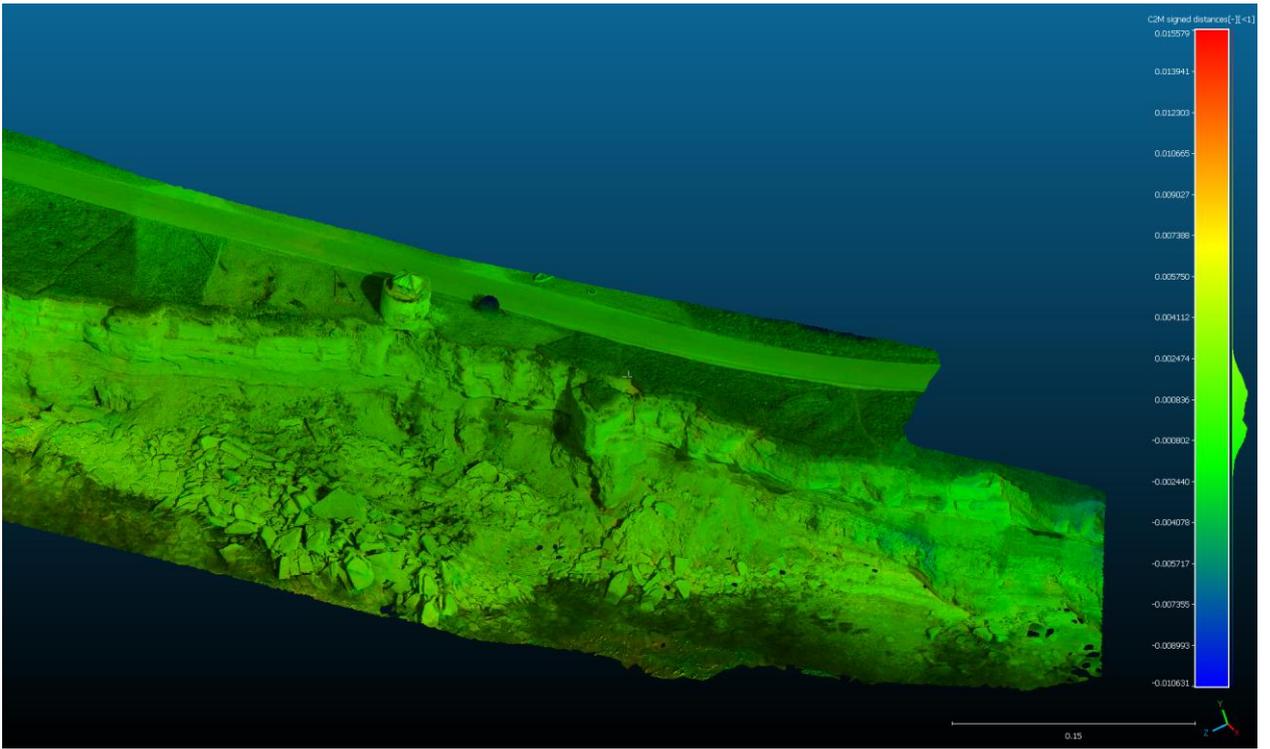
Figure 24. Compared ODM and Meshroom 3D models between themselves

5 Results

5.1 OpenDroneMap

OpenDroneMap has proven to be a good photogrammetry software that has its advantages and disadvantages.

Advantages:

- Choice between ODM and WebODM
- Graphical interface in WebODM
- Availability
- Open source
- Large selection of simulation settings
- Tools for viewing the finished 3D model in WebODM

Disadvantages:

- Complexity of installation and dependence on other programs
- Huge consumption of CPU resources
- Basic programming language skills required

It is worth noting that despite the long study of the installation and use of the program, 3D models obtained using OpenDroneMap have good image quality and resolution, and there are no noises, extraneous 3D objects that are not related to the project and holes in the models. OpenDroneMap is suitable for an advanced user, and even more so for professionals, since the software is available with open source code and anyone can bring their own improvements and improvements to the program. If the user has a powerful computer and all the necessary knowledge for photogrammetry, then OpenDroneMap has the ability to build 3D models with the highest resolution due to a wide selection of processing parameters.

5.2 Author's computer and TalTech cluster

The construction of 3D models in the OpenDroneMap program was successfully completed on both devices, but during the study, the author could not identify the best of them and choose

between his computer and the TalTech cluster, since each of the devices has its own advantages and disadvantages.

