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MODIFICATION AND PERSONALIZATION OF A 3D SCANNED MODEL

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MODIFIKACIJA I PERSONALIZACIJA 3D SKENIRANOG MODELA

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ABSTRACT

3D scanning is a technology that analyzes real object or environment and collects data about shape and eventual appearance of the scanned field. Gathered data can then be used for constructing a 3D model, and its wide field of application. 3D scanning is a new technology that saves time and makes production process easier in many fields, from design to production. The wide application of 3D scanning makes this topic appealing, because among a lot of advantages of this technology, there are some shortcomings and unexplored possibilities. 3D scanning has greatly developed in the last decade, that development is ongoing and leaves a lot of space for exploring. Along with 3D scanning, other 3D technologies are developing rapidly and reverse engineering is gaining ground. Combining 3D applications such as 3D scanning, 3D modeling and production (e.g. 3D printing) is becoming an everyday thing.

Focus of this diploma thesis is ultimate personalization of scanned 3D model, modifying it according to human face. In this case, the object is frame for glasses that is entirely adjusted to the previously scanned face. Optical optimal measurements are also taken into consideration for producing a functional frame. Also, this kind of a model can be subdued to different modifications on the field of design in PowerSHAPE CAD software. As a final result, a prototype of new, personalized model of glasses frame is produced.

Key words: 3D scanning, 3D modeling, 3D printing

SAŽETAK

3D skeniranje je tehnologija koja analizira stvarni objekt ili okolinu i prikuplja podatke o obliku i eventualno izgledu skeniranog polja. Prikupljeni podatci se zatim mogu koristiti za konstruiranje trodimenzionalnog modela, te njegovu široku primjenu. 3D skeniranje je novija tehnologija koja štedi vrijeme i olakšava proizvodni proces na mnogo područja, od dizajna do produkcije. Upravo široka primjena 3D skeniranja (3d modeli, grafički dizajn, video igre, vizualni efekti, vizualizacija, virtualna stvarnost, virtualna kinematografija, industrijski dizajn, reverzibilno inžinjerstvo, proizvodnja, itd.) čini ovu temu privlačnom, jer osim mnogobrojnih prednosti ove tehnologije, postoji i dosta nedostataka i neistraženih mogućnosti. 3D skeniranje se značajno razvilo u posljednjem desetljeću, a taj razvoj se nastavlja i dalje te ostavlja dosta prostora za istraživanje.

Fokus ovog diplomskog rada je ultimativna personalizacija skeniranog 3D modela, modificirajući ga prema ljudskom licu. U ovom slučaju radi se o okviru za naočale, koji se u potpunosti prilagođava prethodno skeniranom ljudskom licu. Pritom su uzete u obzir optički optimalne mjere za izradu funkcionalnog okvira. Također, takav model može podleći raznim modifikacijama u polju dizajna. Kao konačan rezultat dobiva se prototip novog, personaliziranog modela okvira za naočale.

Ključne riječi: 3D skeniranje, 3D modeliranje, 3D printanje

CONTENTS

1. INTRODUCTION

3D scanning is a way of creating digital models of real, physical objects surrounding us every day. Soon enough, a number of industries found a need for 3D scanning, such architecture, medicine, landscaping, graphic design, industrial design, video games, visual effects, and use it for various applications such as visualization, virtual reality, virtual cinematography, reverse engineering, production etc. This evolving technology allows capturing indoor and outdoor objects, or whole landscapes during day or night.

3D scanning is just a tool for obtaining a 3D model that can be put to further use, and be modified in different CAD (Computer Aided Design) software's. From inspection and measuring it can find its way to CAM (Computer Aided Manufacture) software and finally, create a finished product of copied or improved original scanned object from the beginning.

The main goal of this work was to explore lifecycle of such product, from existing object to reproduced product. At the beginning it was supposed to be an emphasis only on 3D scanning-it's advantages and disadvantages, but it developed to final application of scanned model for further modification and manufacturing.

2. SELECTION OF OBJECT FOR SCANNING

As the idea was to make a 3D scan of an object, modify it in applicable software and creating a prototype of altered model, the focus was on creating an object useful in everyday life. This object was chosen to be frame for spectacles. It is an everyday object that can cause a lot of discomfort for users if it’s not made properly. This discomfort may be caused because of several reasons such as differently positioned ears (both in height and distance from nose in horizontal axes), difference in eyes position, uneven nose sides, etc. This frame will fit perfectly to one individual, as this person will make a head scan. This head scan will help, combined with scan of original frame, in producing a „perfect-fit” frame for one person. It will take into consideration all facial features, applying rules about facial division, as well as optimal dimension set for frame design.

Therefore, two “objects” are scanned: a human face and randomly chosen sunglasses from a local supermarket that everyone has access to.

3. OBJECT ACQUISITION

Object acquisition methods are continuously developing as they are being recognized by experts from various industries, hence gaining on importance. Methods differ from each other in a number of fields, all stressed out in this paper, but a general definition of optical measurement technology can be set as analysis of a physical object or environment for gaining data on its shape and possibly appearance in order to create a digital version of captured object/environment.

3.1. 3D scanners

A 3D object can be measured by a variety of technologies that will in the end acquire its digital version. Devices used for gaining 3D coordinates of a given region of an object surface are 3D scanners that collect data automatically and in a systematic pattern, at a high rate (hundreds or thousands of points per second), achieving the results in real time. [1]

The term “3D scanner” cannot be assigned to a single device, but to any device that measures the physical world using laser, lights or x-rays. These different devices can also go by different names including 3D digitizers, LiDAR (light detection and ranging), laser scanners, industrial CT, white light scanners etc. Each of them comes with its own advantages, limitations and costs.

A comparison of 3D scanners and cameras can be possible in terms of field of view (both use cone shaped field of view), or visibility of observed surface (objects cannot be obscured)., but when it comes to “creation” of picture- 3D scanner will collect and reproduce distances between surfaces at each point of observed area.

In this massive collection of available technologies, there is still a main classification of 3D scanners dividing them into two distinctive types: contact and non-contact 3D scanners.

3.2. Contact 3d scanners

As the name implies itself, contact 3D scanner obtains data through physical contact with the object. The object is placed on a precision flat surface plate or in such case where the object is not stable or flat and cannot stand by itself; it is then supported by a fixture. Because of the contact that occurs between scanner probe and the object, the object has to be ground and polished to a specific maximum of surface roughness. These scanners collect data using movable probes. Contact points between the probe and the object are generated as coordinates on the grid that will use as a guide for modeling. The position of the probe is supervised with a series of encoders that track movement of the measuring probe with accuracy described in nanometers (even microns with industrial sensors). The measuring probe is attached to an "arm" that can be *rigid* (figure 1) (in strictly perpendicular formation) or *articulated* (figure 2) with calculated wrist rotation and hinge angle of each joint; which makes it more versatile, but at the same time may cause less accurate data due to higher tendency to flex or lose calibration.

If needed, contact 3D scanners can be combined with non-contact technologies in order to obtain full surface data.

Figure 1: Contact scanner, rigid arm


Figure 2: Contact 3D scanner, articulated arm

3.3. Non-contact 3D scanners

Non-contact vision systems can further be classified as *passive* and *active.*
Similar optical components are present in both vision systems and therefore can relate to similar causes of errors, but the difference lays in ways how accuracy of both systems get affected.

3.3.1. Passive non-contact 3D scanners

In passive non-contact measurements image data is gained by one or multiple cameras, with no external light sources - they do not emit any kind od radiation themselves, but record solar or artificial radiation backscattered by objects in the camera's field of view. [2]

Techniques of measuring surroundings vary, but most common are multi-image photogrammetry, stereoscopic systems and silhouette analysis.

In photogrammetric systems, image is acquired using a single or multiple cameras from different angles. Corresponding coordinate points from different images are being matched by a sophisticated algorithm, in the end providing a dense 3D point cloud.

Another technique of passive vision system (Stereoscopic systems) can be compared to a human stereo vision: two sensors capturing the surroundings from slightly different position. This parallax makes perception of depth possible for each point. (Figure 3)

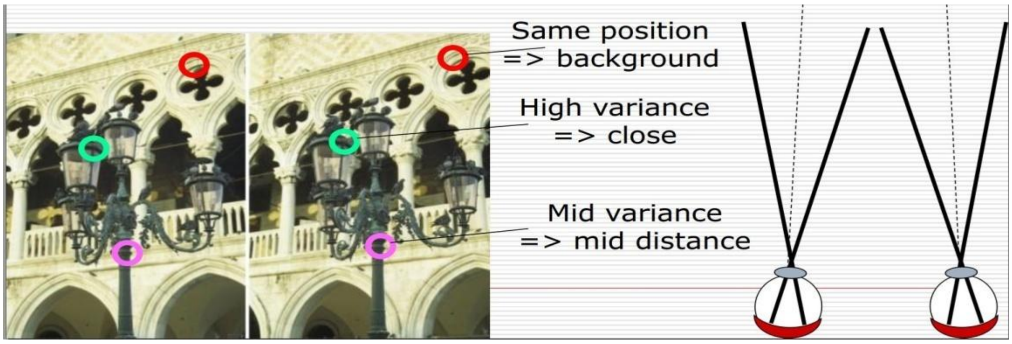

Figure 3: perception of depth obtained by paralax

Silhouette analysis is also based on a sequence of photographs from different directions, but in controlled conditions- the three dimensional object is positioned in front of a well contrasted background. Operating principle is obtaining a 3D volume *“visual hull”* by intersecting field of views from multiple cameras. Precision of gained visual hull is influenced by a number of cameras. For further use, scanned object has to be separated from the background. Another disadvantage of this technique is its inability to capture hidden areas such as openings in the object or surface. The company 4D View Solutions does it by capturing 8 photographs in order to obtain visual hull, extracting silhouettes and finally creating a 3D reconstruction (Figure 4). [2]

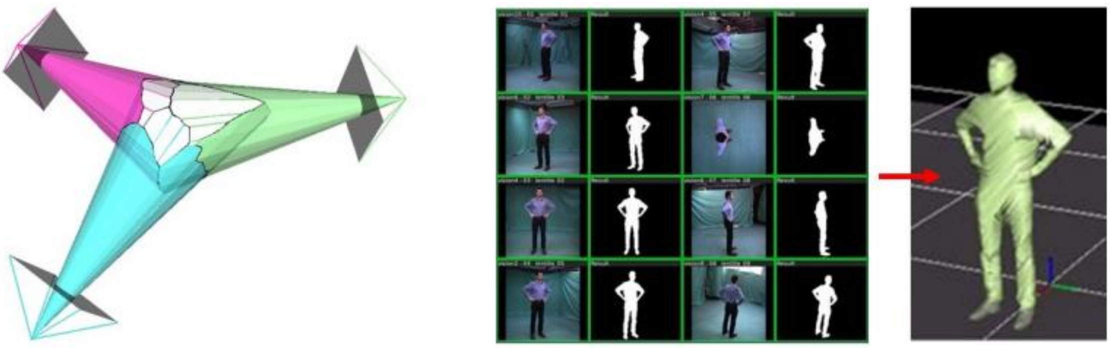

Figure 4: The Principle and an example of obtaining a visual hull

3.3.2. Active Non-contact 3D scanners

Basic active vision system contains an active light source, a detection unit and a data processing unit. The only difference between two main commercial types of scanners is in the way of obtaining data for determination of the actual object point coordinates: single spot of a laser beam or a unique surface phase map produced via phase shifting.

