FACULTY OF INFORMATION TECHNOLOGY CTU IN PRAGUE

Assignment of bachelor's thesis

Title:	Virtual production for dancing performances
Student:	Anastasiia Pastukhova
Supervisor:	Ing. Jan Buriánek
Study program:	Informatics
Branch / specialization:	Web and Software Engineering, specialization Computer Graphics
Department:	Department of Software Engineering
Validity:	until the end of summer semester 2022/2023

Instructions

Among the modern methods of realization of performances is the use of the so-called Virtual Production, i.e. a combination of a live performance with a foreground and background created with the help of computer graphics. The work aim is to explore and describe the technology of virtual production, to compile a complete chain of data processing, including a real demonstration of the usage of the proposed workflow for dance performances.
1) Study the available literature on the issue of virtual production. Find examples of real virtual production projects in our country and in the world.
2) Describe the principle and procedures (workflow) used in virtual production.
3) Create your own workflow for virtual production focused on dance performances.
4) Create a scenario of your own dance performance and implement it using your designed workflow. Record the dance performance, footage for at least 30 seconds.
5) Process the work, including pictorial attachments and comments.Evaluate results.

Electronically approved by Ing. Radek Richtr, Ph.D. on 24 February 2021 in Prague.

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Bachelor's thesis

Virtual production for dancing performances

Anastasiia Pastukhova

Department of Software Engineering
Supervisor: Ing. Jan Burianek

May 13, 2021

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Declaration

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Citation of this thesis

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Abstrakt

Práce se zaměřuje na využití technologie virtuální produkce (Virtual Production) pro vytváření tanečních vystoupení pro TV, video nebo obecně živá vystoupení. Součástí práce je i popis celého technologického řetězce nutného pro virtuální produkci, včetně diskuse praktických aspektů jednotlivých komponent. Všechny popisované postupy byly prakticky ověřeny na ukázkách, kde součástí procesu bylo 3D scanování těla, snímání pohybu tance a následné nahrání krátké ukázky prezentující technické možnosti virtuální produkce.

Klíčová slova Virtuální produkce, LED plátno, Chromakey technologie, Unreal Engine, Sledování pozice kamer, Snímání Pohybu, Taneční Vystoupení

Abstract

This thesis looks into using Virtual Production for creating a dance performance video. A discussion on problems of Virtual Production, Virtual Studio and other related technologies is a part of the thesis. Virtual 3D models created with 3D scanning are a part of the dance performance. These models are animated with motion capture technology. The real-time dance performance was shot on both green and LED screens with different camera tracking technologies. As a result, there are several short videos that showcase technical possibilities of Virtual Production.

Keywords Virtual Production, LED screen, Chromakey technology, Unreal Engine, Camera Tracking, Motion Capture, Dance Performance

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Introduction

The continuous development in the computing power of graphic stations in recent years has led to a significant qualitative improvement in virtual graphic technology. Virtual studios have become not only better, but also more affordable products. Modern virtual graphic systems work in real-time and automatically combine computer objects with real-world objects.

The best approach in combining the virtual world with the real one is a completely seamless merging of computer graphics with a live studio. This is possible only if the computer graphic stations generating virtual objects know the exact position of the camera in the studio space and the current optical parameters of the lens. The key tool that is used in virtual reality technology is a background, usually a green, blue or LED screen.

The newest virtual projects no longer use chromakey technology, instead, one or more LED screens are placed in the background. They are located on the sides, in the background and on top of the stage, thus creating the feeling of immersion in a virtual scene during shooting. Participants of the shooting can immediately see the graphically created environment in which they are in real time.

During the shooting, it is possible to change the virtual environment: move objects, change their location, change lighting and camera settings. A real-time data processing engine combines physical objects with virtual objects and displays the result. Tracking cameras create a stream of data that contains information about the perspectives of the camera in real time.

Task Definition

The first problem deals with creating as humanlike 3D model as possible - a virtual character that would be able to interact in real time. Next, the model must be “brought into life” and be given a so-called skeleton to implement the animation.

In this thesis, the presented animation has a dancing nature, the main actor and the virtual character performs the same choreography. That presents a challenge for the character's movements to be natural and humanlike, and for the movements to create an effect of a collective synchronized dance.

To create the effect of real shooting, it is necessary to use a real camera, which is connected to the virtual camera, using a tracker. In order to achieve a smooth transition and capture virtual and real characters simultaneously, it is necessary to have a green screen or LED screen for the effect of merging real and virtual spaces.

Objectives

The objective of this thesis is to create a dancing performance videos using virtual production.

For the technical part of the thesis, I visited television and production studios (Česká televize, TV Nova, Xlab, Virtuplex, AV MEDIA SYSTEMS) equipped with virtual reality technologies. During the visit, I learned about data transmission, camera settings and engines used.

In order to achieve the objective, I studied camera tracking characteristics, such as configuring the camera for working in virtual reality, calibrating the camera, reading data about the position of the camera in physical space and changing its position in the virtual environment.

Chapter 1

Analysis

1.1 Timeline of the Virtual Production

1.1.1 Sensorama

A filmmaker Morton Heilig invented the world's first virtual simulator sensorama. It is a theatrical booth that stimulates all senses. The device includes stereo speakers, a stereoscopic 3D display, fans, odor generators and a vibrating chair. Hailing created a prototype with his own money. Then he began to seek financial support from businessmen. However, the device was not appreciated: for those times it was too revolutionary and expensive, so in total, only six films have been released [21].

Heilig created and patented the Telesphere mask device for immersion in films. It was the first head device. It broadcasted a stereoscopic and wide-angle image with stereo sound.

1.1.2 First VR helmet

Sutherland Saberland and his student Bob Sproull created the first VR-AR helmet that was connected to a computer, not a camera. It was a massive phenomenon. Therefore, the helmet was nicknamed "The Sword of Damocles" [21].

1.1.3 VIDEOPLACE

The next stage of development of technology happened in 1974, when a computer specialist Myron Krueger developed the VIDEOPLACE - an artificial reality laboratory [7].

It consisted of several rooms connected through a network, each of them contained a large screen with a video projector located behind it. When someone entered a room, they saw an image on the screen - an outline of

Figure 1.1: First VR helmet, 1968 [2]

their silhouette and also silhouettes of other people in different rooms. All the images of silhouettes could change their color or size and interact with simple objects as well as each other [7].

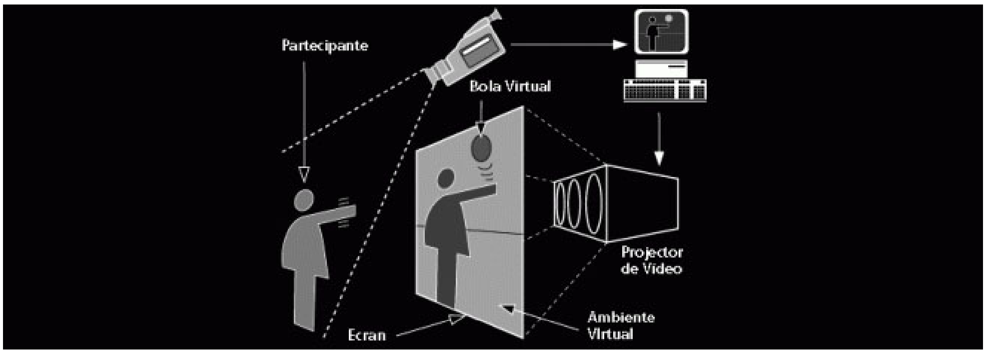

Figure 1.2: VIDEOPLACE, 1974 [2]

1.1.4 Mandalorian

The real breakthrough in virtual production technology [40] is the series The Mandalorian [40], which was filmed by Jon Favreau's Golem Creations in partnership with Industrial Light & Magic (ILM) and with Epic Games. By using a real-time game engine and surrounding light-emitting diode displays (LED) [47], filmmakers created a lot of effects in real-time, which before could have been created only by using post-production process. The stage was curved and it was a 180 degree LED video wall comprising 1,326 individual LED screens [30].

It became possible to change a background according to camera movement in real-time by using LED screens. It is necessary to use motion capture volume to track the trajectory of the camera to achieve interaction between

Figure 1.3: The Mandalorian film processing [30]

LED screen and camera. Over 50 % of The Mandalorian was filmed using virtual technology [30].

1.2 Virtual Production Technology

The Virtual Production (VP) is a technology of combining computer graphics and live action footage in real-time [24]. Accordingly to the Unreal Engine, the Virtual Production workflow is shown on the table 1.4.