The cluster is more suitable for advanced users who already have sufficient knowledge in the field of IT and can freely use the programming language, the cluster provides a large amount of memory and high Internet speed, and also makes it possible to perform resource-intensive processes of any complexity and volume.

In turn, thanks to the use of the author's computer, he manages to get acquainted with many useful programs that help in photogrammetry and programming. The process, from installing all the necessary applications to building a finished 3D model, took a lot of time, as well as computer resources and memory, but this allowed the author to work in comfort and slowly get acquainted with new information step by step.

5.3 Meshroom

The Meshroom program showed excellent results in building 3D models and does not have obvious shortcomings, but on the contrary, it shows itself only from its strong side.

Advantages:

- Availability
- Open source
- Convenient interface
- Large selection of options and tools
- Reconstruction quality
- GPU usage
- Large set of points that make up the model

Installation and use of this program will be understandable even for a novice user, Meshroom does not require knowledge of a programming language and is easy to use, and the program interface, which shows a 3D model in the process of its construction and a report on all actions performed, greatly facilitates the work. It is also worth noting that all the necessary settings are set by default and are divided into stages that the user can change at any time. An excellent decision from the developers was to split the resource-intensive reconstruction process into CPU and GPU, as this reduces the load on the computer's RAM, and also speeds up the processing process.

5.4 CloudCompare

The software for comparing 3D models also turned out to be easy to use, it did not take much effort and time for the author to understand how the program works and how to start the process of comparing 3D models. The program is free and also has its own official web page with application guides and detailed explanations for users.

CloudCompare has a lot of tools for viewing, editing, measuring and comparing 3D models. In this dissertation, the author got acquainted with only a part of all the possibilities, but it can be said with accuracy that the performance of the program is at a high level, as is the speed of the process of comparing 3D models.

5.5 Comparison of 3D models

Comparison of 3D models was successful, and the author performed 3 main comparisons:

- Comparison of 2015 and 2018 models built with CloudCompare
- Comparison of 2015 and 2018 models built with Meshroom
- Comparison of two models based on 2015 built in OpenDroneMap and Meshroom

Based on the results of the comparison, it can be concluded that within three years there were 2 strong collapses of the Pakri cliff in this area, the maximum length of the collapse was 26 centimeters.

Comparison of 3D models built in different programs showed that the maximum difference between the models is 1.5 cm, which is a very accurate result and a small error, this may be caused by different software settings, invisible noise or image quality.

Summary

At the beginning of this thesis, a theoretical digression was made on such concepts as photogrammetry and open source programs, these concepts give the reader the opportunity to get acquainted with the methods of conducting this study and the basics of the programs. There was also an acquaintance with the object for research - the Pakri cliff and the software that the author chose for the process of image processing and reconstruction of 3D models.

Further in the dissertation, the process of building 3D models using the OpenDroneMap and Meshroom programs is described in detail.

The OpenDroneMap software proved to be a photogrammetry application that does the job with ease, but requires basic programming language skills, as well as downloading additional applications to make the program work properly.

In parallel, it turned out to conduct a study, as well as a comparison between the two devices, with which it was possible to carry out reconstructions of 3D models. An analysis was carried out and the main disadvantages and advantages of each of the devices were identified.

Building 3D models using the Meshroom program was also successful and without any problems. Moreover, this program proved to be even better than OpenDroneMap, as it is easy to use and easy to learn.

All four built models turned out to be of high quality, and were successfully compared with each other in the CloudCompare program, according to the results of the comparison, it turned out that within three years there were two strong collapses in the area of the old lighthouse, the maximum length of the collapsed rocks was 26 centimeters relative to the surface. Comparison of 3D models built in different programs showed that the reconstructions almost do not differ from each other and the maximum difference between them was 1.5 centimeters.

Based on the work done and the results obtained, it can be said with confidence that the purpose of this dissertation has been fully achieved, and also there is the potential to continue research and to further monitor the Pakri cliff, both to ensure the safety of passers-by and tourists, as well as to prevent the collapse of such sights and historical monuments like the old lighthouse, research in the field and annual comparisons of rock falls are required.

Summary in Estonian

Käesoleva lõputöö alguses tehti teoreetiline kõrvalepõik sellistele mõistetele nagu fotogrammeetria ja avatud lähtekoodiga programmid, need kontseptsioonid annavad lugejale võimaluse tutvuda käesoleva uuringu läbiviimise meetoditega ja programmide põhitõdedega. Tutvuti ka uurimisobjektiga - Pakri pankranniku ja tarkvaraga, mille autor pilditöötluse ja 3D-mudelite rekonstrueerimise protsessiks valis.