Used light sources can emit coherent light (laser beams), non-coherent structured light, or can be produced by plasma spot in the laser/plasma ablation process. They can also differ in number and shape of light spots: it can be either from a single point, line or a series of fringes. Selection of projection method can greatly influence the measurement speed, spatial resolution, accuracy and size of a single view measurement volume. Most common arrangement is a rectangular array of photodiodes used for recording spatial and temporal position of light spot on the object's surface. [3]

Data processing units are mostly microcomputers with ability to run both on-line and off-line analysis of measured data. When using on-line processing, latency in the time-dependent measurement techniques can occur, as well as a complete loss of gathered data. Most of known shortcomings can still be solved by proper software routines.

The following image demonstrates the principle of one or more static detection units that records projected coherent laser beam reflected off the object surface. On this particular example, the laser is based on principle of synchronized scanner (Figure 5) where laser and detector have synchronous motion.

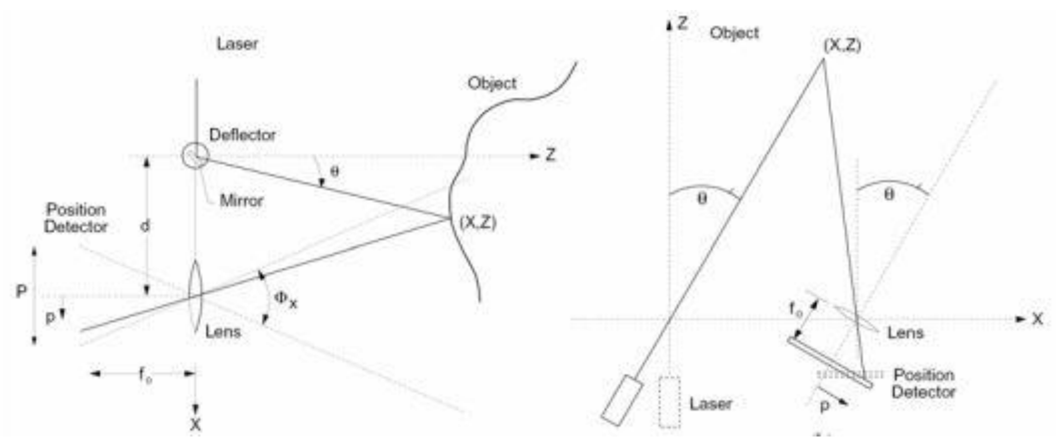

Figure 5: principle of synchronized scanner

Reflectance of projected beam, changes in the ambient light, sharp corners and edges, reflectance, sensor occlusions, speckle noise, sudden shape discontinuities and inaccurate location of the projected line/point center can all be a cause of error in accuracy of calculated object point. Illumination conditions usually vary in a great difference, so bright laser source as a monochromatic, focused light source is a logical solution. Disadvantage lays in speckle effect that occurs while projecting a spatially coherent light beam onto optically rough surface, which can effect point triangulation. Therefore, it is suggested to use a non-coherent fluorescent light source. [4]

Structured light source is also based on triangulation, but projects different patterns on the scanned object. This kind of illumination can be more precise, but requires additional hardware.

Another general division of laser scanners (Figure 6) is based on field of range caught by scanner. They are known as: scanners-cameras, panorama scanners and hybrid scanners.

Scanners-cameras have a restricted field of recording (eg.40°), capturing everything in this narrow field of view. Advantage of this scanners in their recording distance, they can scan from distances greater than 1000m.

Panorama scanners can record everything in their reach, excluding areas above the scanner itself. Horizontal rotation is 360°, while vertical is 310°. Even though they have a larger field of scanned area, their main disadvantage is a short recording distance. This kind of laser scanner gives best results in interior recording.

Hybrid scanners have a horizontal rotation of 360°, and vertical rotation of 60°. It contains a rotational prism or mirror, rotation around horizontal vertices. This type of scanners is mostly used nowadays.

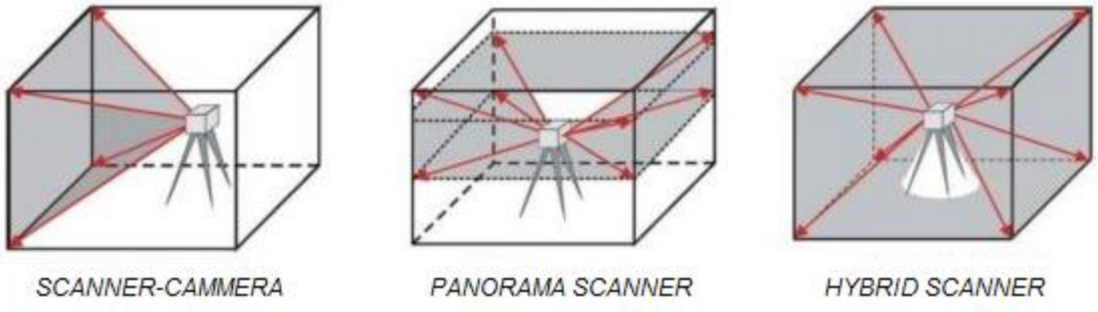

Figure 6: Types of laser scanners

4. 3D SCANNING METHODS

Previous chapter named types of scanners and mentioned in general how they work, while this chapter will explain main principles of 3D scanning on which are based mentioned scanners. For easier understanding, two separate diagrams are presented; one showing division of 3D scanners (Diagram 1), and the other one division of scanning methods (Diagram 2).

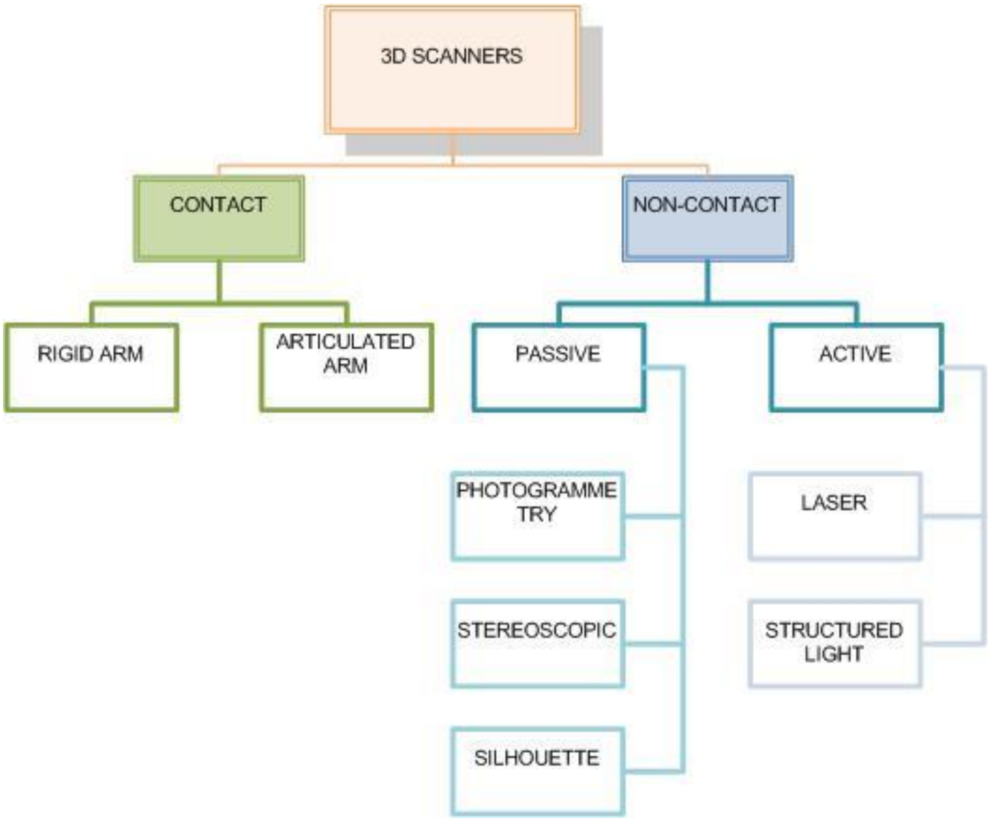

Diagram 1: Division of 3D scanners

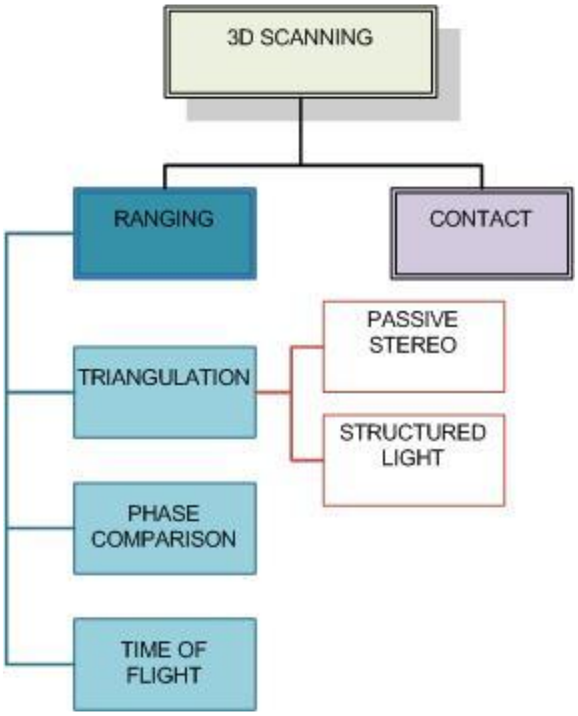

Diagram 2: Division of 3D scanning methods

Contact method doesn't need more explanation than what was given in previous chapter; those are hand-held scanners, time consuming and less accurate than ranging (non-contact) methods.

Ranging methods are further divided into time-of-flight, phase comparison and triangulation method.

Time of flight method can bluntly be described as emitting a pulse of light on given object (Figure 7), measuring time needed for a detector to capture the reflection and calculating the distance between transmitter and reflecting surface by using round-trip time and known speed of light.