Virtual production combines a wide range of practices, such as motion capture, interaction with CG elements of computer graphics, camera tracking and much more [22]. The main difference between virtual production and chromakey technology is that the VP allows layer combining in real-time while chromakey technology requires post-production for the layer combining process. The key infrastructure needed to virtual production workflow are described in the table 1.5. Today, the technology of VP allows its user to immerse into virtual reality by using the Cave Automatic Virtual Environment (CAVE) in real-time [20]. The CAVE is a high-resolution environment equipped with three walls, a ceiling and a floor 1.6. When the location sensor of the viewer moves in CAVE, the surrounding virtual environment moves with him and the viewer is able to see the correct perspectives of the image around him [20]. Both LED displays and canvases can be used as the walls and

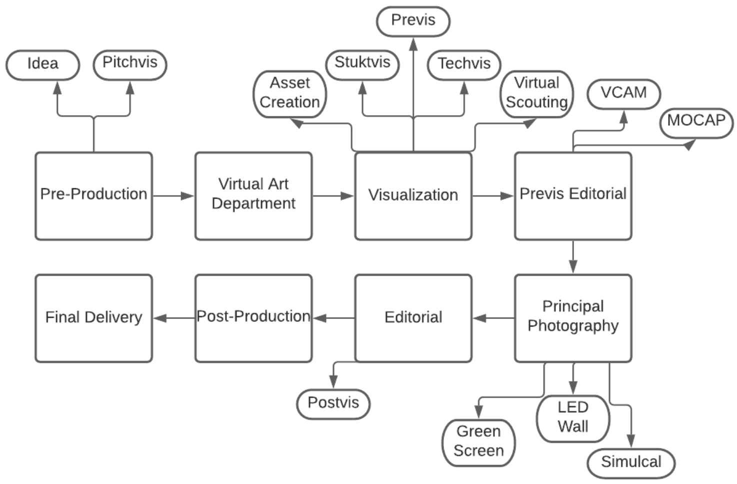

Figure 1.4: Virtual Production Workflow [39]

Stage and virtual production	
LED Display Wall	LED modules, processors, rigging, high-end workstations
Brain Bar	High-end workstations, video assist
Tracking	Inertial, optical, and encoder-based solutions
Networking Infrastructure	Used for production and editorial to move media/loads. For data-intensive workflows like mocap, an isolated network with high bandwidth switches is needed
Sync/Timecode	Genlock and time code hardware required to keep all acquired data in sync and lined up
Lens Data	Tracking of focus, iris, and zoom to determine lens distortion, field of view, camera nodal point

Figure 1.5: Virtual Production Gear [39]

ceiling onto which images can be projected. Virtual production is commonly used in the form of virtual studios [24].

1.2.1 Virtual studio

The Virtual Studio is a set of tools that provides a seamless composition of people or real objects and computer-generated space and objects in real-time

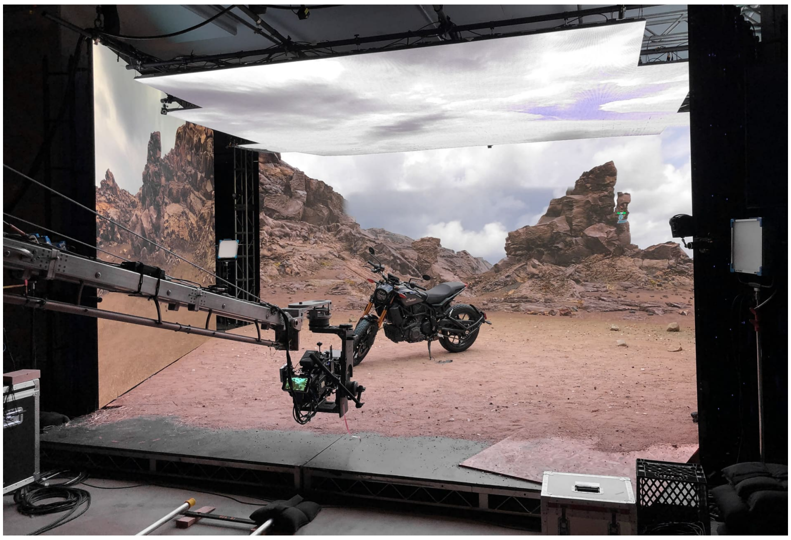

Figure 1.6: Virtual CAVE [46]

[24]. The main tools needed for a virtual studio are chromakey, camera, engine, tracking and lighting. The main advantage of virtual studio is that it uses less space than a real studio yet achieves the same or a better result.

The effect of shooting in a real studio is achieved by the combination of a real-time recording using a green screen with a virtual set. Virtual studio requires a minimum of maintenance: green/blue screen or LED screen background, virtual sets and correct lighting [22].

Camera tracking is one of the fundamental technologies of a virtual studio. It is necessary to accurately track the real camera in space to estimate the correct position of the virtual camera in a virtual environment. Information about position from real camera transmits through protocol to the game engine with a delay. This delay creates problems for users of visual studio because audio lags behind the video [27].

1.2.2 Chromakey technology

The chromakey is a technology of combining two or more images or frame layers in one composition based on color. By using chromakey technology, its user can replace the green or blue background with an image, video or virtual environment.

A traditional production has four phases: development, preparation, production and post-production. All these phases are shown in the table 1.7. In the traditional production, the film crew was able to see the final result only between the third and fourth phase, when the green screen was replaced by the virtual environment in post-production.

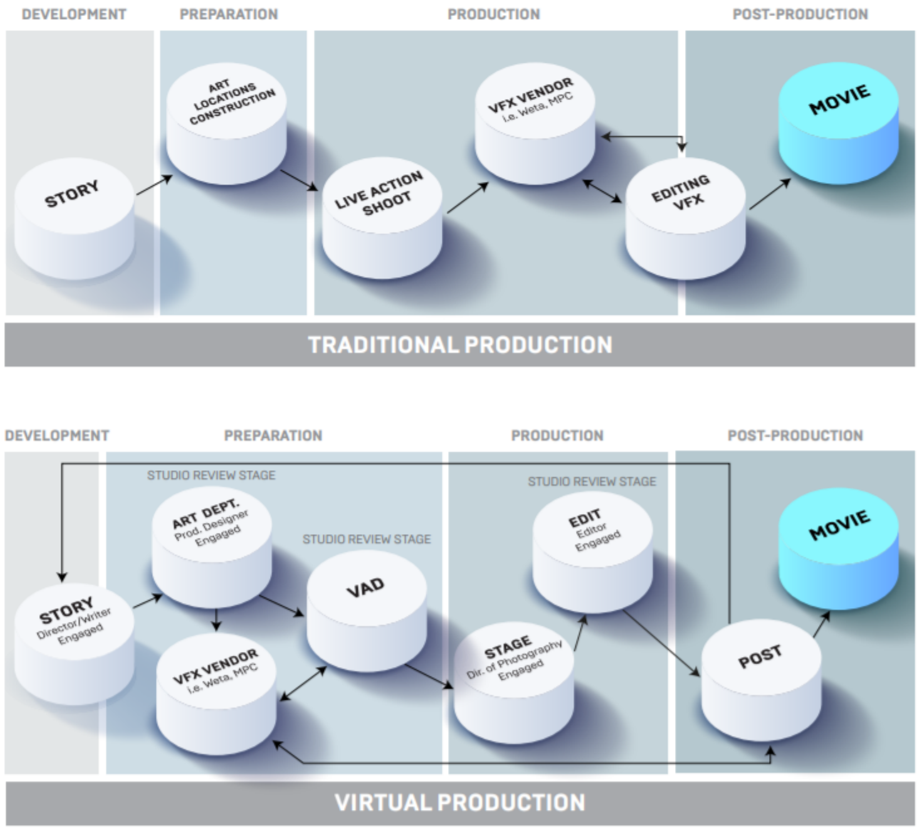

Figure 1.7: Traditional Production vs Virtual Production Workflow [39]

The Virtual Production process also has four phases, however, the film-maker team is able to see the studio review stage and edit the VR environment already in the second phase [39].

The most common background colors for shooting are green, which is used for film, and blue, which is used for shooting TV broadcasts [27]. The color of the background for keying depends on the task (the director's vision of the final outcome) and the color of the actors clothes and objects appearing in the frame. By the end of the 1970s, green backgrounds began gradually replacing blue ones. There are several reasons for this transition:

- green background usually requires less lighting
- green channel has the highest luminance value of RGB signals
- green background enables to transmit more pixels for digital camera using RGB channels [27]

1.2.3 Synchronizing of Multiple Screens

The real-time graphics industry has always faced the challenge of simultaneously displaying and synchronizing images across multiple screens. The screens are not always rectangular surfaces, they can also be spherical and curved, on which it is necessary to display the image in the correct resolution and in the best quality. For a long time, in order to achieve the effect of a curved screen, ordinary rectangular screens were placed close to each other at special angles. Now it is possible to create screens of almost any shape and resolution. The Unreal Engine platform has developed a plugin nDisplay that allows its users to launch multiple instances of projects across different computers on the network.

1.2.4 Camera Tracking

1.2.4.1 Camera Calibration

Camera calibration is the process of estimating internal and external camera parameters. Internal parameters of the camera are focal length, optical center, skew and distortion. External parameters that are related to the orientation (rotation and displacement) of the camera relative to world coordinate system. Camera calibration is used to eliminate an aberration form - distortion [23]. Knowing intrinsic parameters allows the user to estimate the scene's structure in Euclidean space and remove lens distortion, which degrades accuracy.

Information about external parameters allows the game engine to change position, orientation and zoom of the virtual camera accordingly to the real camera.

1.2.5 FreeD Protocol

FreeD protocol transmits external camera parameters, information about the position, orientation and zoom of the camera, directly from the camera to the virtual game engine. FreeD protocol use a XML Protocol Description structure. This protocol is sent every frame [37].

1.2.5.1 AW-UE100 PTZ

AW-UE150 PTZ is a remote pan, tilt and zoom camera that supports 4K/12G-SDI and also is compatible with 4K/60p format. The camera features the FreeD protocol that transmits information about the pan, tilt, and zoom via Serial (RS 422) and IP (UDP) from a physical camera to a tracking system. The camera can record video in different conditions because of its high sensitivity [4].