Edasi on lõputöös üksikasjalikult kirjeldatud OpenDroneMap ja Meshroom programmide abil 3D mudelite ehitamise protsessi.

Tarkvara OpenDroneMap osutus fotogrammeetriarakenduseks, mis teeb selle töö lihtsalt ära, kuid eeldab elementaarseid programmeerimiskeele oskusi, aga ka lisarakenduste allalaadimist, et programm korralikult töötaks.

Paralleelselt oli võimalik läbi viia uuring, samuti kahe seadme võrdlus, millega oli võimalik teostada 3D-mudelite rekonstrueerimist. Viidi läbi analüüs ning selgitati välja iga seadme peamised puudused ja eelised.

Ka 3D-mudelite ehitamine Meshroom programmi abil sujus edukalt ja probleemideta. Lisaks osutus see programm isegi paremaks kui OpenDroneMap, kuna seda on lihtne kasutada ja seda on lihtne õppida.

Kõik neli ehitatud mudelit osutusid kvaliteetseteks ja neid võrreldi edukalt CloudCompare programmis, võrdluse tulemuste põhjal selgus, et kolme aasta jooksul toimus kaks tugevat kokkuvarisemist. vana tuletorni puhul oli kokkuvarisenud kivide maksimaalne pikkus maapinna suhtes 26 sentimeetrit. Erinevates programmides ehitatud 3D-mudelite võrdlus näitas, et rekonstruktsioonid peaaegu ei erine üksteisest ning maksimaalne erinevus nende vahel oli 1.5 sentimeetrit.

Tehtud töö ja saadud tulemuste põhjal võib kindlalt väita, et käesoleva lõputöö eesmärk on täielikult täidetud ning sellel on ka potentsiaali jätkata uurimistööd ja Pakri pankrannik edaspidi seiret nii möödujate ohutuse tagamiseks. - ja turistide poolt, aga ka selliste vaatamisväärsuste ja ajaloomälestiste, nagu vana tuletorn, kokkuvarisemise ärahoidmiseks on vaja valdkonna uuringuid ja iga-aastaseid kivilanguste võrdlusi.

Resources

1. Alicevision. (n.d.). Retrieved from https://alicevision.org/#meshroom

2. Chron. (n.d.). Retrieved from https://smallbusiness.chron.com/winscp-77185.html

3. CloudCompare. (2016-11-17). Retrieved from https://www.cloudcompare.org/doc/wiki/index.php/Introduction

4. CloudCompare. (2018-08-27). Retrieved from https://www.cloudcompare.org/doc/wiki/index.php/Interactive_Segmentation_Tool

5. Education, I. C. (2021-6-23). *idm.com*. Retrieved from ibm: https://www.ibm.com/in-en/cloud/learn/docker

6. Einasto, R. (n.d.). Retrieved from http://vana.loodusajakiri.ee/eesti_loodus/artikkel2323_2312.html

7. Geostart. (n.d.). Retrieved from https://geostart.ru/post/293

8. Github. (2019-3-20). Retrieved from https://github.com/alicevision/meshroom/issues/423

9. Hewlett Packard Enterprise. (n.d.). Retrieved from https://www.hpe.com/ru/ru/what-is/open-source.html

10. Jartour. (n.d.). Retrieved from jartour.ru: https://www.jartour.ru/info/dostopr_paldiski.html

11. Mapscaping. (n.d.). Retrieved from https://mapscaping.com/podcast/open-drone-map/

12. Nizametdinov, I. (2021-4-23). Retrieved from ERR.ee: https://rus.err.ee/1608188932/geologi-prizyvajut-ljudej-k-ostorozhnosti-vozle-paldiski-obrushilsja-kusok-beregovoj-skaly

13. OpenDroneMap. (n.d.). Retrieved from https://www.opendronemap.org/odm/

14. OpenDroneMap. (n.d.). Retrieved from https://docs.opendronemap.org/installation/

15. ReviverSoft. (n.d.). Retrieved from https://www.reviversoft.com/ru/file-extensions/obj

16. Uptodown. (n.d.). Retrieved from https://meshroom.ru.uptodown.com/windows

17. US. (n.d.). Retrieved from https://www.sussex.ac.uk/its/services/software/owncomputer/putty

18. Zingfeld, A. (2022-1-11). Retrieved from digikogu.taltech.ee: https://digikogu.taltech.ee/et/Item/be27c1ee-013e-46b2-9297-b27127fc3dd0