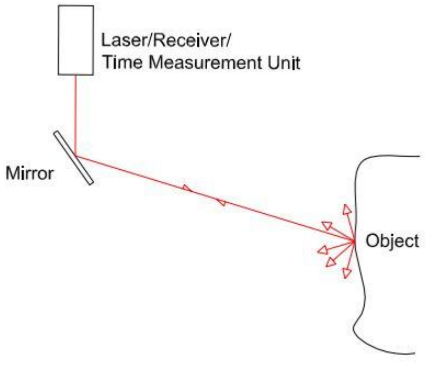

Figure 7: Time of flight method

Small rotating devices are used for angular deflection of the laser beam. Algorithms are used for computing the distance, which may produce standard deviations in matter of few millimeters. The accuracy of this measurement is nearly the same for the whole surface of the object, since ranges are relatively short. Angular pointing of the beam to the surface may also influence final presentation of the object. Influence of this phenomenon is still under investigation. [1]

Phase comparison method also computes the distance between scanner and the object, but emitting a beam modulated by a harmonic wave (amplitude modulation), therefore calculating the distance using the phase shift between transmitted and received wave. Results of signal analysis have a higher precision, but at the expense of the measuring rate. It is also restricted by a reduced range. [5]

Triangulation method transmits a light beam at a predefined angle onto the object, reflecting it to a detector on the other side of scanner (Figure 8). Position of the reflecting surface is computed from the resulting light beam triangle. Using trigonometric calculations, position of a single point on illuminated surface can easily be recovered. By having a predefined emission and reception angle, and knowing the distance between the emitter and receiver, the position of each point is calculated. Accuracy of the distance between the scanner and the object decreases with the square of this distance. These scanners are most suited for short distances and small objects where they show greater accuracy than other ranging scanners.

Other variations with multiple cameras are also possible. For example triangulation principle with two CCD cameras which detect reflected light (Figure 9). Also, projections of light may vary: moving light spot or line, moving stripe patterns, or a static arbitrary pattern.

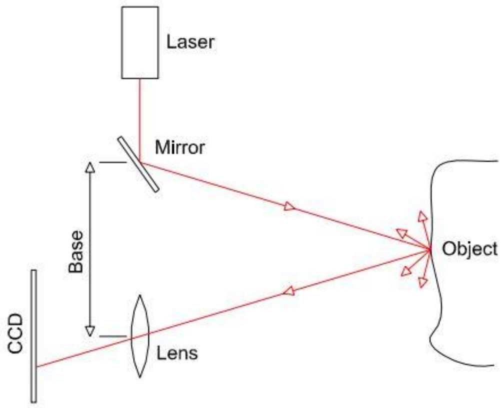

Figure 8: Triangulation principle

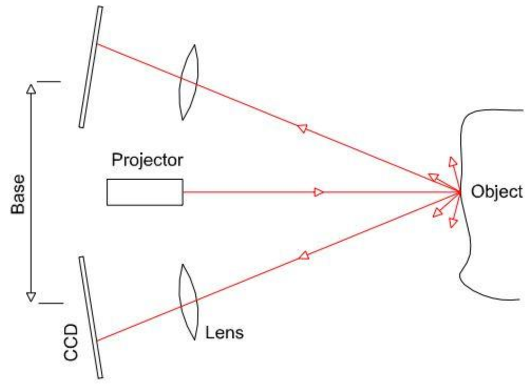

Figure 9: Triangulation principle with two CCD cameras

Passive stereo matching method compares recorded images from multiple cameras and matches features, creating one 3D model. This method has no need for active light/laser, but in order to match images-needs color features and sparse and noise samples.

Structured light method projects black and white patterns on the object in order to identify pixels. Light patterns are projected from an LCD projector or other stable light source. Projected light patterns are predefined, where each stripe has assigned unique light code. Patterns are projected several times over time and given color pattern identifies row/column giving the information about the position of a single pixel. [6]

The advantage of this method lays in speed and precision. Speed is gained by scanning multiple points or entire field of view at once, what gives profiles that are exponentially more precise than laser triangulation. Recording a greater surface also contributes to elimination of the distortion from motion. This method is still an active area of research.

5. FEATURES OF A SCANNED OBJECT

While scanning, it is important to take the object, or more precisely, surface of the object into consideration. The most important element in 3D scanning is reflection, which is under great influence of color and amount of reflection from surface. White surface will reflect greatly, while dark surfaces will reflect significantly less amount of light. Therefore, bright objects are used for scanning. In case that a dark object needs to be scanned, the surface of the object needs to be treated before scanning by covering it with powder or chalk. It is also important that the object is opaque – transparent objects like glass will reflect light refraction and give wrong data about shape of the surface. Also it is difficult to precisely scan non-solid surfaces like hair, fur, feathers, etc.

Another important condition for scanning is not to have an external bright light directed to sensor that could influence recording.

6. DIGITALIZATION

Creating a digital version of a physical object gives ability to store it in a database and have access to a digital model whenever it is needed. A model can be stored in such a way that it can be re-edited and give it a new purpose. Making a model digital opens a possibility o making it available for other researchers or general public. Creating a CAD model of real objects can help in capturing lost designs, update existing products and make new ones. Making a digital version of a physical object with 3D scanning technology gives results with high accuracy in color and geometry of an object.

Quality of products can be verified by comparison to existing designs; objects can be customized to the fullest as it is the case in this research work. Digitalized model of spectacle frame is entirely adjusted to previously scanned human face. In this case, we have two digital models that can be accessed at any time, taking measurements of both frame and face for any purpose. 3D model of a human face was therefore given an entirely new purpose, as it was scanned and used before in some other way.

With most of scanners, one scan is not enough to present all points in area that is being scanned, so therefore cannot give an entire model. For creating an entire 3D model it is necessary to make numerous scans from different sides of object in order to gain all data about objects surface. This can be achieved by replacing scanner around the object or rotating the object in front of static scanner, depending on objects size and available scanner.

Scanned parts of an object, presented in software as point cloud, are stitched together in joined referent system where different data are aligned.

6.1. Point cloud

Scanned model is presented in software as a point cloud which is by definition a set of data points in a three-dimensional coordinate system. This set of points was measured by 3D scanner and represented in digital form. Points are defined by X, Y and Z coordinates, all together creating a surface of a model. Point cloud can immediately be rendered and inspected but it is not applicable for further use in most 3D software and applications. In order to make it usable it is often converted to a 3D surface using techniques like Delaunay triangulation, alpha shapes and ball pivoting for creating a network of triangles over existing vertices of the point cloud or with marching cubes algorithm to create a volumetric distance field. Point cloud is usually converted into polygon mesh or triangle mesh models, NURBS surface models, or CAD models, depending on further use of a model.

Polygon mesh models are a polygonal representation of a shape, useful for visualization but take a lot of memory and editing is limited in his form.

Surface models use parts of curved surface patches in order to model a shape using curves like NURBS, TSplines or other. This makes it mathematical sphere. These types of models take up less memory regarding mesh models, but limitation in editing is still present, even though model can be distorted by moving selected parts of the surface.

Solid model is truly editable form, a parametric CAD model what makes it suitable for other 3D software’s. It differs itself from other models by emphasis on physical fidelity. This technique allows automation of complicated engineering calculations. It effectively reproduces and manipulates three-dimensional geometry.

Processing of the collected data can be further categorized in two categories: Digital modeling and Reverse engineering.

7. MODELING

As it is previously mentioned, 3D models are mathematical presentation that holds collection of data in 3D space interpreted in virtual form on screen. Besides of conventional way of creating a 3D model through 3D applications this research is making both emphasis on creating a 3D model from scanning and reconstructing a solid model in CAD software for further use. This further use, or in other words desired file output and shape (organic/geometric) of a model is what categorizes it as digital modeling, e.g. organic shapes, polygonal/mesh models and NURBS.

When comparing digital modeling and reverse engineering, it is obvious that it is a fine line between them. Some advantages of digital modeling may be found in faster and more cost effective solution, dimensional accuracy, utilization for comparative analysis or as a base for design work and Boolean functions, or visualization in rendering software as a solid object.

Digital modeling and reverse engineering can sometimes overlap. For producing a usable solid model that can be manufactured, sometimes it is necessary to use modeling tools in order to make it readable for some CAD packages.

8. REVERSE ENGINEERING

Reverse engineering is a process of determining technological principles of a device, object or a system through analysis of its structure, function and operation. Work process of selected device, object or system is analyzed to details in order to use it in maintenance or reproduction of a new device with same functions, without copying anything from original.

The purpose is to determine decisions about design of final product with little or no additional knowledge about processes involved in production of the original.

Need for reverse engineering often lays in lost documentation (sometimes never even made). Integrated parts are often designed on outdated systems, so if it is important to make it functional nowadays, using reverse engineering it is possible to redesign existing part.

Another reason for reverse engineering is product analysis. In order to investigate how a product is functioning, what components does it contain, and to determine general cost.

It is also used for digital repairs, updates, security trials, creation of unlicensed duplicates, academic purposes, competitive technical intelligence, learning on mistakes, etc.

Keeping pace with development of computer aided design (CAD) made reverse engineering an acceptable method for creating 3D virtual models of existing physical objects for further use in 3D CAD, CAM (Computer Aided Manufacture) and rest of program packages. Process of reverse engineering includes measuring object's shape and reconstructing their 3D models. In this research work physical object (sunglasses) is measured with 3D system for digitalization GOM ATOS. Gathered data is further processed in order to get a detailed polygonized network that describes the object. Model is subdued to reconstruction in CAD software in order to create solid model. Before reconstruction of a CAD model, it is important to decide whether new model should describe physical object entirely or should a CAD model create an original idea of a new designer? This will be settled in practical part of research work.

9. CAD/CAM

CAD or Computer-aided design is computer tool for creating engineering products. Originally, CAD systems were focused entirely on geometrical modeling, while nowadays more and more CAD systems integrate other aspects of designing. In general, there are three levels of Cad systems:

1) Low-end systems, mostly for not so demanding 2D methods, often not integrated in more complex systems.

2) High-end systems with more complex approach, with additional functions such as shading and 3D view.

3) Complete high-end systems where defining a form is only one of many functions. These systems use complex approach, very expensive and have a lot of additional functions with need for quality graphic work stations.

CAD software increases productivity, improves quality, communication through documentation and creates a database for manufacturing as well as raising profitability.

CAD system outputs files ready for printing, machining, or other manufacturing operations. Even though it is vector based graphics, it can reproduce raster graphics in order to create a satisfactory appearance. CAD takes an important role in design and potentially a manufactory cycle. It is a part of digital process in *Product Lifecycle Management* (PLM) where, combined with other systems creates a complete cycle of a product.

While CAD relates to all activities related to designing (analysis, modeling, testing and documentation), CAM (Computer Aided Manufacturing) is another part of cycle that is focused on specification of materials, details of treatment, development, equipment etc.