The camera setting is carried out in a web browser. When the camera connects to the main computer, it is necessary to open Google Chrome web

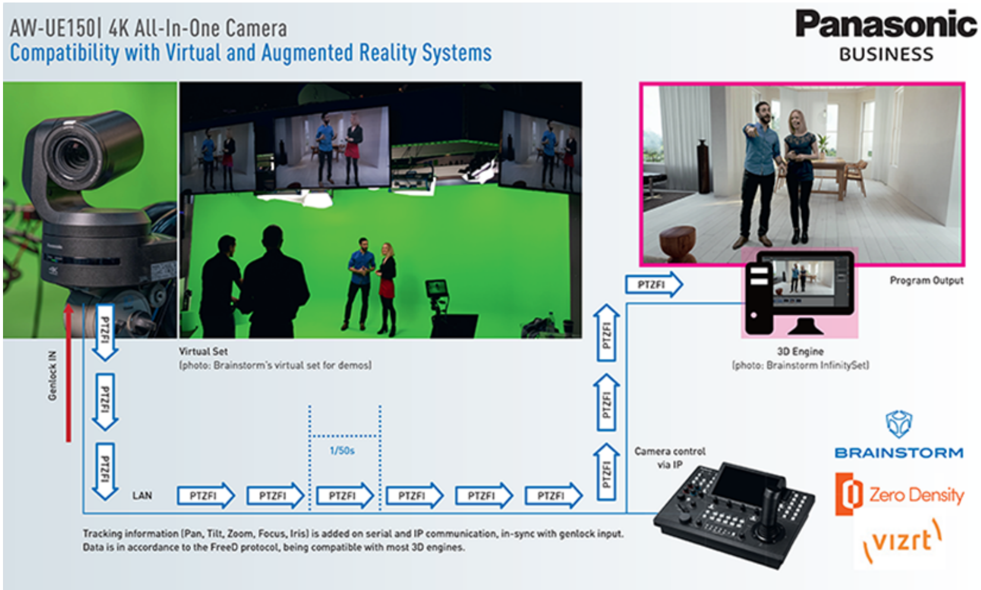

Figure 1.8: AW-UE150 PTZ Camera AR/VR Workflow [4]

browser where the window with camera settings appears. After proper configuration, AW-UE150 PTZ camera broadcasts rotation, position, and zoom via FreeD protocol to the computer(s). The PTZ camera supports high bandwidth Network Device Interface (NDI) for low transmissions. The camera can be remotely controlled by a control panel in NDI software.

1.2.6 Position Tracking

Position tracking is one of the virtual reality technologies based on interaction of people with the virtual environment.

An important characteristic of modern virtual equipment is the Six Degrees of Freedom (6DOF), directions in which an object moves in a space. There are two categories that describe degrees of freedom: movements and rotations. The three-rotational movements are a pitch, yaw, and roll. The three spatial movements are left/right, forward/backward and up/down.

Position tracking provides the 6DOF tracking of the position and orientation of a tracked object by using sensors or markers. Sensors take a signal from a moving object and transmit the received information to the computer. Position tracking uses a combination of a software and a hardware to determine the absolute position of an object in a 3D environment.

1.2.6.1 Optical tracking

Optical tracking is a three-dimensional technology based on monitoring a space by using two or more cameras. Each camera contains a special infrared filter before the lens and an infrared LEDs ring around the lens [13]. The infrared light is not visible to the human eye. Tracked objects also contain infrared sensors that reflect infrared light back to the cameras. After reflecting, the signals are processed by the optical system, which calculates the position of the marker in coordinates. The presence of a larger number of cameras allows the systems users to determine the location of the object more accurately.

There are several types of position tracking, some of them are: inside-out tracking and outside-in tracking.

1.2.6.2 Outside-in tracking systems

Outside-in tracking system is an optical tracking system. In order to use this optical tracking system, several infrared cameras have to be set up in the soundstage. They are pointed to the inside of the soundstage and cover a certain area - the capture volume. Retro-Reflective markers are located on tracking objects [13].

The quality of the tracking depends on the number of cameras. Occlusion is one of the problems of the outside-in tracking system. If the camera can not determine the sensor location due to occlusion with another object, the sensor can not be tracked. Sensors have to be efficiently tracked 360 degrees in space. The outside-in tracking system allows its users to track both performances and camera movements.

However, there are many tracking issues in the outside-in system:

- The issues with the correct location of the cameras.
- It takes a long time to set cameras at the right angle and in the right position.
- Installation may require special equipment: mounts, base station, cables.
- Portability

1.2.6.3 Inside-out tracking system

Inside-out tracking system is a position tracking system used in virtual reality to track the position of motion controller devices. The main difference between inside-out tracking and the outside-in tracking is the location of cameras and sensors that are used to track. In the inside-out tracking system, the sensors or cameras are located on the tracking object [13].

Special devices for tracking determine how the position of the object changes in the relation to the environment. When the tracking object moves,

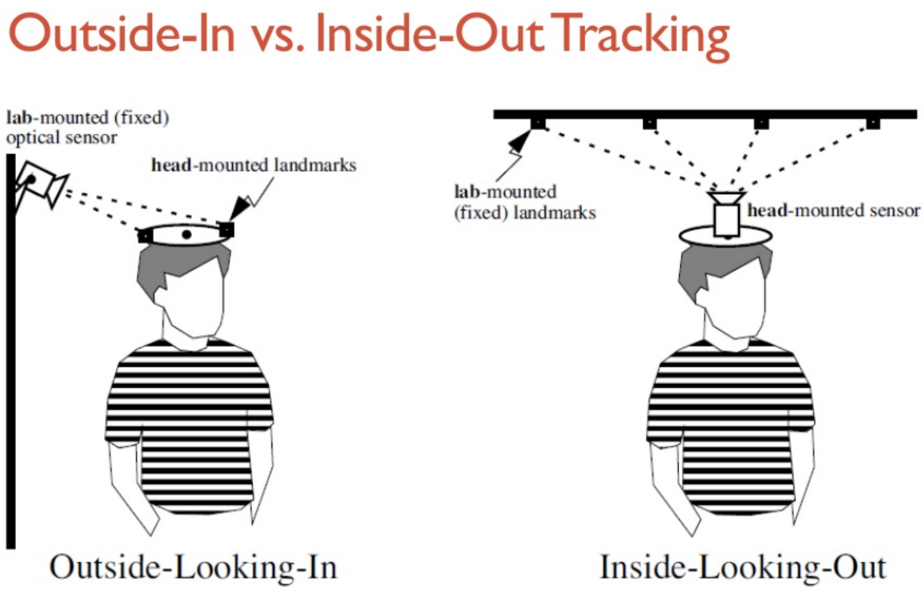

Figure 1.9: (a) outside-looking-in; (b) inside-looking-out [31]

the sensors capture the movement of the object in space and the virtual environment position changes accordingly.

1.2.7 Camera Tracking Systems

1.2.7.1 Vicon

Vicon is a company that has been a market leader in the motion capture industry for more than 35 years. One of the products of the Vicon is the Origin system, designed specifically for working with virtual reality projects. It includes software, cameras, LEDs clusters for tracking players, as well as additional devices [16].

Evoke is a software developed specifically for the Origin. It allows users to combine all the technologies of Vicon. The advantages of this software are quick setup of helmet, props, tracking setup; the ability to track the full movement of the body; automatic recalibration of the camera when it is damaged or disconnected [16]. Calibration takes less than one minute and can further perform accurate calculations in tracking. A seamless game engine that provides smooth tracking and low latency.

The Vicon Vantage system is a set of network cameras for video capture, as well as hardware devices for synchronization, such as Vicon Vue and Vicon Lock, applications that provide motion capture data, Vicon Vantage host PC to run the software. Motion capture data from the Vicon Vantage cameras

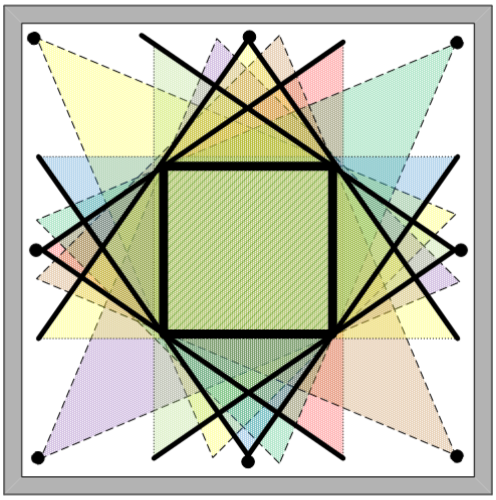

Figure 1.10: Vicon tracking system [16]

connects through PoE+ switches to a Vantage host PC, which runs the required Vicon application software. All Vantage cameras and Vicon Vue and Vicon Lock devices require PoE+ switches [16].

The PoE+ switch provides power and data transfers for cameras. The PoE+ switch transfers the data stream to the Vicon Vantage host computer on which the software for processing and visualizing data is installed.

Vicon Vintage Cameras are specially designed cameras that provide real-time image processing. In the normal motion capture mode, the cameras contain data of the movement of the markers, not of the movement of the whole body on which these markers are located. Markers are spheres that are attached to an object which movements the user wants to track. Markers reflect light back into the motion capture camera, so the camera can track the movement of the object. A minimum of two cameras is required to determine the coordinates of the object in three-dimensional space [16].

Each camera has a built-in function of recalibration in case of a damage. Before the first setup of the camera, it needs to be touched to warn the system about the settings of this particular camera.

The Vicon software informs its users if the camera has overheated. Users can change the range of possible temperatures the camera warns them about in the Vicon application software.

There is a special device in the Vi on system for calibrating of the optical video cameras - Active Wand. The Active Wand is used to determine the source of light reflectors and axes. The calibration device contains five pairs of LEDs that are used to calibrate the cameras.

Camera calibration is being done by using Vicon software and a calibration wand. At the time of calibration, the calculation of external and internal

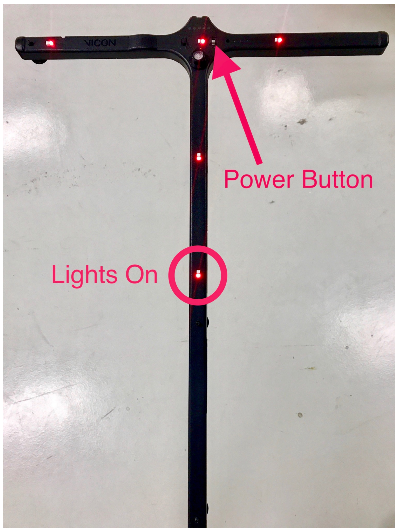

Figure 1.11: Active Wand [16]

parameters are being estimated.