## Add 1. GPU load - Meshroom
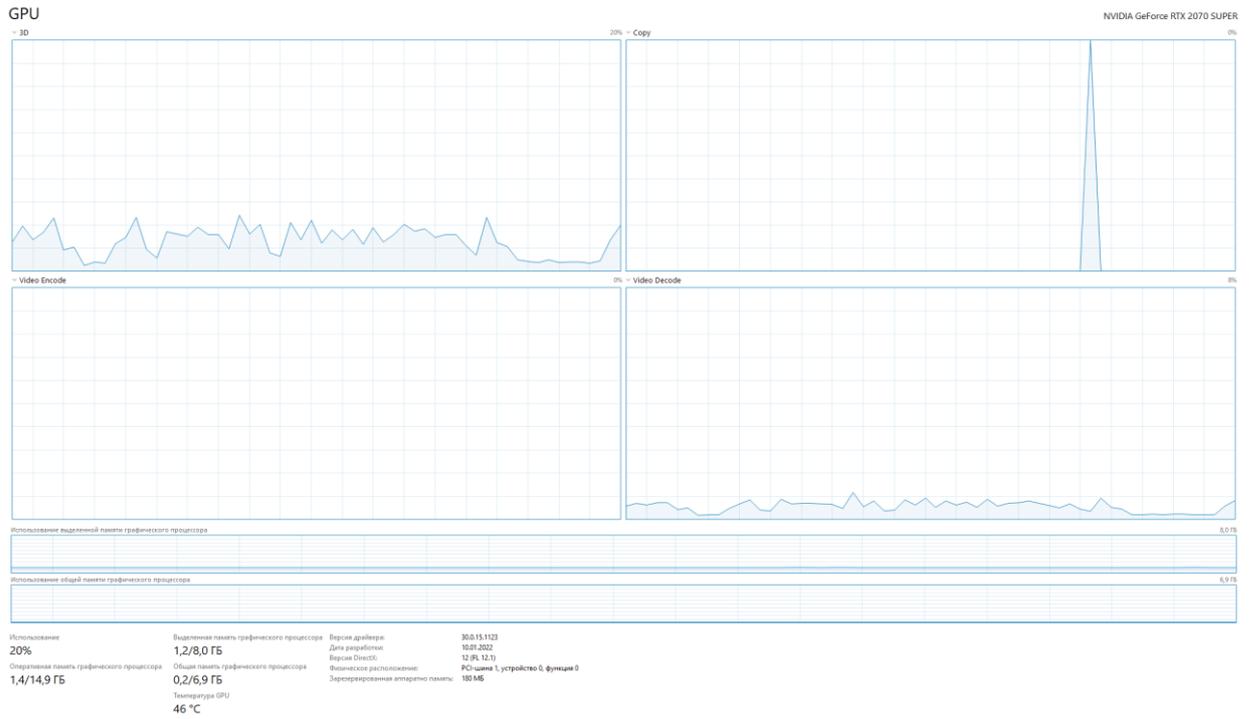
Figure 25. GPU load when creating a 3D model in Meshroom