For purposes of this research, main focus is on connection of CAD and CAM systems and in this way realization of automation of overall designing, construction and manufacturing processes. CIM (Computer-integrated manufacturing) entirely integrates CAD and CAM with other operations and databases e.g. CAP, CAQ, etc.

9.1. PowerShape software

In this research work CAD software (Delcam PowerShape) was used for manipulating with a mesh model. This software was suggested by faculty as it can reconstruct models, contains direct modeling tools and should be easy to use. Powershape containes a *Core module* and few specialized modules: *Draft* (generating detailed drawings), *Toolmaker* (mould design), *Electrode* (Electrode solid model wizard), *Assembly* (Assemblies of solid models) and *Crispin* (Shoe design).

PowerShape models are combined out of various types of entity: workplanes, wireframes, surfaces, solids and meshes.

Wireframe incorporates lines, arcs, curves, points, text, dimensions, etc. presented in two or three-dimensional way. These parts are vital in *Drafting* as a skeleton for generating most types of *Surfaces* or *Solids.*

Wireframe can construct a **Surface**, which is considered as standard primitive shape. Surfaces can also be converted from a side of solid model. It can be described as a shield stretched over element of wireframe network. Closed 3D model made out of surfaces has hollow filler. Surfaces can be:

Primitives – Based on a simple standard shapes and wireframe extrusions or rotated forms. They can further be divided into Primitives, Extruded surfaces ad Surfaces of revolution. Restriction is that it can modify only existing parametes.

NURBS (Non-Uniform Rational B-Spline) is made out of control points that can dynamically be moved in coordinate system, but with limitations in dimensional accuracy. Primitives can be converted into NURBS.

Power surfaces are created out of network of 4 sided wireframe elements presented as curves along and across the surface area. These surfaces can create complex shapes and still retain full editing capability.

Solids are made out of wireframe. They are also considered as standard primitive shapes or can be converted from one or more surfaces. Unlike Surface, 3D solid model has enclosed mass.

PowerShape interface can contain **single** or **multiple work planes**, but only one can be active at any given time. Work planes define a position and alignment of the object in coordinate system. Work plane can be determined by software, or manually given from three points, or creating arbitrary points.

10. PRODUCING A PHYSICAL OBJECT

After digital form of a model, next step would be creating a physical form of a digital model. Regarding 3D scanning and modeling, there are two possible approaches:

- Additive Manufacturing
- Milling

The main difference is in a way of producing a physical object from a 3D model. Additive manufacturing is based on layering materials and can be done through process of *rapid prototyping* or *3D scanning*. Devices for AM (Additive Manufacturing) generate the layering instructions for building up a physical object. The object is made out of cross sectional layers. Fusing layers together will make an exact physical replica of the 3D model. On the other hand, *Milling* is a subtractive process of removing material by cutting away from existing solid material.

For purposes of this research a short comparison of these methods can be made which will explain the reasoning behind choosing the final method, even though it is limited to availability of devices, leading to home version of a 3D printer.

Additive manufacturing has a primary advantage in its ability to produce almost any shape or geometric feature in a quick and inexpensive way. The price naturally rises exponentially with complexity and volume. Generally, if an object can be created from a single build, it is done by AM, while larger objects are done with milling. Further comparison of RP (Rapid Prototyping) and 3D scanning shows that cost of material, machine depreciation, system maintenance and labor, and built part goes in favor of 3D printing. Even though 3D printers are less complex and easier to use, they are limited to smaller parts and less material choices.

10.1. 3D scanning

As already mentioned, 3D scanning is a process of producing three-dimensional objects from 3D digital model. Work principle is based on consecutive layering. Three dimensional printing, especially color printing gives designers and engineers a clear insight in process of production, and ability to spot possible mistakes on time and fast and effective solutions. Besides for producing prototypes, they are also used for tool production. Materials for producing prototypes are generally plaster powders, while metal and composite or ceramic powders are used for functional objects. 3D construction of a model can nowadays be produced within few hours or in a matter of days, depending on used methods and the complexity of a model.

Object can be produced in two ways; through a 3D program for modeling (CAD software) entirely new model or through 3D scanner that copies an existing object. Layers are threaded from bottom to top. Process of strengthening is repeated for every layer separately until the whole construction is made. Each of these layers can be seen as thin cut horizontal cross section of an object. After printing process is finished, next step is disposal of unwanted and unnecessary material, polishing, sanding and coloring if necessary.

There are a lot of competitive technologies and 3D printers available on the market. Main difference between printers is in a way of creating layers and parts of structure. Some of them soften materials in order to get layers, other pile liquid thermopiles fixed in various ways, and third cut thin layers of materials and then join them together.

10.1.1. Selective Laser Sintering

This technique of additive manufacturing) uses lasers of great power in order to connect small pieces of plastic, metal, ceramics or glass in mass with wanted 3D shape. Laser connects powder material by scanning cross sections from 3D model settled on powder bed. After one section is scanned, powder bed is lowered for distance equal to thickness of one layer. New layer of material is added on top and the process is repeated until wanted 3D object is finished. SLS manufacturing can produce various shapes since there are different powders available for manufacture. This technology is in global use because of its simple production of very complex geometric shapes directly from CAD software.

10.1.2. Direct Metal Laser Sintering

In process of DMLS method, 3D CAD software is used, converted into STL file and sent to printer software. Geometry of a 3D model is properly oriented in order to construct a certain structure and support construction is added. This technology connects metal powder into solid by melting if with a focused laser beam. Parts of an object are produced by adding material layer by layer, usually using layers of 20μm of thickness. DMLS method is characterized by production of high accuracy in details and high surface quality, as well as providing excellent mechanical features of a printed object. This method allows freedom in construction and more efficient constructional solutions in technical applications. Since objects are made layer by layer, it is possible to create internal shapes and transitions that couldn’t be milled or made in some other way. DMLS had more advantages in reference to traditional manufacture techniques, such as shorter time of production without any additional tools, production of more different structures at the same time and the ability of producing structures out of different alloys. [7]

10.1.3. Fused Deposition Modeling

This method begins with software process that processes STL file for some time (usually in terms of minutes) mathematically slicing it and orientating it for production. If it is necessary, support construction is automatically added by software. Printer has two materials stored; one for production of an object, and another for support construction that is removed after the process is finished. Plastic thread or metal wire is melted and goes through nozzle that moves horizontally or vertically, according to path defined by CAD model.

From fused deposition modeling and addictive manufacturing new techniques evolved into FFF (Fused filament fabrication) and started a “Reprap Project”. RepRAP (Rapid Replicating Prototyper) is an initiative to develop a 3D printer that can print most of its own components. The Reprap project started in 2006 by Adrian Bowyer and colleagues from the University of Bath.

Evolutions of Reprap printers started with the Darwin in March 2007, followed by the Mendel in October 2009, the Prusa Mendel and the smaller Huxley in late 2010. Currently the Prusa Mendel is the most current and up to date design.
The idea of this project is based on ability of self replication; that is all the custom parts are printable by the printer itself and the rest of the components should be available at a regular hardware store. This is what enables to cost effectively distribute Repraps to the public in an affordable and accessible way.

Reprap 3d printer contains the thermoplastic extruder which is coupled with a Cartesian coordinate system platform (3 Dimensional Axis, X Landscape Horizontal plane, Y Portrait Horizontal plane, Z vertical plane). Through the Extruder, plastic filament is forced into a heated chamber (Hot End), where it is melted and extruded. This is controlled by a motor running a bolt. The filament is forced round with a bolt and into the heat chamber. The 3D models are then built up layer by layer. [8]

User controls the Reprap 3D printer with software known as Gcode. Gcode is a list of serial instructions letting printer know exactly what to do and when. In order to generate G code a 3D model has to be designed in some form of CAM or CAD. 3D model is then interpreted by a G Code converter, such as Skienforge, which generates the G Code required to control the printer to print the 3D model. There are several open source applications which incorporate the G Code generation element (skeinforge) within a user friendly user interface such as (Printrun/Pronterface).

The RepRap Prusa Mendel 3D printer used in this research work can extrude ABS (Acrylonitrile butadiene styrene) or PLA (Polylactide) plastic. It can also be further upgraded by modifying the printer to print with al manner of materials and this way customize extruder for printing materials like chocolate or clay.

ABS plastic is a highly impact resistant and tough plastic, with good thermal properties for the purposes of extrusion. It is petroleum based and recyclable. This plastic enables smooth edges and a versatile print quality. Color can be changed due to prolonged exposure to the sun. For purposes of printing filament can make a maximum of 3mm depending on wanted layering. ABS melting temperature is 240°C and needs a heated bed in order to adhere to the build surface. On the bed should also be a kapton tape to ensure good adhesion and prevent warping. ABS can be recycled-granulated and then re extruded into filament again.

PLA plastic is a thermoplastic aliphatic polyester derived from renewable resources (corn starch and sugar cane), what makes it environmentally friendly. This material allows printing of translucent non opaque 3D objects. PLA has a melting temperature at 180°C and doesn't necessarily require a heated bed or kapton tape as it is dimensionally stable.

Even though it is produced put of renewable sources, PLA is harder to recycle/reuse than ABS. It is also sticky when it reaches 90°C which can effect smoothness of the surface on 3D printed object. Also, color pigments in PLA can affect the extrusion width and print properties of the printer.

11. OPTICS

Spectacle frame is made out of few fundamental elements and component parts which will be taken into consideration while measuring original model and redesigning a new prototype. When it comes to fitting of the spectacle frame, the bridge has the most important role because it concentrates the major bearing surface and contact area between the front of the spectacles and the face. It should unite a comfortable and supportive fit which maintains the position of the lenses over eyes in natural position of the gaze.

Definition of the bridge width says it is “the minimum horizontal distance between the nasal surfaces of the rims on a plastic or metal frame, or the minimum horizontal distance between the nasal surfaces of the lenses in rimless frames.” [9] In such case, when a frame has adjustable nose pads on metal arms, pads can be altered in a satisfying way.

Definition for the lens width is “the distance between the vertical sides of a rectangle containing the lens shape (in mm).” [9]

Functionality and comfort of spectacles are important; frame has to be light, and made out of material with neutral influence on skin. The weight of frames is often ignored, but based on this surface of nose pads can be determined, based on the fact that most of the weight lays on them. ISO standard (BS EN ISO 12870:2012) regulated a minimum 200mm^2 nose pad surface for frames weighing under 25g, and a minimum 250mm^2 nose pad surface for frames weighing over 25g.

While designing, optimal dimensions (Figure 10) of spectacle frames have to be taken into consideration.