To calibrate the camera, the user must turn on the Active Wand and actively move it around the room so that the cameras can fix the position of the Active Wand. The Vicon application software display provides feedback so that the user determines when enough information is received to calibrate the camera.

1.2.7.2 NCam

Ncam Reality is a real time tracking solution. The nCam software is operator free.

Information about the physical position and orientation of the camera in space is sent via the Free-D protocol or Ncams SDK.

NCam allows its users to create a 3D object in various graphics programs and place it in a camera eyepiece so that the user can see it as an augmented reality. The presence of two fisheye lenses at a certain distance from each other allows the user to immediately find the position of an object in three-dimensional space without the use of markers. The software displays a clean feed and a feed with a digital element, so the user is able to see the result.

Tracking can be carried out both indoors and outdoors, with complete freedom of movement. Both stabilized cameras and wireless camera systems can be involved.

Depending on the conditions, it is possible to work with any lighting, either with visible light or infrared light. The distinctive feature of nCam is that it can work with any types of camera lens.

Figure 1.12: Ncam camera with CGI elements [17]

1.2.7.3 MoSys

Mosys is a company that specializes on different areas such as camera tracking, broadcast robotics and remote camera systems.

A StarTracker is a camera tracking system that works with fixed reflective markers on the ceiling. The reflective markers are randomly attached to the ceiling of the studio or the lighting grid. A special sensor, which is pointed to the markers, measures the angles and distance between markers, thus calculating the absolute position of the camera.

Markers can be located randomly, without a specific pattern. While the markers are illuminated with an LED sensor built into the studio camera, Mosys users can capture so-called stars, reflective markers, and create a map of the stars' position, which is later transmitted from the StarTracker system to the engine. By using this map, the StarTracker is able to determine the position and orientation of the studio camera in real-time. The camera can be located in any location, provided that the tracking system can capture enough of reflective markers. The tracking sensors are always pointing up to the markers, so the tracking system is not affected by the studio's conditions, such as moving objects and changes in lighting settings.

After attaching the markers, Mosys user has to do calibration. Several cameras can track the star map at the same time. After the calibration process, the system becomes fully automatic, no additional operations are required for configuration, the user has to only turn on the system and tracking begins.

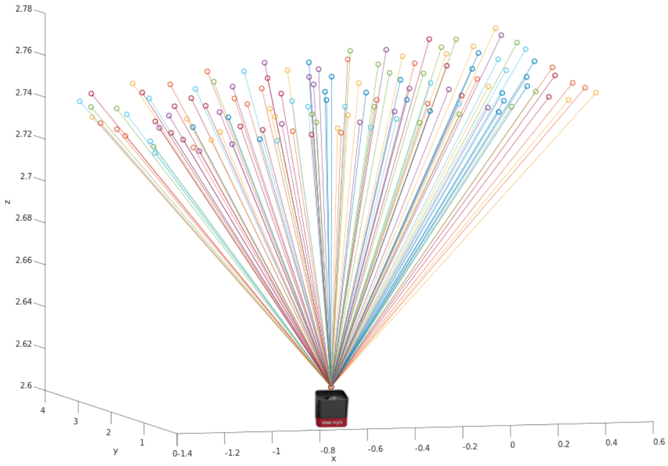

Figure 1.13: Camera tracking system with reflective markers [18]

1.2.8 Motion Capture

Motion analysis is a technology used in computer vision and it allows users to get information about moving objects. This technology is used in virtual reality to track the movement of moving objects or cameras [9].

Motion capture is a method of capturing actors' performances, so that it can be used for animating a computer-generated 3D character. Motion capture is commonly used to capture the movement of an actor or another object in real life and process this information in real time or by recording [10]. Motion capture allows its users to capture not only the movements of a body, but also facial expressions and emotions. Motion capture is used in animation, games, live broadcasts, medicine and military.

The history of the creation of motion capture goes back to 1930, when the Disney studio used rotoscoping - outlining the movements of actors to create animations. Some of the first cartoons made with this technology are Snow White and the Seven Dwarves, Cinderella and Alice in Wonderland [11].

Computer technology was developed separately from cinema. The first device to motion capture was developed by professor Tom Calvert. He tied a prototype of the exoskeleton to elbows and knees of the human body in order to get information about joint movements and use them in medicine.

The game and film industry quickly picked up on this tool and tried to implement it in their own field. Nintendo used motion capture to animate the Mario character in real time for commercials. The main breakthrough in motion capture was the release of the second part of the Lord of the Rings trilogy, where actor Peter Jackson played Gollum. The actor's movements, including facial expressions, were recorded using motion capture. It was the

Figure 1.14: Rotoscoping process [6]

very first time motion capture had ever been used in film production [12].

In order to achieve the maximum accuracy of the transmission of movements, the actors were filmed simultaneously on 120 cameras located around the perimeter of the set. The actors wore special suits, on which motion sensors were fixed. To capture the emotions of the actor, special head rig was developed with an additional wide-angle camera, which recorded the changes of each face muscle. No matter if the actor spoke, ran, fell or shouted, the cameras constantly recorded the facial performance locked off [12].

1.2.9 Optical motion capture systems

Optical system uses cameras that track markers located on the object and reads the 3D position of each marker per frame. Each marker has to be seen by at least two cameras in order to be tracked by a tracking software. Optical systems require a large number of tracking cameras, which affects portability and cost. Examples of systems using optical technology:

- Vicon

Figure 1.15: Filming ”The Lord of the Rings” [8]

Figure 1.16: Filming ”Avatar” [14]

- OptiTrack
- PhaseSpace

1.2.9.1 Active Optical Systems

The optical tracker uses reflective markers, which are attached to the actor’s costume for tracking. The markers use LEDs with built-in processors and radio synchronization. Each LED has its own ID, which allows the system not to confuse markers, to recognize markers if they were covered by another object and then to reappear in the field of view [13]. The disadvantages of using active tracking are: there is no possibility of capturing the movement of facial expressions and the markers require electricity to operate, so they need to be charged after each use.

1.2.9.2 Passive Optical Systems

Passive tracking requires unique cluster placement of markers on each object. The cameras send an infrared beam to the scene, while the sensors located on the stage reflect the received beam directly onto the camera, so the camera can capture the position of the object [13]. Markers are mostly black or transparent. This tracking method is the most common.

Disadvantages of using passive tracking are:

1. The system may confuse markers because they do not have their unique ID
2. The system require specific hardware and software programs
3. It takes a long time to attach markers to an actor

1.2.10 Performance Capture

1.2.10.1 Inertial systems

Inertial systems use inertial measurement units (IMU). These are small sensors that can be hidden under the actor's clothes and be unnoticeable. Inside these devices are magnetometers, accelerometers and gyroscopes. The gyroscope measures the angular velocity and is used to determine the angle and rotation of the IMU. The magnetometer measures the magnetic field, and these calculations are used to determine the orientation of the sensor. The accelerometer detects acceleration and gravity [26].

The advantages of inertial systems:

- Quick setup time
- Possibility of using motion capture output data for 3D model
- Occlusion independence

The biggest disadvantage of an inertial system is that positions of joints can be tracked only after the calibration process. The reason is that the positions of joints have to be calculated based on the calibration process and root position estimation. However, the rotation data of joints is available immediately [26].

Examples of systems using IMU:

- Xsense
- Perception Neuron

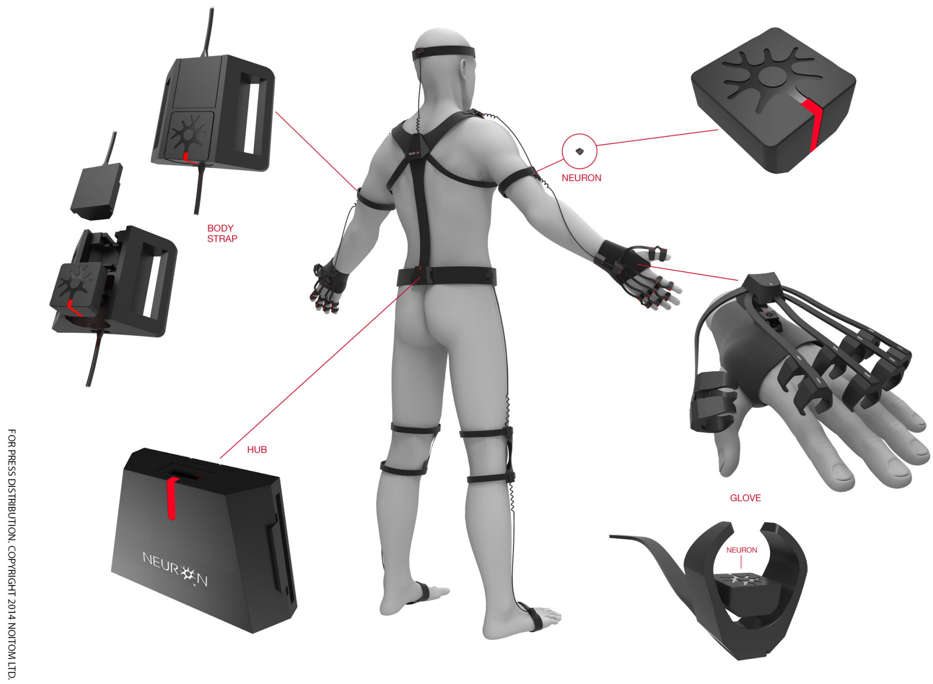

Figure 1.17: Components of the inertial system Neuron: HUB, Body Strap, Neuron, gloves [15]

- Rokoko
- Nansense

1.2.10.2 Magnetic systems

Magnetic systems are systems in which the markers are magnets, and the cameras are receivers. The system calculates their positions based on magnetic flux distortions [25].