Add 2. CPU load – Meshroom and ODM

ЦП   Intel(R) Core(TM) i5-9600K CPU @ 3.70GHz

Использется %   100%

60 секунд   0

Использование	Скорость		Базовая скорость:	3,70 ГГц
100%	4,77 ГГц	Сокетов:	1	
		Ядра:	6	
Процессы	Потоки	Дескрипторы	Логических процессоров:	6
274	3688	129639	Виртуализация:	Включено
			Кэш L1:	384 КБ
Время работы			Кэш L2:	1,5 МБ
3:21:09:41			Кэш L3:	9,0 МБ
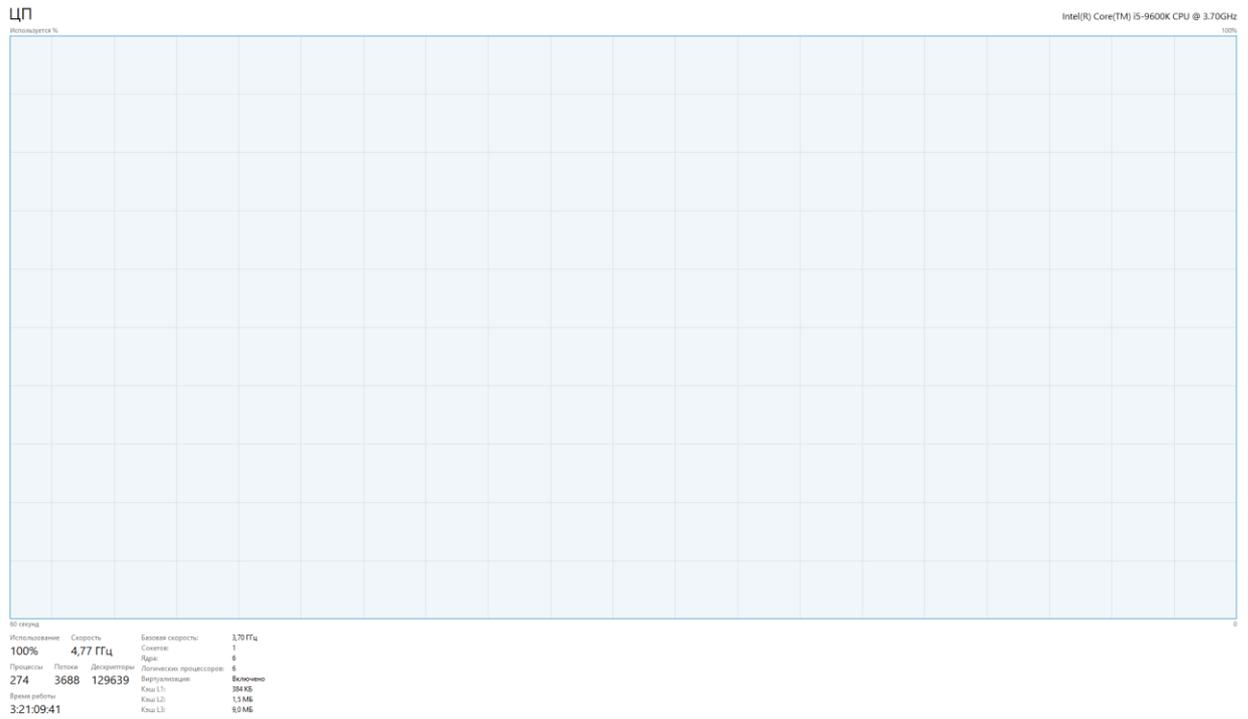
Figure 26. CPU load when creating a 3D models in Meshroom and ODM

44

Add 3. Internet using
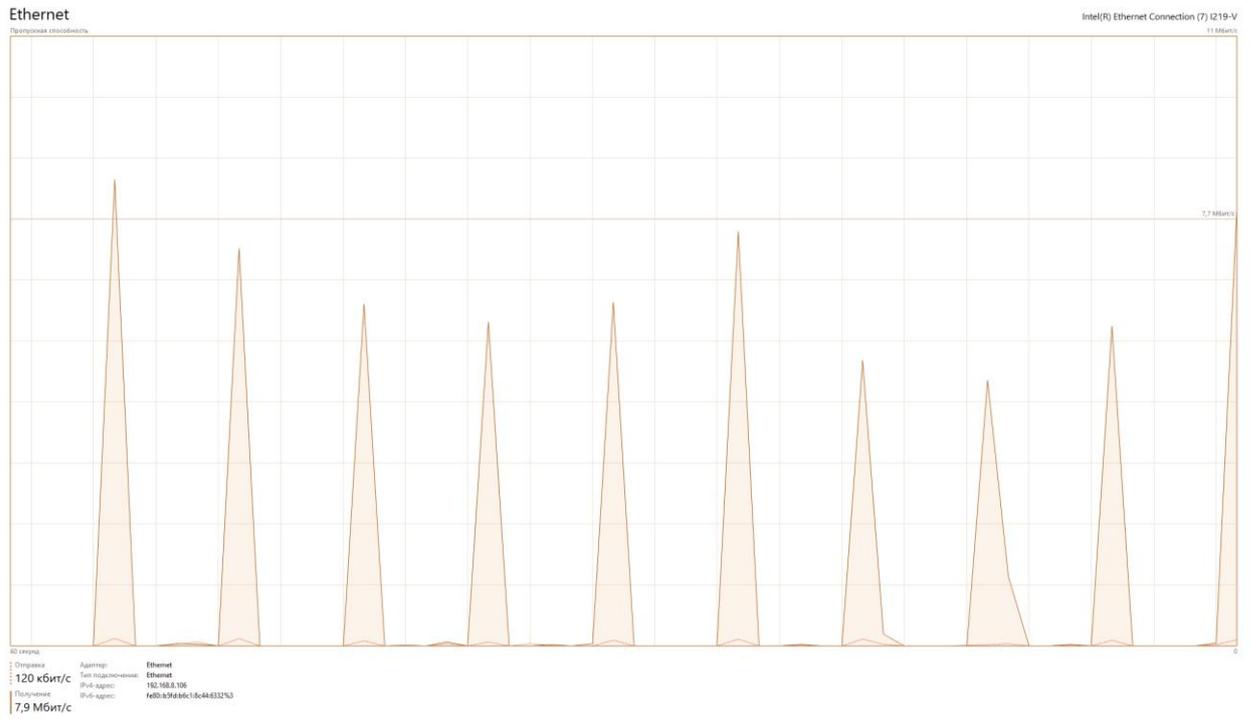
Figure 27. The Internet using in 3D modeling