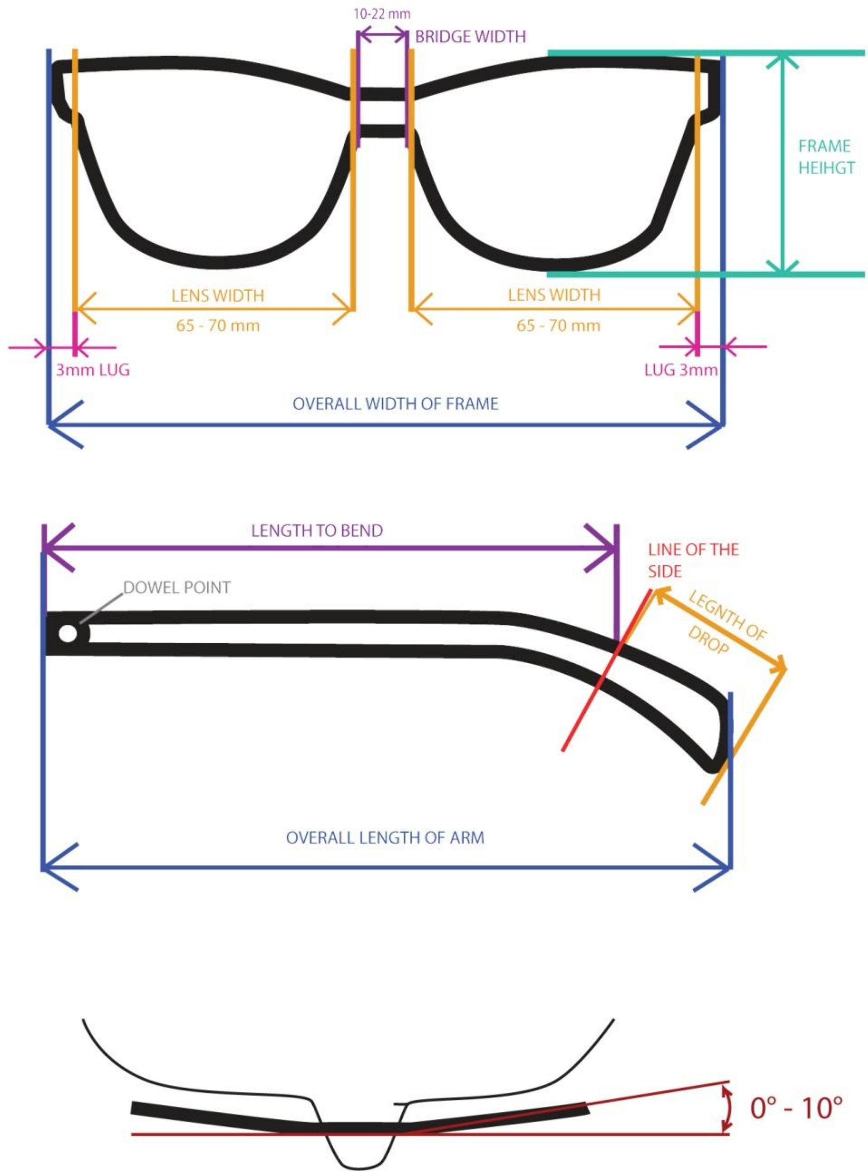

Figure 10: Optimal dimension of spectacles frame

12. PRACTICAL WORK

12.1. Used scanner

All scanning was made on GOM ATOS II Rev. 02 SO MV320, an active laser digitizer (Figure 11). It is combined out of convergent configuration of two cameras and centrally located non-coherent projector with coded light. Cameras are identical, two 8-bit monochromatic Sony XC-75CE, with CCD sensor resolution 768x582 pixels. Cameras are set at 28° with measuring distance of 490mm and through the scanning process they remain still. Projector has an additional air cooler, while cameras don't. For commercial reasons, complete mathematical model of this device will never be published entirely, but few specifications are listed below:

Measuring volume (L x W x H) in mm	320x240x240
Measuring point distance	123.93µm
Recommended reference points	490mm
Camera angle	28°
Focal length-camera lenses	12mm
Focal length-projector lens	30mm

Figure 11: GOM ATOS II Rev. Scanner

The scanner is based on combination of triangulation and projection of raster pattern of lines, using non-coherent blue led light source. As shown in image below, projector illuminates the surface with predefined raster structure which enables a space reconstruction of surface based on analysis of recordings gathered with left and right camera. Computing of object coordinates is achieved by triangulation in which one peak is objects reference point, and other two peaks are reflection of measured reference point on each camera sensor.

12.2. Process of scanning

First step is preparation of the subject: the original model is dark sunglasses, used only as a reference for frame. Besides being dark, another problem are glasses that are shiny and translucent, therefore the object needs to be treated. Entire glasses are covered with chalk in spray, resulting with object in white color and no reflections.

Object also has to be marked with reference points around its surface: for our purposes and scanner type non coded reference points with diameter of 1,5mm are used. The amount of reference point and covered surface field depends on the measuring volume (in this case 320) which is middle. In general, small volumes need more points, while bigger measuring volumes need fewer points.

While arranging reference points on surface it is important to take into consideration that it is needed to capture minimum 3 points in every rotation. Using these reference points, software stitches them together and allocates them in space. Since the object's surface was treated with chalk, it is important to clean all reference points from any chalk so it can be detected by scanner (Figure 12). Few reference points are also put on surface of turntable on which we place the object (Figure 13). The turntable is placed in front of scanner and manipulates the object as it is programmed. The turntable is also dark colored, not shiny in order to reflect as less light as possible.

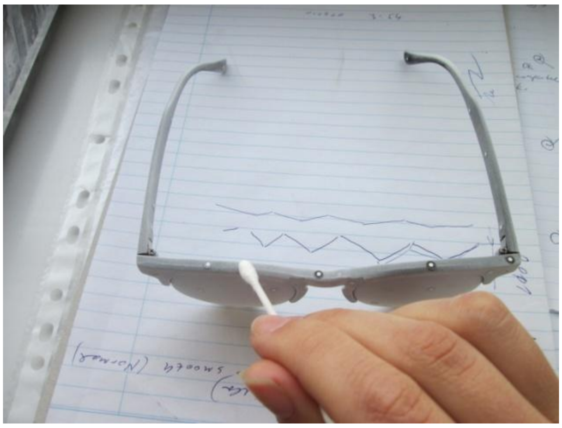

Figure 12: Cleaning of reference points

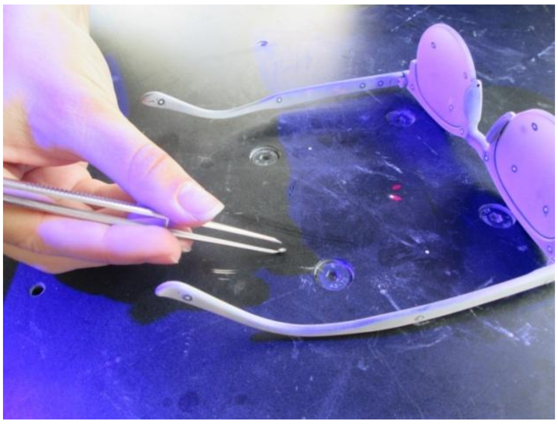

Figure 13: Placing of reference points

After placing the object on turntable, it is set to 0 position. The software recognizes the reference points and marks them with green crosses (in case it doesn't, reference points need to be cleaned again or place a new one).

Based on the complexity of the shape, measurement with rotation table is determined. It sets how many rotations of the table will there by how many degrees in full rotation of 360°. The minimum is 10 steps, but in this case it was set to 16steps.

As scanning begins, projector emits light onto object in predefined raster coded lines several times in one position (Figure 14), and turned in 15 more steps (every time for 22,5°) and every time illuminated. As one step of recording is being finished, the software reconstructs coordinates and stitches with new recordings, creating a 3D point cloud model (Figure 15). After completing all 16 steps and closing 360°, the object is repositioned in order to record areas that weren't approachable from previous position. Again, the object is prepared for scanning (surface treatment) and few additional reference points are placed on the turntable. New measurement series is opened (again 16 steps) and scanning starts.

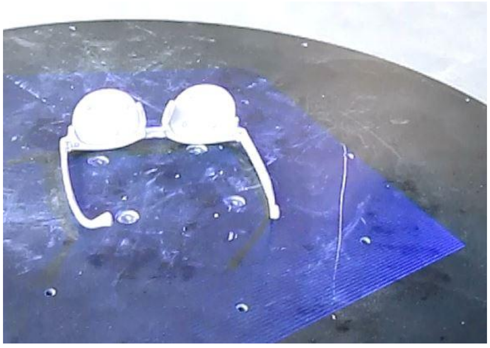

Figure 14: Emitting the light on the object

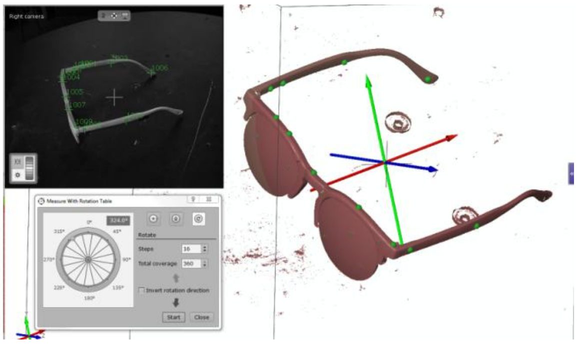

Figure 15: Digital model presented in software

When both measurements are finished, these two sets of measurements are combined by manually selecting common reference points (minimum 3) (Figure 16). Speckles can be removed in software and given model is point cloud. The model is then polygonized and all points that are unwanted can be removed, for example: removing glasses from frame. Another quick tool is to fill holes interactively (Figure 17). When satisfied with a model, it is exported as a mesh, an .STL model (Standard Tessellation Language). STL file is a software language for spatial description of volume. It describes only the surface geometry of a 3D model without other attributes such as color, texture, shading, etc. This format represents 3D surface that is made out of collection of planar triangles. More precision is achieved by greater number of triangles, which leads to increasing STL file size and automatically prolongs time of processing.