Disadvantages of magnetic systems:

- Magnetic systems are susceptible to magnetic and electrical interference from metal objects and the environment (room wiring, office equipment, fittings in building slabs)
- Variable sensitivity of sensors depending on their position in the working area
- Smaller working area compared to optical systems
- Lack of ability to capture movements and facial expressions

1.2.10.3 Mechanical systems

Mechanical systems use a mechanic suit (exo-skeletal) for measuring position and rotation of captured subject joints. These systems are real-time and free of occlusion, magnetic or electrical interferences [25].

Figure 1.18: Mechanical motion capture suit [35]

Mechanical systems have several disadvantages:

- Inability to capture facial expressions
- Inability to capture interaction of two or more actors
- Mechanic suit limits the movement of an actor

1.2.10.4 3D Face And Body Scanner

Scanning of a person with 120 cameras CANON 250D, five cameras Canon 5D MarkIV and 4 light generators Hensel makes possible to get a professional and maximally humanoid character model. After simultaneous shooting with all cameras, in a few seconds it is already possible to track the resulting materials, each frame can be viewed in the best resolution. Further, the process of joining all photos and automatic creation of a model takes about 3.5 hours for each pose, which can be absolutely any, depending on the size of the studio in which the shooting takes place [19].

Figure 1.19: Manikin scanning process [19]

1.3 Virtual studios in Prague

I visited studios that use virtual reality technology in practice in Prague. Every virtual studio I visited has a different purpose. Some focus on virtual events, such as entertaining shows and games, other on online conferences with hundreds of participants and presentations of the latest developments in various fields like automotive industry, medicine, military equipment. Some studios focus on production of live broadcasts - weather, news and sports. Each purpose requires its own technical equipment.

For a long time, green screen has been used for weather forecasts. The anchor person could see on a screen in front of him/her what is displayed to the viewer and simultaneously broadcast news.

1.3.1 TV Nova

In 2014, TV Nova stopped using green screen and switched to Kinect technology, which allows the anchor to control the weather forecast graphics only with gestures and movements.

The main advantage of this technology is that the graphics are right in front of the anchor, not behind him/her. Therefore, there are only two layers: the first is the anchor and the physical studio, and the other is infographic, which is located in front of the anchor person. One of the technical issues is sound delay, which is about 10-15 ms.

In order to fix this, the video has to be manually delayed during the shooting. The length of delay is not constant; it may change so it is necessary

Figure 1.20: Shooting of weather broadcast [33]

to measure it again every six months to ensure a better performance. First,

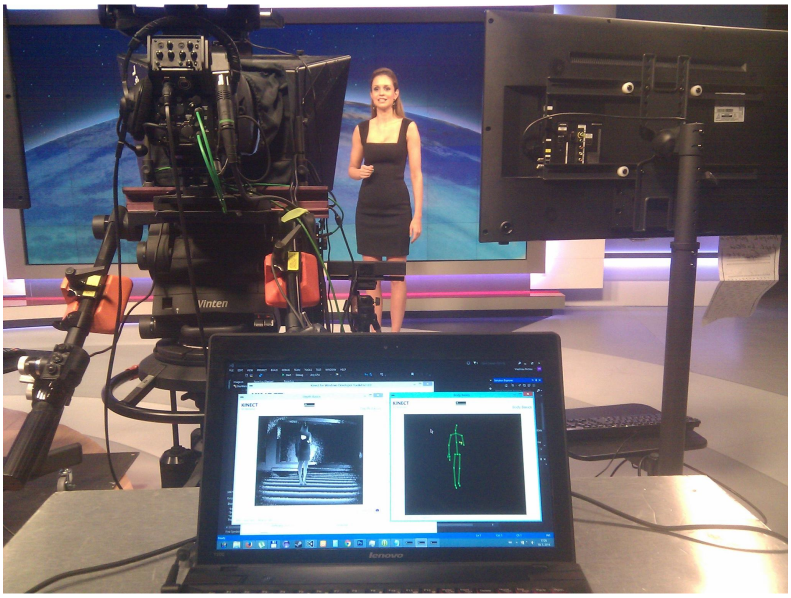

Figure 1.21: KINECT calibration process [34]

the calibration of the anchor person is done. The person stands in front of sensor in a T-pose and KINECT software measures a skeleton, which is a virtual representation of the anchor person. Calibration is carried out right on the spot in front of KINECT. These measurements allow the software to accurately detect the anchor's movements and for the anchor to control 3D graphics on the screen. So, when the anchor talks about a specific geographic object, he/she can easily highlight the area, which he/she talks about, and move it or scale it. As a result, the news anchor can control the 3D graphic elements on the map himself without having to touch anything.

Another technology the studio uses for motion tracking is nCam. For camera calibration, it is necessary to pick a point where the camera is constantly located. If the camera changes position, the system need to be calibrated again. NCam in TV Nova faces the light park, the light in the studio is adjusted based on the task, not on the requirements of nCam.

Then the software fixates on a light model and then guides the entire shooting. If the light turns off, saturation or anything else may change. In that case, the system must be recalibrated. The camera can be rotated in any direction. It can also zoom in on the scene, but it always needs to stay in one place. The data from the camera is transferred to the vizArt engine, which TV Nova uses.

1.3.2 Virtuplex

The next studio I visited was Virtuplex. This studio has the largest area out of all the studios I visited - about 300m2. It uses its own developed Virtuplex OS platform as engine. The studio gives an option to present various products, from cars to projects of premises of branches of various companies.

Figure 1.22: VR conference in Virtuplex studio [36]

The virtual presentation of the product for sale is more convenient for the buyer as the potential buyer can see the details of the product, rotate the model and change the size for better clarity. The virtually presented product doesn't need to be transported. During the viewing of the internal spaces, viewers can walk around the entire branch.

1.3.3 Czech Television

Virtual studio technology was used on the Czech Television (CT) for the first time in 1998. Back then, The Czech Television used an ORAD RTSet software and static cameras that were able to zoom and focus only. Since 2010, the Czech Television used Vizart software for Virtual Studio workflow. Vinten

Figure 1.23: Studio in Czech Television

tripods and a Shotoku Broadcast system are also a part of Virtual Studio on

CT. Vinten allows its users to localize cameras in space. No matter where the real camera is located, the game engine always shows the scene in the right perspective accordingly to the camera. Shotoku tracking systems does not have the camera localization function, however, the Shotoku system has a built-in sensor for tracking. The shotoku system can be controlled either manually or remotely. Back then, the entire scene was rendered on one computer station in the Onyx software, but rarely synchronization crashed. Almost a third of the setting time only took to do the optimization, so the broadcast could run 50-60fps. Now CT has four cameras and for each camera there is its own render engine. Three cameras are located on Vinten tripods and one camera is located on Shotoku. CT broadcasts in HD and in 4k resolutions. During the past several years, the Virtual Studio started to be used not only for real studio simulation, but also for showing different scenes and animations. A prime example of using VS is the Assassination of Reinhard Heydrich, which aired on CT on 24.5.2019. Participants of the shooting were in an animated 3D virtual space, where the location and the storyline of the assassination was displayed.

Figure 1.24: The screenshot from the ”Assassination of Reinhard Heydrich” [38]

Chapter 2

Realization

2.1 Dance performance

The main objective of my practical part of the thesis is to create a video by using virtual production technology. I decided to create a dance video so I can show the wide possibilities of virtual production.

2.1.1 Creating a performance scenario

The dance performance takes place on the scene of my choice on the static beach with a dynamic graphic element - water. Because the beach scene is not a common place for a classic dance performance, I chose a samba performance for my video. There are three layers in the final video. The first layer is a foreground with the 3D animated model, the second layer is a real-time shooting of me and the third layer is a background with the scene and one more animated 3D model. Each of the three dancers performs a different choreography but dances the same style.

2.1.2 Technical aspects

There is a certain equipment that is required for shooting videos by using Virtual Production technology. In order to create a 3D model, I picked a 3D scanner technology that allows me to receive a human-like 3D model of myself without manual 3D modeling. After editing the 3D model in a software Blender, I was able to animate this 3D model. For capturing dance movements and animating my 3D model I picked an Inertial motion capture system called Neuron Perception. I picked Unreal Engine for generating virtual background and foreground. Real-time shooting is shot on both LED and green screens. It is also necessary to have additional lighting. In case of LED screen, additional lighting is necessary so I am also illuminated from the ceiling. In case of Green Screen, additional lighting is necessary to key an object correctly. I picked the Vicon tracking system to track a real camera and to transmit external parameters of the camera via FreeD protocol to Unreal Engine. When shooting without Vicon tracking, I used a AW-UE150 Series PTZ camera [4] that allows me to transmit external parameters of the real camera to the game engine without other tracking systems.

2.2 Virtual Dance Character

I decided to use the 3D scanning technique instead of manual 3D modeling for creating a 3D model that would look like me as much as possible.

2.2.1 3D scan

I visited the studio 3D Body and Face scanner, where 125 cameras took pictures from different angles simultaneously. After processing the 3D scan in the programs Reality Capture and Pixologic zBrush [19], which took about 3 hours, I received a 3D model in the format ".obj". I also received the texture of my clothes, skin and hair in ".jpg" format.

Figure 2.1: 3D Scan Shooting Process

2.2.2 3D model clean up

The next stage in the practical part of the thesis was to edit the 3D scan to use it in the Unreal Engine. For this task, I used the Blender program.

Initially, the 3D scan had noise (separate vertices in the space around the model), 1.600.000 faces and the surface under the feet of the 3D model. First, it was necessary to get rid of the surface because 3D model animation required the legs to be free, not attached to anything.