Add 4. Reporton the loads

ЦП
100% 4,77 ГГц

Память
11,2/13,9 ГБ (81%)

Диск 0 (C:)
SSD
1%

Диск 1 (D:)
SSD
0%

Ethernet
vEthernet (WSL)
О: 0 П: 0 кбит/с

Ethernet
Ethernet
О: 0,1 П: 5,8 Мбит/с

Ethernet
VirtualBox Host-Only Network
О: 0 П: 0 кбит/с

Ethernet
VirtualBox Host-Only Network #2
О: 0 П: 0 кбит/с

Графический процессор 0
Intel(R) UHD Graphics 630
8%

Графический процессор 1
NVIDIA GeForce RTX 2070 SUPER
17% (46 °C)
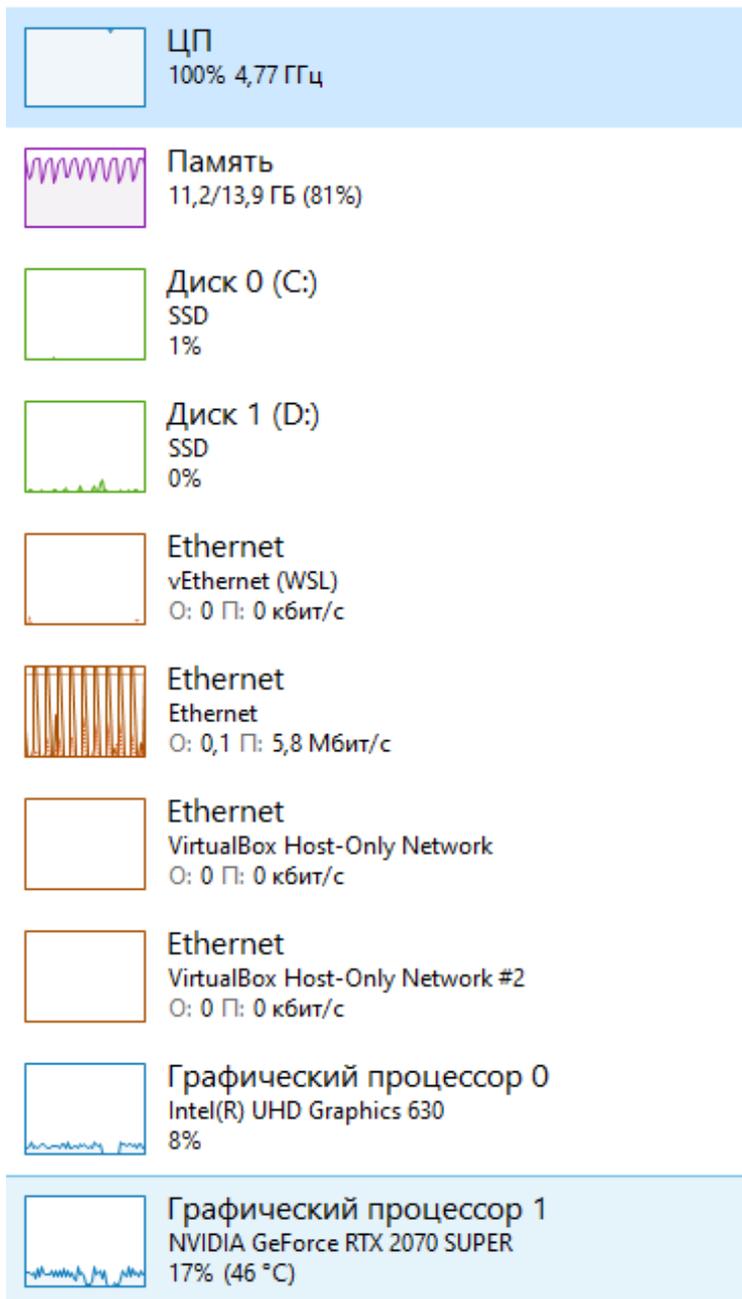
Figure 28. Report on the loads on all computer resources during the construction of a 3D model in Meshroom