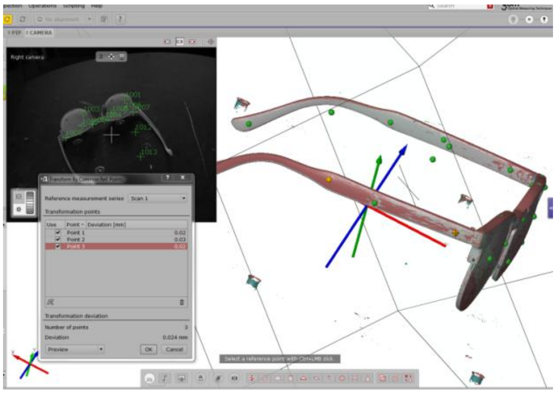

Figure 16: Selection of reference points

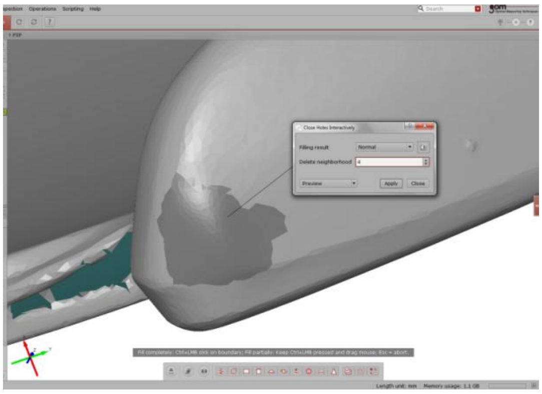

Figure 17: Filling holes in digital model

12.3. Frame measurement

After scanning the frame, it was measured to compare it with optimal values (Figure 18):

GLASS: 50mm	BRIDGE: 16mm	ANGLE: 3°
LUG: 5mm	A=103,01mm^2	TOTAL WIDTH: 140mm
ARM: 145mm	WIDTH OF THE FRAME: 4,24mm	

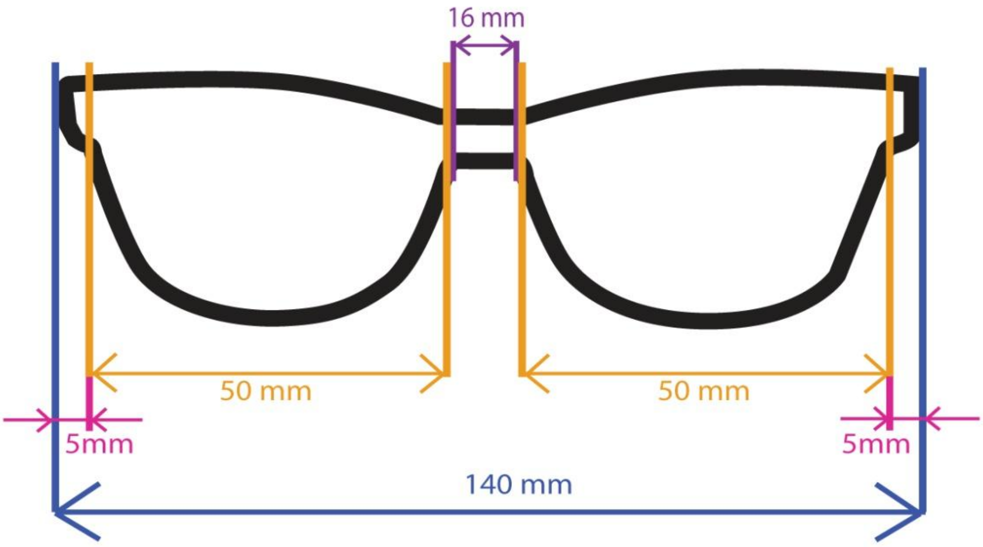

Figure 18: measured values

Conclusion: Glass dimensions are not within ideal standard as the ideal is 65-75mm, and this one is only 50mm. Another Dimension that is not in accordance with standards is area of the pads- less than 200mm^2 which makes it way under required minimum of 200mm^2.

Therefore, while creating an altered model these dimensions will also be taken into consideration and adjusted to a human face.

With process of rapid prototyping, now obtained model could directly be produced with a 3D printer and this is the time to make decision about leaving the model intact and reproducing an exact replica of original frame or redesigning it in desired way. Since measurements weren’t within optimal specifications, decision was clear and the next step is modeling of an ideal frame based on gathered data of a 3D model.

12.4. Modeling

For purpose of this research PowerSHAPE software was used. In order to start with modeling, first step was to set a work plane or in other words positioning of a model in workspace defining X, Y and Z coordinates (Figure 19).

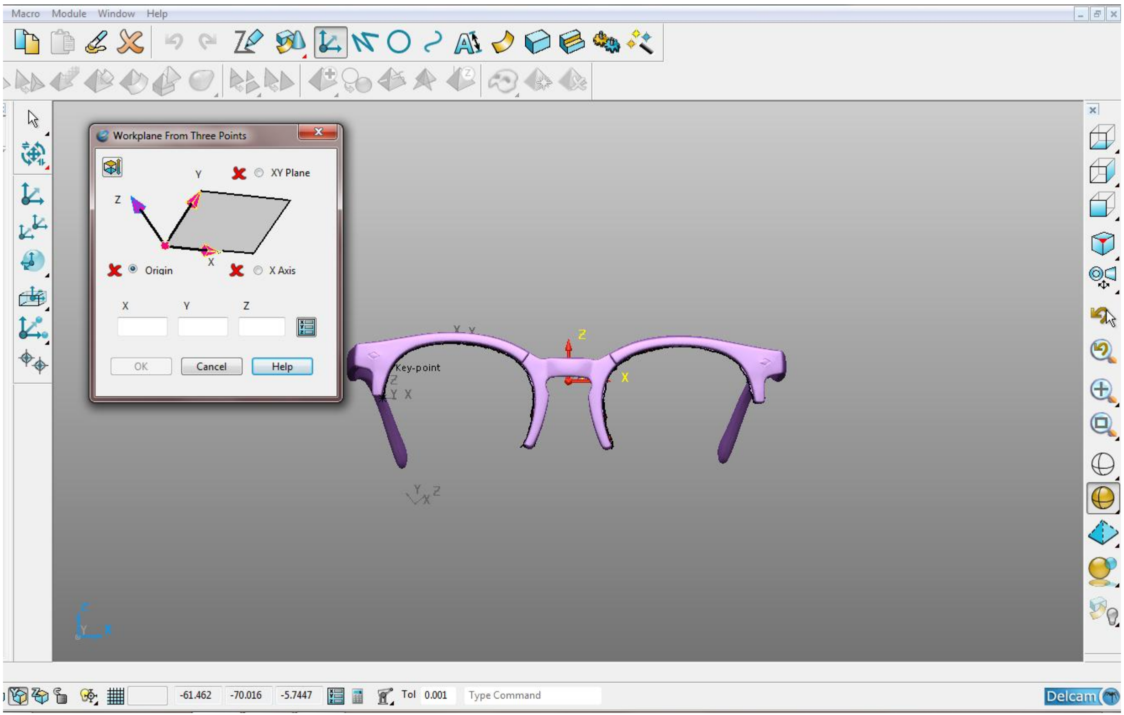

Figure 19: Setting a work plane

Since this model is very limited in editing and unfortunately available version of CAD software doesn’t allow more complex surface manipulation and conversion, there are three possible options of recreating a model:

1) Recreating with a **drive curve** – this type of surface is made out of spine curve and section curves that are aligned perpendicular to the spine points

2) Recreating with **dynamic sections** – this tool dissects (manually) solids, triangles and surfaces in sections and recreates surface over selected parts

3) Recreating with **surface fitting** – Creates surface from selected composite curve

My choice was third option because it is most detailed from mentioned three and can easily be adjusted while creating surfaces. This option is also most time consuming.

First step is to make a composite curve along the surface of original model. While drawing the curve, we can create few "middle steps" – points along the curve in order to correct the path if we want to. Also, angle between these points can be adjusted. On Figure 20 composite curve is presented with a yellow curve, and selected blue adjustable points:

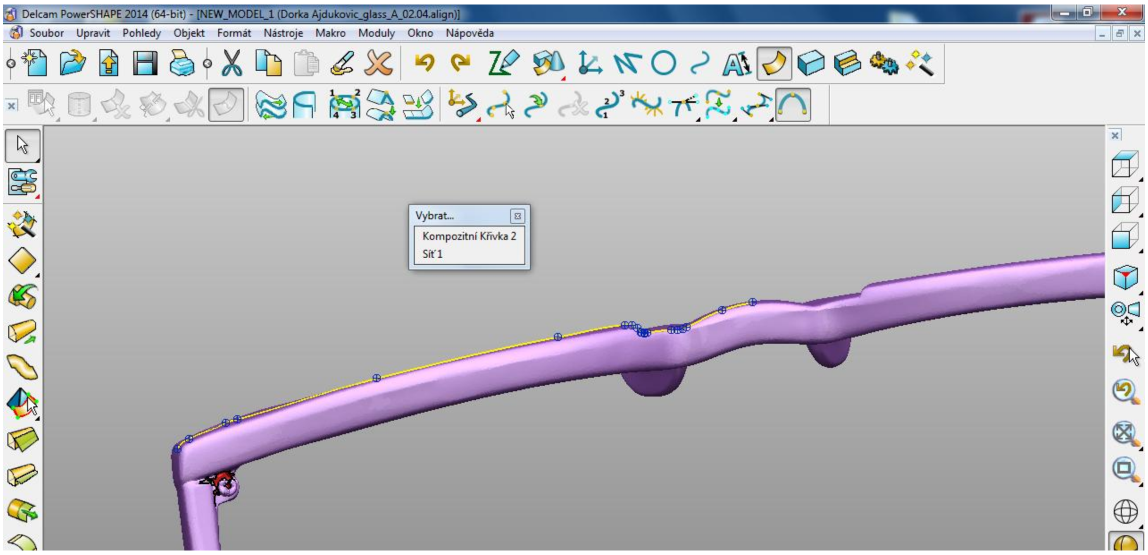

Figure 20: Creating a composite curve

From this composite curve it is necessary to create a surface (Figure 21). This surface will be the front surface of new model. To every surface we can address "inside" and "outside" sides, blue presenting the "out" and red presenting the "in" part. Another command that is determined even before drawing is dimensions: setting how extended will be this surface in each way from original curve. Created surface also has its own coordinate system that can be set manually or by command bar (marked with orange frame in the image below) in the bottom of PowerShape's workspace.