Figure 2.2: 3D model processing in Blender software [41]

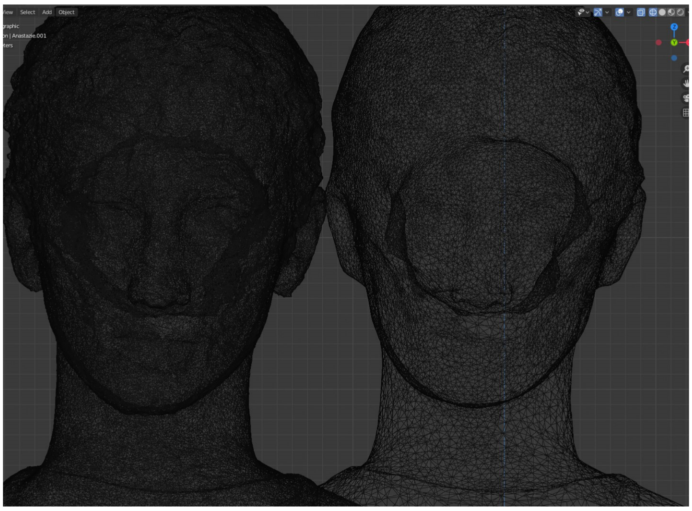

Figure 2.3: Ware-frame 3D model processing in Blender software [41]

After removing separate vertices and cleaning up the 3D model, I separated the feet from the surface and reduced numbers of polygons. For convenient removal of vertices, I used the key C in Blender, which allows its user to choose required vertices using rounded grabbing, as well as control the size of grabbing.

Modifier Decimate is a useful tool for reducing numbers of polygons. I used this modifier with ratio 0.3. This modifier connects small polygons and combines them into bigger polygons. The Decimate modifier allows its users to improve the appearance of the 3D scan. After applying the Decimate modifier, the surface of the model becomes smoother and model noise decreases.

The next step is editing the 3D model using the Brush tool in Blender. To create an effect of smooth skin and straighten clothes without noise created by 3D scan, I used Smooth Brush. I used Crease Brush to highlight clothes creases and face contours.

After all these steps I cleaned up the separate polygons one more time and filled holes, which were created during the editing. The stage of the editing model is done and the next step is animating.

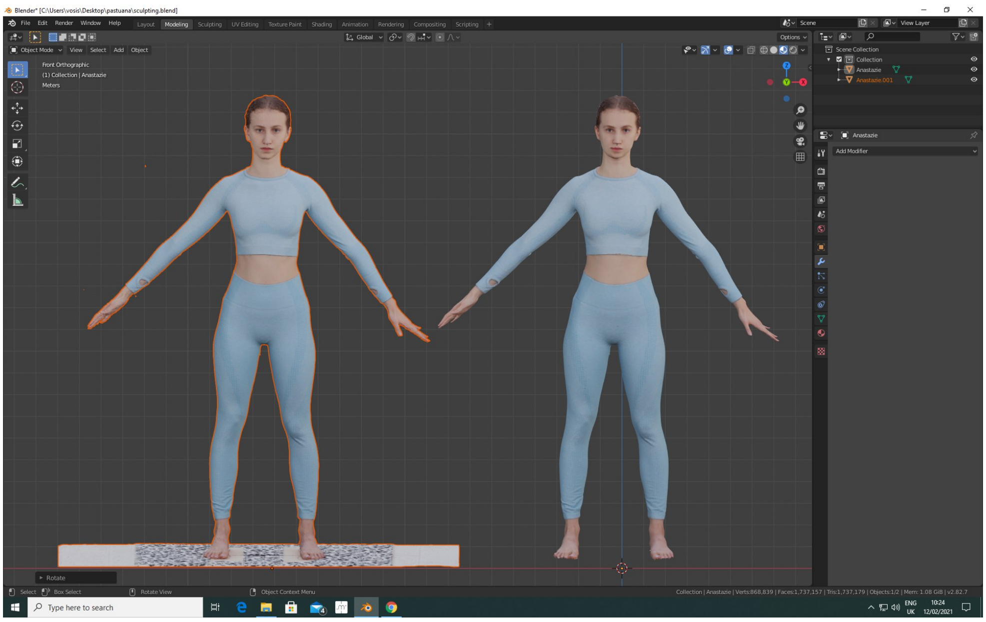

Figure 2.4: Processing result [41]

2.2.3 Motion capture processing

I use the Perception Neuron motion capture tool for animation recording. The Neuron is the Inertial Measurement Unit motion capture system, which allows its user to capture movements in real-time. Neuron has 15 sensors, which are located on the tracked subject. The Neuron set has special rubber bands for attaching the sensors to a body. Six sensors are placed on feet, six on arms, two on a back, two on shoulders and one on a head. Each specific sensor has its own defined place on a body.

After placing the sensors on the right position on a body, the calibration can start. During the calibration process the tracked subject has to stay in front of the Studio Transceiver, a calibration tool, and take certain poses: T-pose, A-pose, A-pose with arms raised and fingers touching. After the calibration, the user can immediately see the result of capture in an Axis Studio, a software for motion capture.The data stream is transmitted in three different ways: via WIFI, via USB or recorded on board using the built-in micro-SD.

By using this system, I capture several minutes of dance choreography. Next stage of my practical part is applying captured choreography to the 3D model.

Figure 2.5: Motion capture processing with Neuron Perception Technology

2.2.4 Animation of character

To create and assign a skeleton to the 3D model I used plugin called Rigify to ue4 by Unreal Engine and Blender. This plugin allows its user to have access to Rigify control of the 3D character. The first step of assigning a rigidified skeleton is to select a source of 3D model, which is a static skeleton of my character. Then, I need to select a template and to create a new template for my own animation. The rigify rig is automatically a human with facial bones, but the user can select any other character from the template, if wanted. In my case, it is Basic Human without facial bones, only with rig body. Then, I name that template and save it. By clicking Convert button, the rigify rig converts into the control rig, but does not work yet. The reason for it is that I have not set my control rig (metarig) properly yet. For setting up metarig of character I switch to Edit metarig section and connect automatically created bones to bones of my 3D character.

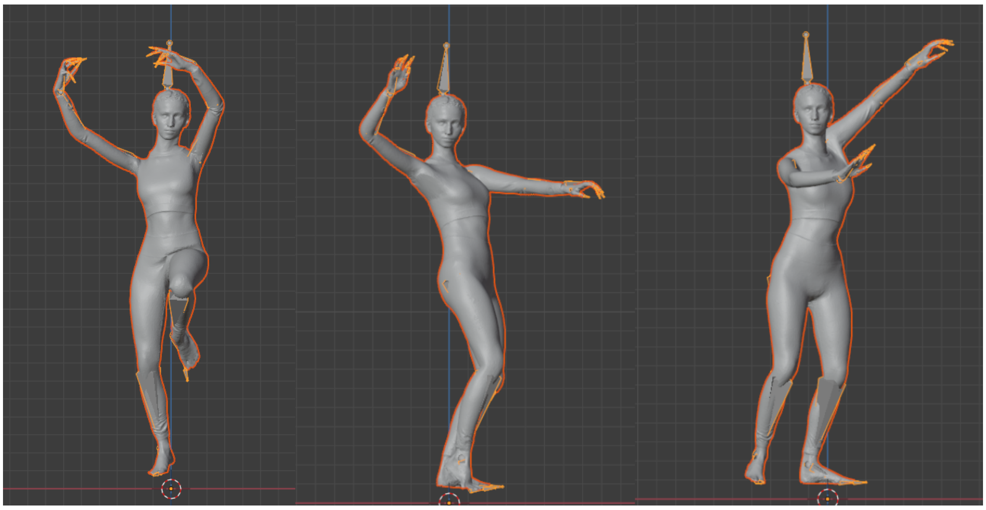

Figure 2.6: Animation of 3D character in Blender software [41]

By clicking and matching individual points with individual joints, I connect all the bones. The next step of setting up metarig is linking bones. For this task, I switch over to FK to source mode. By clicking at matching joints and using keyboard shortcuts Alt + 1, I link all bones in the body. The final step of riging is switching to Source to Deform mode and linking match Source to joints to get control of moving of the body. After these steps, I check the boxes on Overwrite animation and then my rigify rig moves with my source rig animation.

By the end of this stage, I have created a virtual 3D model of myself, made by 3D scanning technology, and several animations of my 3D model, created by using motion capture technology. These are a base for the background and foreground.

2.3 Virtual Production Image Generator

2.3.1 Game engines

Game engines are a software for optimization of the development of video games. There are many game engines and the most popular ones are Unreal Engine, Unity, CryEngine and Unigine.

Unigine is used in teams as well as individually. Unigine provides three SDK versions for different tasks. Sim SDK is used for creating simulations. Engineering SDK is used to develop engineering equipment. Community SDK version is used among individual game developers. If the revenue from projects does not exceed $100K, Unigine is for free, otherwise it is $150 per month [45].

Unity allows its users to create projects in a variety of fields, such as games, cinematography, automotive, architectural design and construction, gambling, and more.If the game revenue is above $100K, unity if free, otherwise price is $390 per year [43].

CryEngine is a game engine created by the German private company Crytek in 2002 used in the first-person shooter Far Cry. CryEngine costs $9.9 per month [44].

The full version of Unreal Engine 4 is free if the game revenue is less than $12k per year, otherwise 5% of users game revenue is charged [42].

2.3.1.1 Unreal Engine

Unreal Engine 4 is a set of game development tools that has a wide range of capabilities, from creating 2D games for mobile to AAA projects for consoles. This engine is one of the most popular and most demanded on the market.Unreal Engine has a user-friendly interface that allows its users to quickly produce working prototypes [42].

Unreal Engine 4 uses the C ++ programming language but the engine also uses Blue Prints, a visual scripting system that allows its users to create functions by using nodes without writing a code. I picked the Unreal Engine because I think it is the best choice for working with 3D graphics, virtual production and it is for free [42].