Add 5. WebODM Toolbar

Figure 29. Toolbar in WebODM

Add 6. Distances measuring
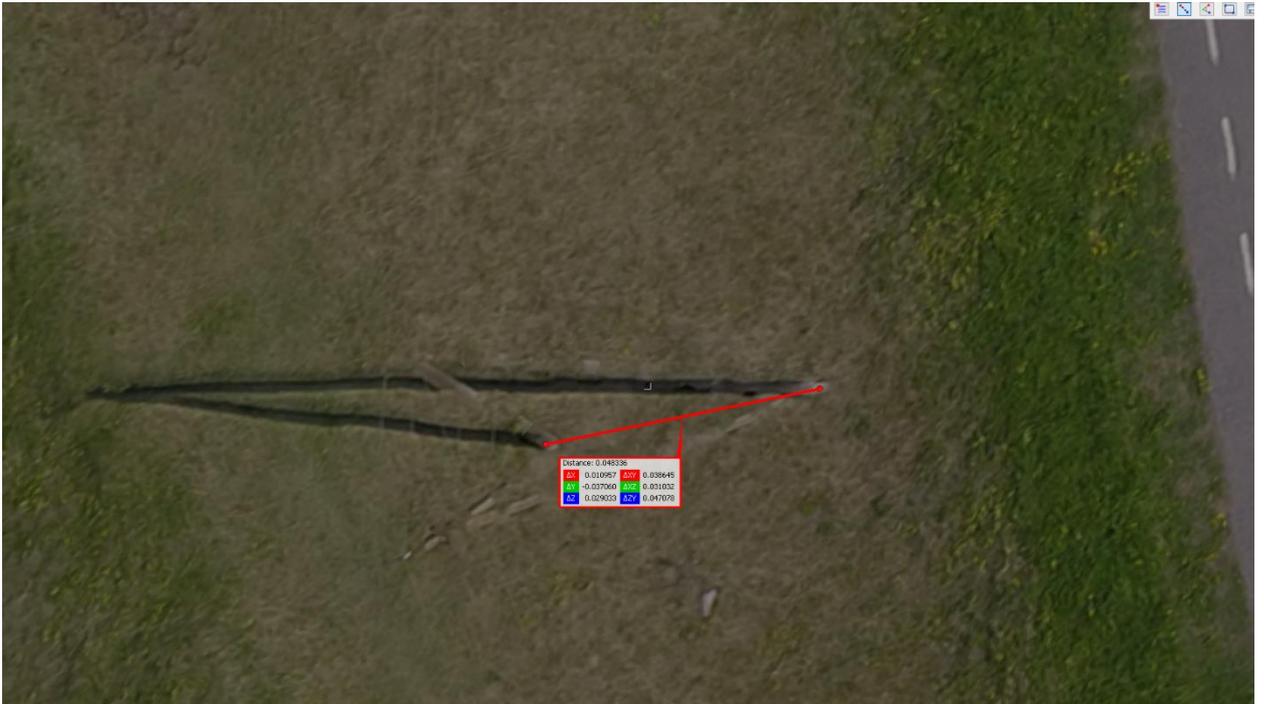
Figure 30. Measuring distances between pole supports