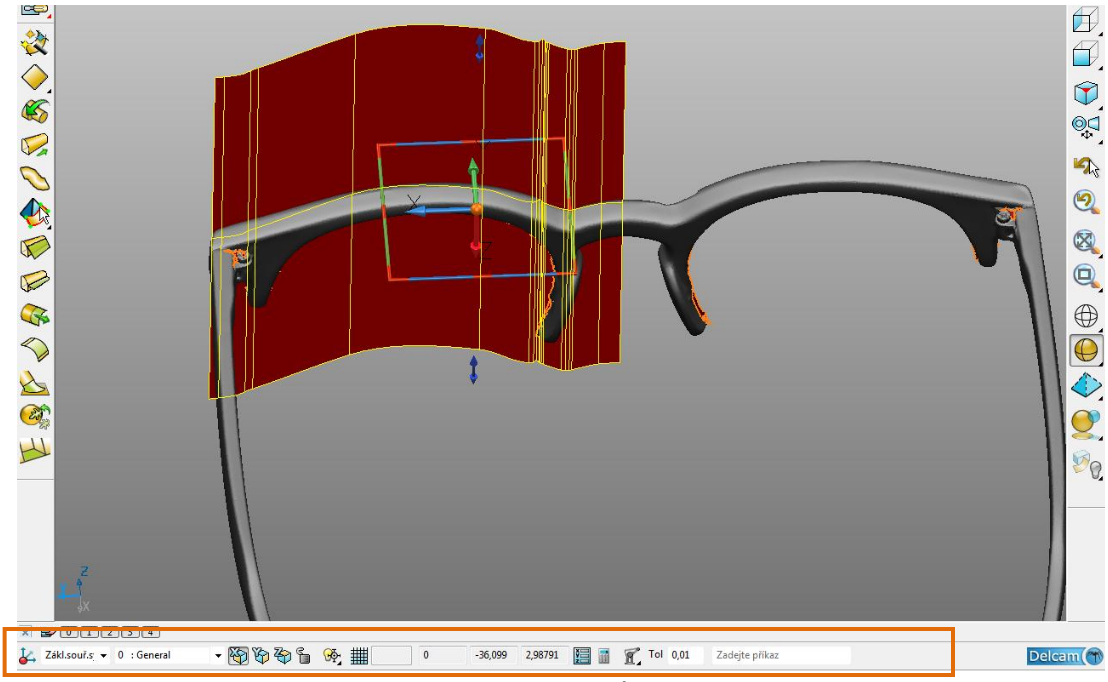

Figure 21: Creating a surface

For easier drawing, we can make this layer invisible and turn it back "on" when we want to. In next step, again the composite curve is drawn but this time, on front of the model (Figure 22). This curve will set restrictions and shape to set front surface that will for now be hidden. Both curve and surface are made only by half of the model as the basic solid model that will be created will be mirrored. After mirroring, taking into consideration that human face is not symmetrical; both sides will be adjusted to scanned face and its features.

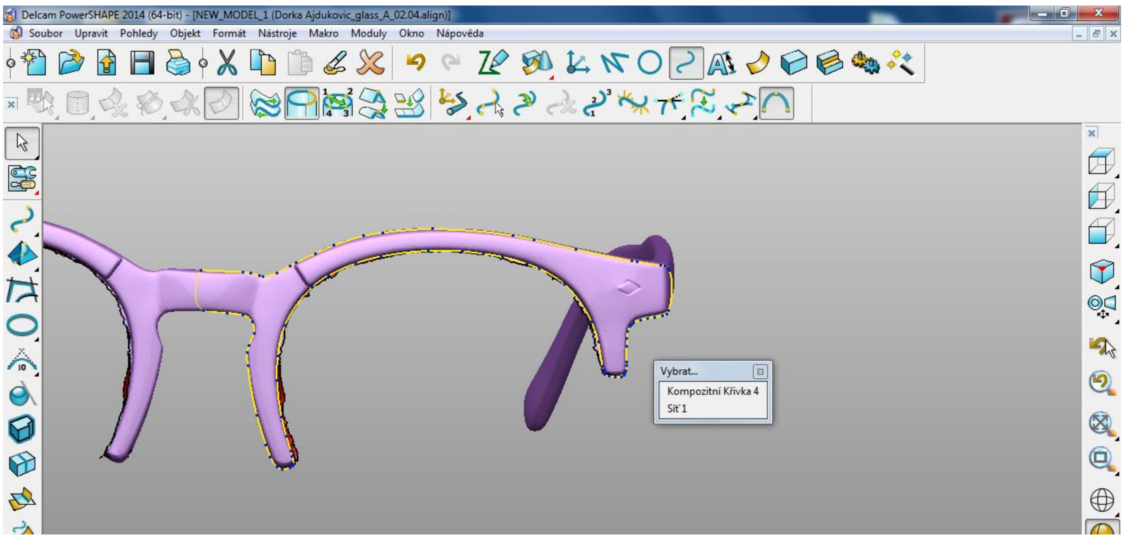

Figure 22: Creating a composite curve

Next step will include new, second composite curve and previously made surface, therefore invisible layer is visible again. Composite curve is projected onto surface and gives surface new limitations in all directions. This is seen as composite curve is marked as green, and projected composite curve on surface (blue) is orange (Figure 23).

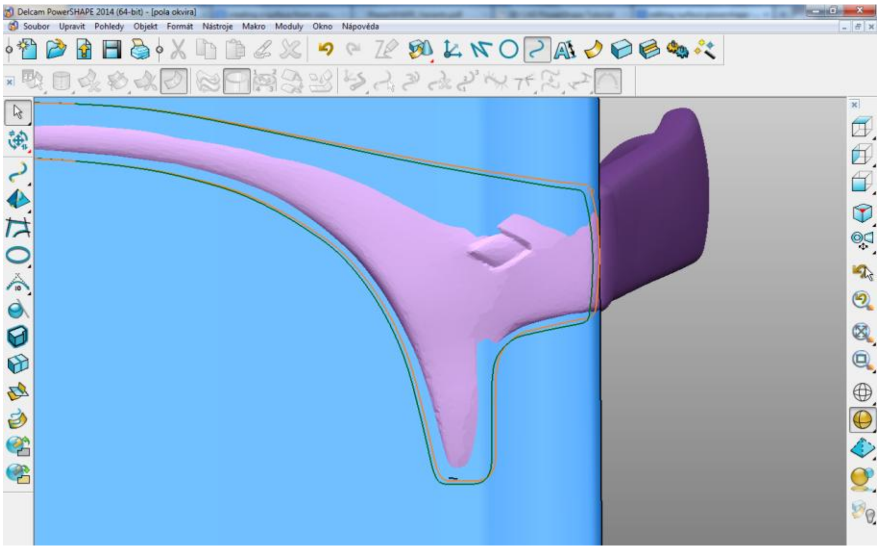

Figure 23: Projection of the composite curve to the surface

Projected curve on surface set new boundaries. Next step is cutting the surface according to these boundaries and creating a new surface of frontal part of the frame shown in Figure 24.

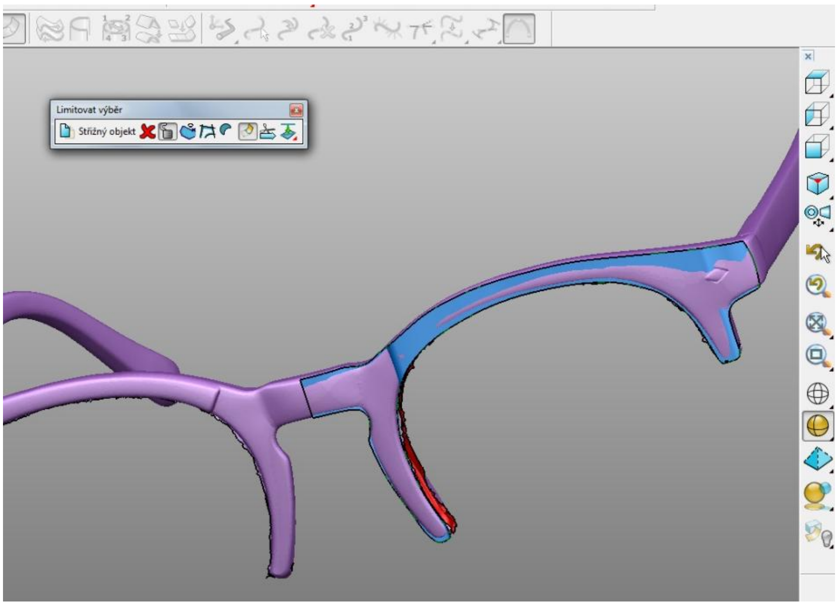

Figure 24: Trimming surface according to composite curve

To achieve depth, existing surface is offset by arbitrary amount. In this case, offset was set to be 5 as that is thickness of the frame. This created two surfaces that surround one part of the model (Figure 25).

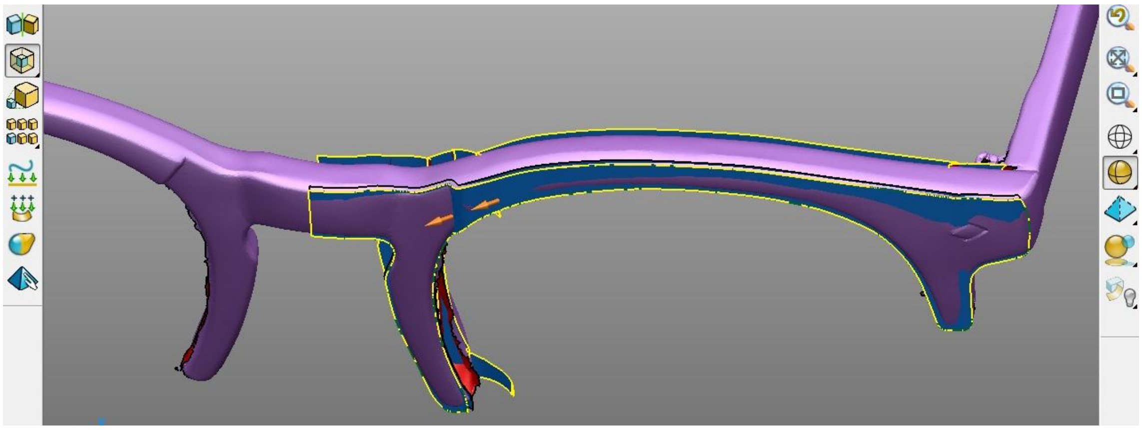

Figure 25: Offset

As it was mentioned before, for creating an object solid model is needed. Connecting these two surfaces gave unsatisfying results that unfortunately were not recorded. Another solution was found, where one of this surfaces could still be used. This will be shown in process of creating arm of the frame. Beginning of the process is the same as the front part: drawing a composite curve and creating a surface out of it. Again, drawing another composite curve and projecting it on created surface. In Figure 26 a dropdown menu for cutting the surface with a curve is shown. It has few options, depending on where will be the boundaries.

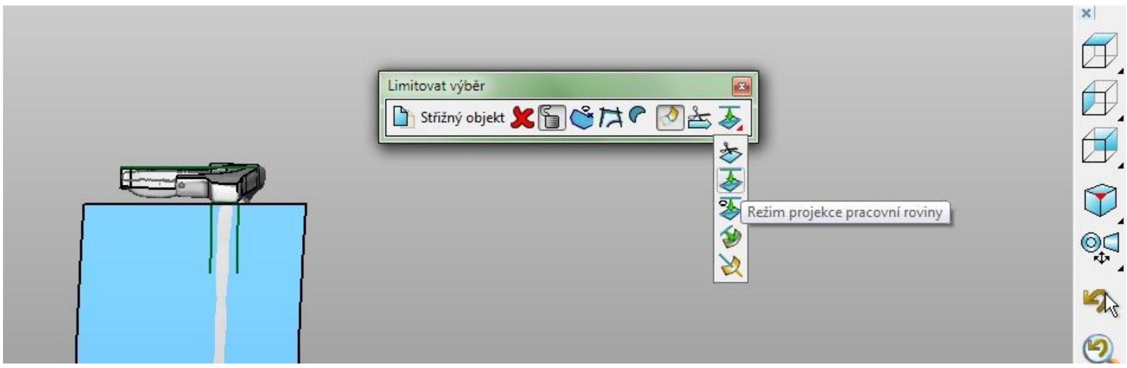

Figure 26: Trimming options

After a new surface with satisfying shape is created, a volume is added, creating a solid (Figure 27). Again, we can set thickness and once more, it is 5mm.