Unreal Engine allows its users to combine tracking object with virtual background by using nDisplay plugin, as well as to show its scene simultaneously on the several LED screens in sync.

2.3.2 Virtual Production with LED screen

The shooting on the LED screen took place in the AV MEDIA SYSTEMS studio. This studio has a curved 15-meters-wide x 3-meters-high LED screen.

This screen contains eight blocks: two main blocks; first 5-meters-wide and 3-meters-high; second 7-meters-wide and 3-meters-high; and six identical 0.5-meters-wide and 3-meters-high screens

It is necessary to correctly set configuration in the NVIDIA panel in order for LED screen and main computer screen to work properly. The first screen in NVIDIA configuration is the main computer screen and the second is the entire LED screen. LED screen is connected to my computer through two cables HDMI and Borco E2 video processor.

2.3.2.1 nDisplay Technology

In the practical part of my thesis, I use the nDisplay plugin to show my scene simultaneously on the several LED screens in sync and to track real-camera. I work with eight separate parts of the main LED screen. To determine a correct start position in the virtual world, I measured the distance from each part of the main screen to the starting point in the real world.

Figure 2.7: LED semi-curved screen (switched off)

Also, I measured height and weight of each part of the main screen. There is a configuration file in the nDIsplay plugin for configuring multiple screens. This file includes the definition of all computers connected to the network, screen characteristics, viewports that will be rendered on each computer, projection configuration, camera configuration and tracking input [29].

Figure 2.8: LED semi-curved screen back-side - LED segments

The plugin allows viewing the simulation of the configuration file. This function is necessary for checking the correct position of the screens in the scene and for editing the position of the root point of the screens.

Figure 2.9: nDisplay screens preview

In order to launch a project on LED screen through the main computer, it is necessary to launch the nDisplay Launcher and nDisplay Listener. These are applications for launching and controlling one or several instances of a project running on one or more computers. In order to start, the user has to add the path of the project and of the configuration file, then run it.

2.3.2.2 Camera Tracking by Vicon system on LED screen

In order to track a camera and to transmit external parameters of the camera to a game engine, I used the Vicon system. I attached several tracking markers, which are being tracked by Vicon cameras, to the real camera. Four Vicom cameras were set on the ceiling so they can track the entire shooting space. Camera calibration was done by a special equipment called Active Wand. For the calibration process, it is necessary to move the calibration tool across the shooting space so the Vicon cameras can fixate the position of the tracking markers that are placed on the calibration tool. After the calibration, I placed the camera in the middle of the shooting set and checked whether Vicon cameras can correctly track the position of the set camera. I named the tracked object in the Vicon tracking software called Vicon Tracker. Then, I added information about the name of the tracking camera and IP address of the computer, where the tracking system is installed, to the configuration file of nDisplay plugin

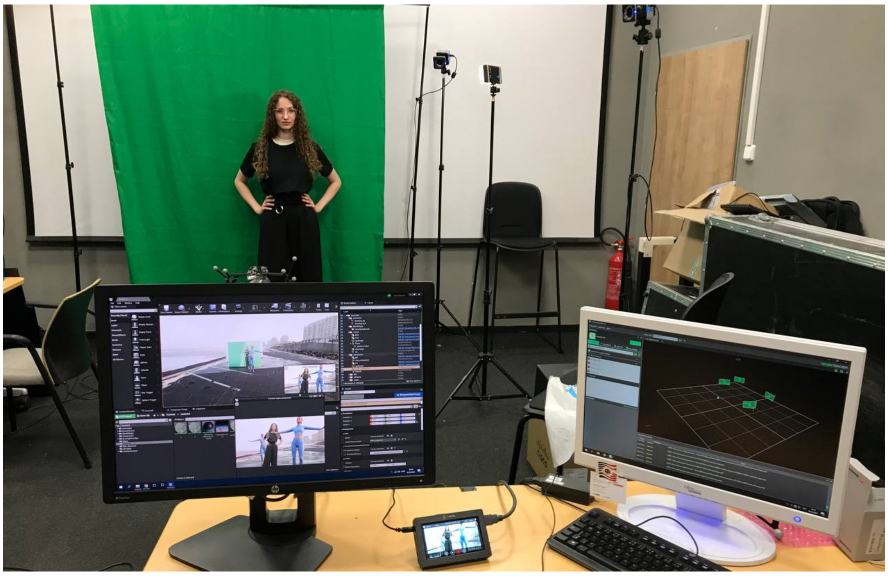

Figure 2.10: Shooting process on green screen with Vicon tracking

2.3.3 Virtual Production with Green Screen

I made two dance performance videos on a green screen. The first video was made with a tracking camera by Vicon tracking system and the second video was made with a tracking camera using PTZ camera.

Figure 2.11: Camera with attached markers

In the making of the first video, I used a Vicon tracking system to track free camera in space. I attached reflective markers to my real camera so the Vicon Tracker can track the real camera and transmit data to the game Engine. In order to track the camera in Unreal Engine, I had to connect Vicon Tracker to the virtual camera by using Live link plugin. This plugin allows me to provide an interface for streaming and consuming animation data from external sources into Unreal Engine [42]. In order to create a new Source of streaming data, I wrote a code in Blueprints form for connecting the virtual camera to data from the Vicon Tracker. I created a node called “Create Vicon LiveLink Source” and added Server Name and Port Number. Then, I created a node “Print String” to see the information about connection with Vicon Tracker. I run the data receiving process and after the entire process of using these datas I need to remove Vicon source to avoid a source duplication in next launch. I created a node called “Remove Source” and “Event End Play” for deleting source after using 2.12.

In the making of the second video, I used Panasonic AW-UE150 Series PTZ camera [4], which transmits external parameters of the real camera to

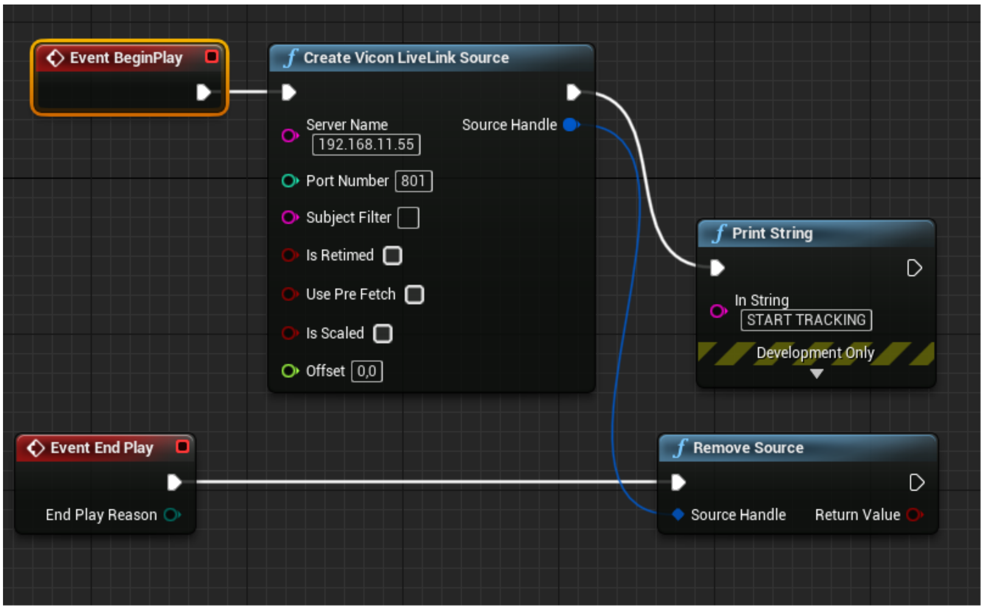

Figure 2.12: Vicon Tracker and virtual camera connection

the game engine. These parameters allow the engine to track the position, orientation and zoom of the real camera and change the position, orientation and zoom of the virtual camera accordingly.

2.3.3.1 FreeD Protocol

I use the Panasonic AW-UE Series PTZ Camera LiveLink Plugin for Unreal Engine plugin to transmit information about position and orientation via FreeD protocol from the camera to the Unreal Engine project. After connecting the camera to the main computer on the network, I edit the camera configuration file so the main computer can receive signals from the camera. It is necessary to determine the IP address of the main computer and port through which the camera and computer can communicate. By using the Live Link plugin, I connect the camera to my Unreal Engine project. Then, I add a Cinematic Camera to my Unreal Engine project and connect the virtual and real PTZ camera via Live Link. When I move or zoom the camera using the control panel in PTZ Application, my virtual camera moves and zooms in the virtual environment too.