Add 7. Live mode in Meshroom
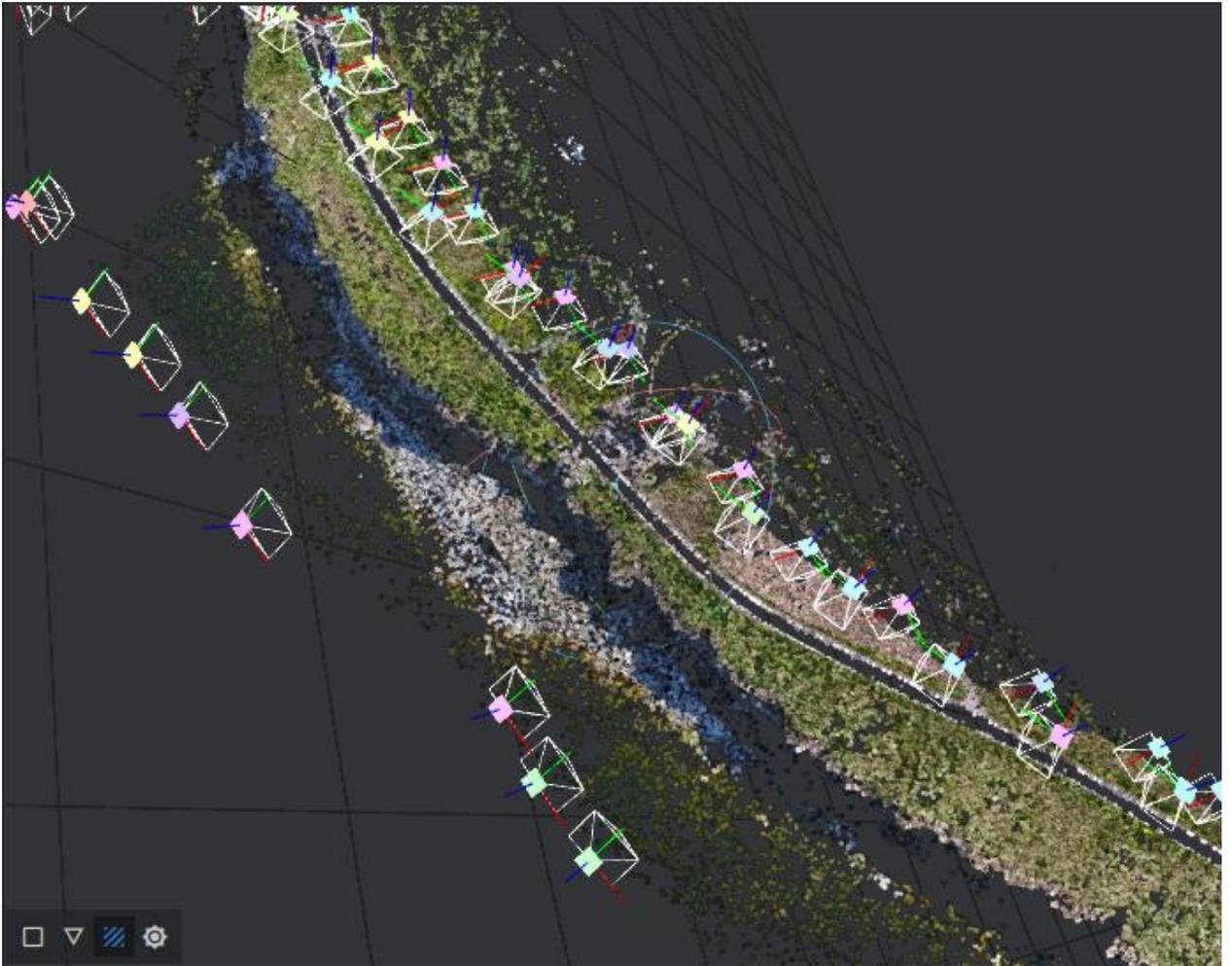
Figure 31. Building a 3D model in Meshroom in live mode

Non-exclusive licence for reproduction and publication of a graduation thesis[5]

I , Artjom Pilags

1. grant Tallinn University of Technology free licence (non-exclusive licence) for my thesis
Assessing changes in Pakri cliff from 3D models using CloudCompare, supervised by Inga Zaitseva-Pärnaste,

1.1 to be reproduced for the purposes of preservation and electronic publication of the graduation thesis, incl. to be entered in the digital collection of the library of Tallinn University of Technology until expiry of the term of copyright;

1.2 to be published via the web of Tallinn University of Technology, incl. to be entered in the digital collection of the library of Tallinn University of Technology until expiry of the term of copyright.

2. I am aware that the author also retains the rights specified in clause 1 of the non- exclusive licence.

3. I confirm that granting the non-exclusive licence does not infringe other persons' intellectual property rights, the rights arising from the Personal Data Protection Act or rights arising from other legislation.

20.05.2022

---

[5] *The non-exclusive licence is not valid during the validity of access restriction indicated in the student's application for restriction on access to the graduation thesis that has been signed by the school's dean, except in case of the university's right to reproduce the thesis for preservation purposes only. If a graduation thesis is based on the joint creative activity of two or more persons and the co-author(s) has/have not granted, by the set deadline, the student defending his/her graduation thesis consent to reproduce and publish the graduation thesis in compliance with clauses 1.1 and 1.2 of the non-exclusive licence, the non-exclusive license shall not be valid for the period.*