In order to find the source of the PTZ camera and to start receiving data from the camera, I write a Blueprints code. I create a "Find Network Source by Name" node and add the name of the PTZ camera "AW-UE100 (NDI_Device-J0TRA0063)", which I received from NDI Studio Monitor software. Then I add a condition node called "Branch" that allows me to create two "Print

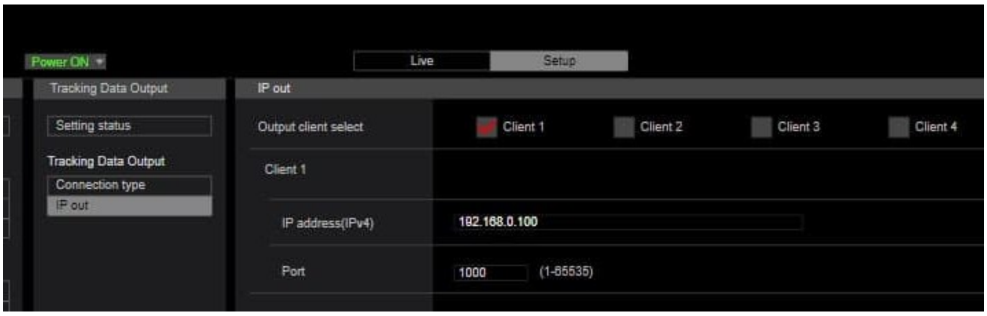

Figure 2.13: PTZ camera connection setup

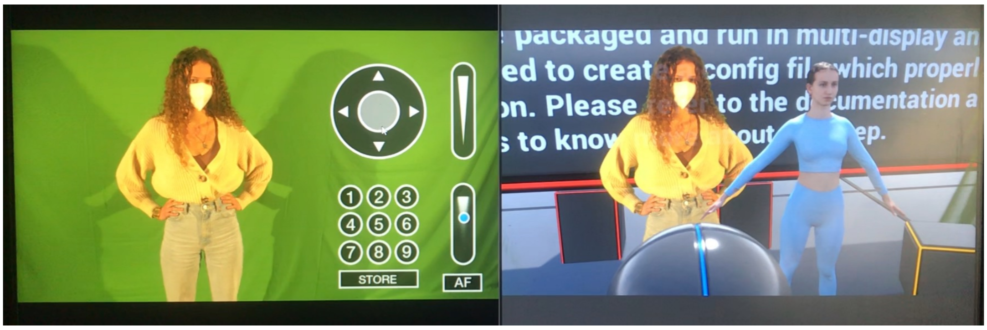

Figure 2.14: PTZ camera connected to the virtual camera

String" nodes. These nodes inform me in two cases: if the camera is connected and if the camera can not be found. In case of successful connection, the next node "Start Receiver" launches. This node allows me to receive images from the PTZ camera to the Unreal Engine 2.15.

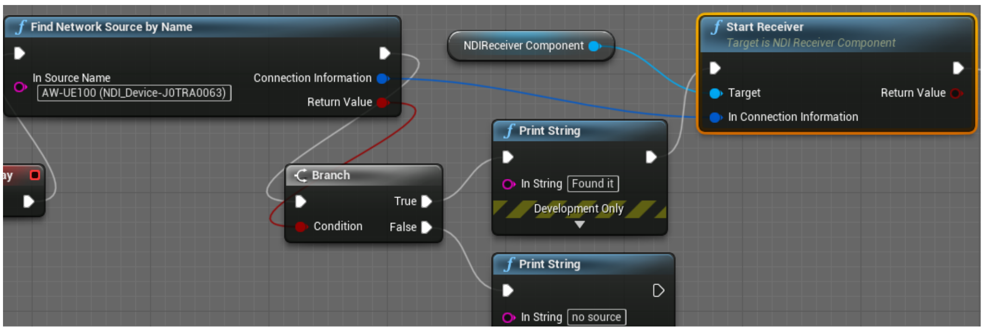

Figure 2.15: NDI connection code

2.3.3.2 Multi-layer Merging

In order to combine all the layers into the final video, I use the plugin Composure, which allows me to combine several layers at the same time.

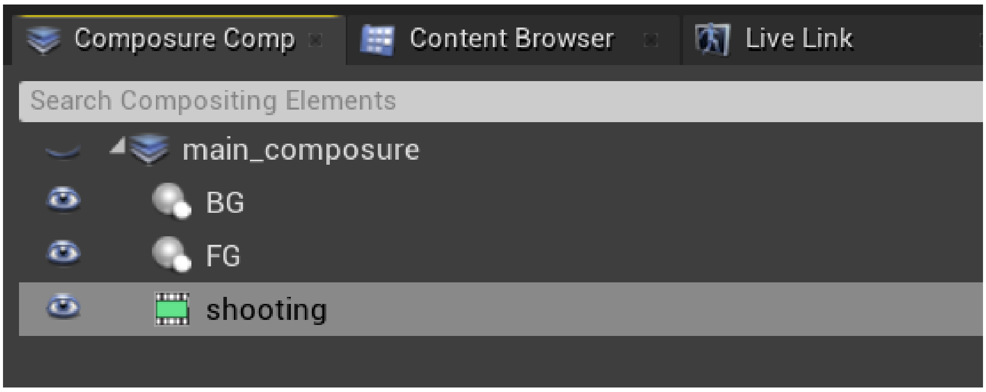

Figure 2.16: Composure structure

In my case, the first layer is a virtual scene with a 3D model, the second layer is a real character, which is filmed in real time and the third layer is a foreground which is the CG element. In order to combine several layers into

Figure 2.17: Composure processing in real-time on LED screen

one, I used a composure material that allowed me to combine several layers correctly. The foreground node (FG) is the first layer of my composition. The shooting node is shooting layer is the real-time shooting on a green screen.

The Garbage node is a Garbage layer, which is a Plane Mesh that limits my video footage, cutting out only the green screen part but not the extra space. The background node (BG) is the background layer of my composition 2.18.

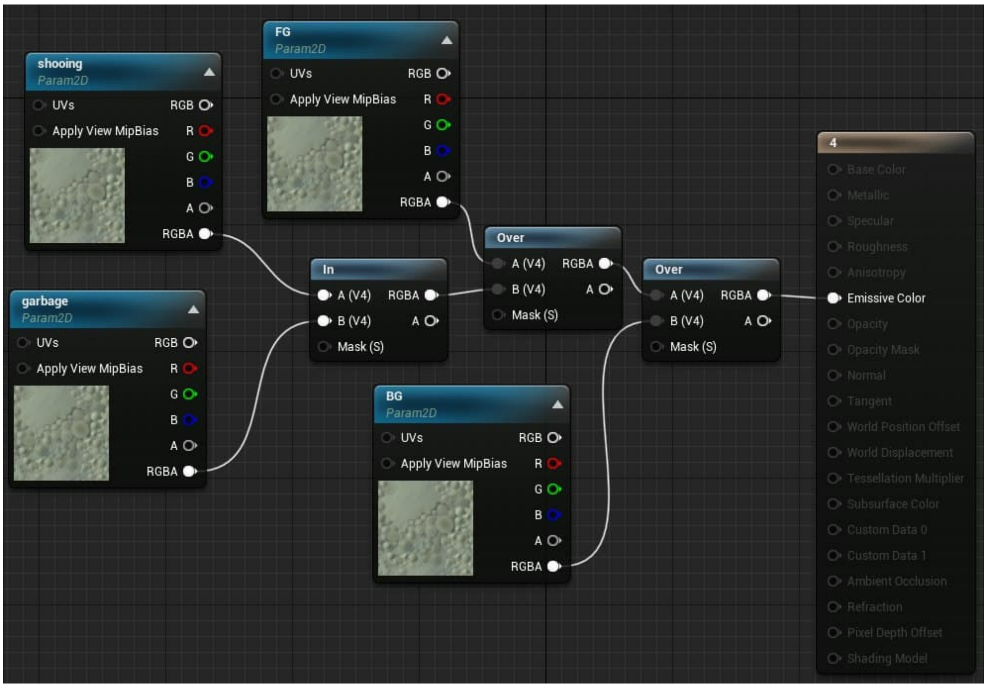

Figure 2.18: Composure material

Chapter 3

Conclusion

Visiting the studios gave me a general overview of Virtual Reality workflow. In the practical part of my thesis I used the tools of Virtual Production for dance performance simulation. Virtual dancers, who were created by using 3D scanning and animated through motion capture technology, are part of the dance performance. Unreal Engine is the main technology used to create the performance. I shot several short videos of dance performance on LED and green screens in the AV MEDIA SYSTEMS and Xlab studios.

Creating even a 30 sec video dance performance on a LED screen is complicated, time consuming and costly. It is necessary to find a studio that has a LED screen, to book a time there and pay for the shooting. LED screens re-

Figure 3.1: Shooting on LED screen

quire a powerful PC and graphic cards. Despite the difficulties, using Virtual

Production technology on LED screen is, in my opinion, the most modern and practical way to filming.

Big advantages of LED screens are that the participant of the shooting can immediately see the surrounding VR environment and there is no need for additional lighting, since the screens already illuminate the participant correctly.

During the shooting, odd stripes and irregular ripples appeared on the LED display, which is called Moire effect [48]. This effect creates distorted perception, but it can be resolved in post-production with a special software, for example, Photoshop.

Figure 3.2: Moire Effect in the camera

In my opinion, the majority of studios that are using VP now is not going to switch to LED technology but is going to keep using green screen technology because it is cheaper and still sufficient.

I used additional lighting when I was shooting on green screen. The lighting is necessary for correct object keying. It was also necessary to pick a color of the clothes so it does not blend in with the green screen. During the shooting I was wearing blue clothes and green reflections from the green screen were visible. This sort of reflection could be avoided by using the correct lighting.

Video frames with external real objects are visible during the final shooting on green screen. The reason is that I have a 2-meters-wide green screen, which is very narrow for shooting. In case of incorrect camera angles, not only is the green screen visible, but so are the external objects outside the green screen.

Figure 3.3: Foreign real objects on the video

It took me two month to create the practical part of my thesis. During this time, I discovered wide possibilities of Virtual Production. Technology of Virtual Production is already used in many industries, from broadcasting to shooting movies such as the Mandalorian. Virtual Production is a suitable tool for a a dance performance, but it requires a thorough preparation, which is described in the thesis. Thanks to Virtual Production, it is possible to create big projects even in small spaces. I believe that technology of virtual production will be useful in the future not only in film production, but also in many other areas, such as education, medicine, military and many others.

Chapter 4

Contents of enclosed CD

- Readme.txt .... the file with CD contents description
- Final Videos .... the directory of the final videos
- Thesis .... the directory of the thesis sources
  - Images .... the directory of thesis images
  - Videos .... the directory of thesis videos
- Unreal Engine Project ...... the directory of the Unreal Engine Project
- Thesis Latex .... the directory of LaTeX thesis source codes

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