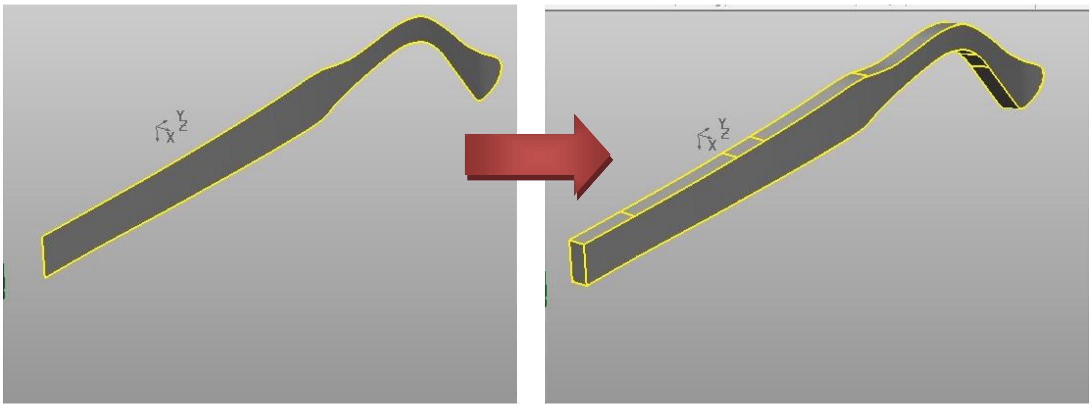

Figure 27: Adding volume

Same approach was with the front and a new model resulted like this (Figure 28):

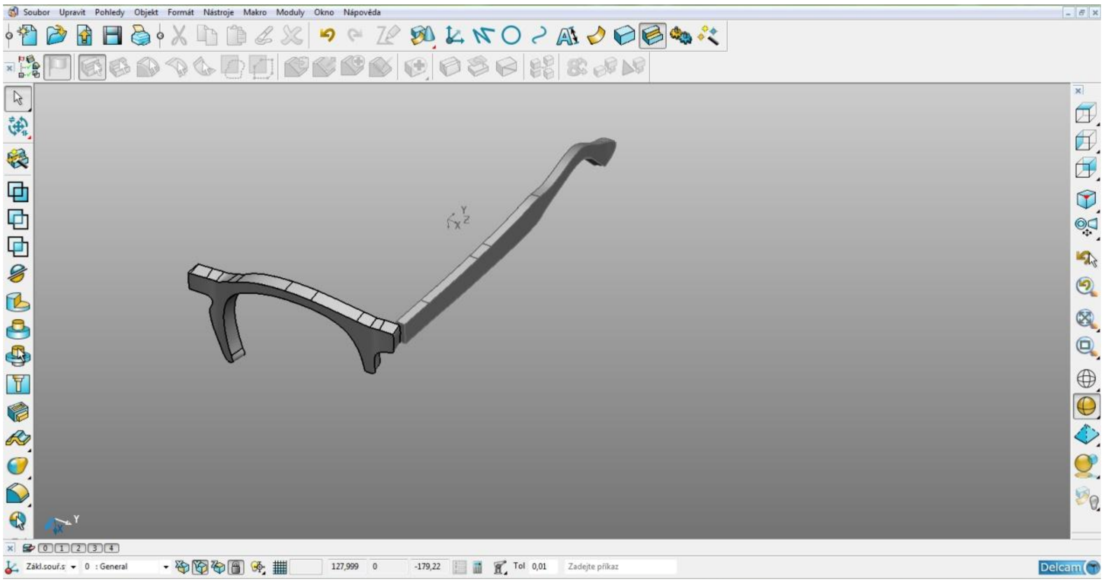

Figure 28: Creating a Solid model

Before mirroring of a new model, some few adjustments were made in order to make it more appealing or enduring. For modifying a solid a whole new group of tools is opened. For example, morphing is possible as one solution of modifying a solid (Figure 29). This tool is not precise as it gives square bounding bow around selected part of the model and can be stretched within these boundaries. Another disadvantage is that it can make big distortions in surface, but for small modifications it is useful. This tool was used to enhance one end of the arm to make it wider for bolt to fit in.

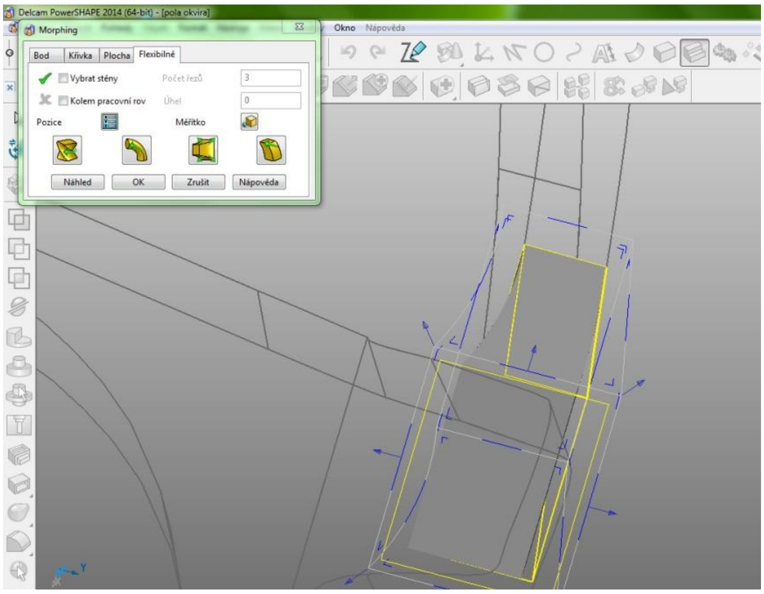

Figure 29: Morphing

In order to make a model within optimized standards, it is necessary to make bigger glasses. This was achieved by scaling the frame in order to make it longer (Figure 30).

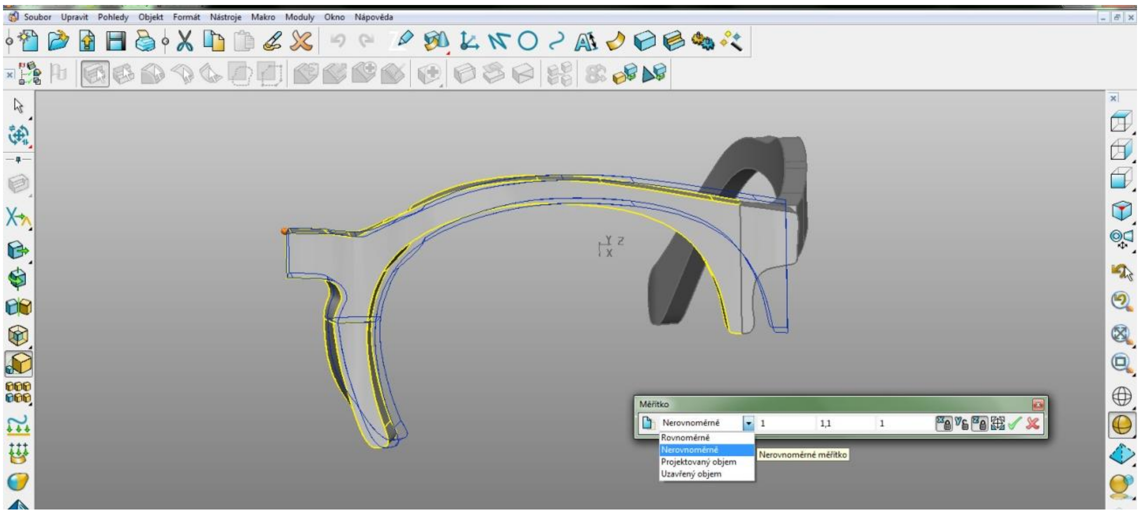

Figure 30: Scaling

The same thing was done with arms of the frame in order to fit the ears accordingly. In order to keep shape of frame’s arm, it was necessary to cut out one part of the arm and scale only this part in one direction. This way, arm will be extended in only one direction, leaving other parts intact. First is then splitting of the solid (Figure 31). Splitting tool allows active solid to be cut using the selected solid, surface, symbol or a work plane. In this case, splitting is done again with surface, which means drawing a line on desired position and creating a surface from it. Before splitting it is important to select the solid part that needs to be cut and in “tree” section turn it into “active” solid. “Tree” presentation of a model allows splitting it into few parts and recording actions done to the model (Figure 32).

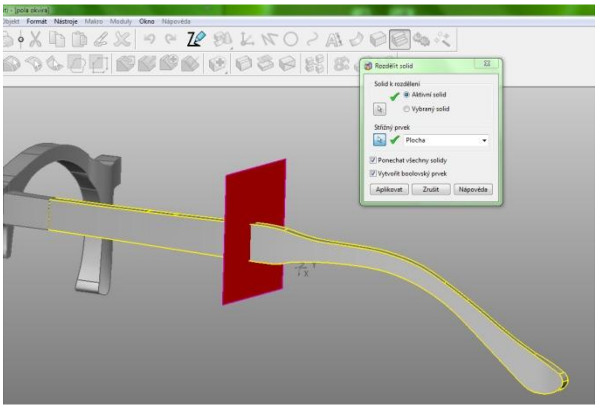

Figure 31: Splitting solid

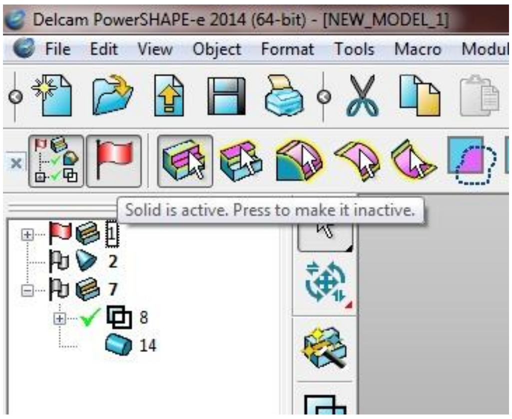

Figure 32: Tree representation

After splitting the model, selected part can then be scaled. The problem with scaling is that the tool shifts scaled part a side (Figure 33). This demands a new tool for replacing the part. For purposes of this model, it was important to connect it to other part of arm. This was done by manually selecting three points on active part of the solid, then three points on dislocated part (Figure 34). It is important to keep in mind which points are going to connect, that is why they are marked with numbers. Unfortunately, this is not the most precise tool.

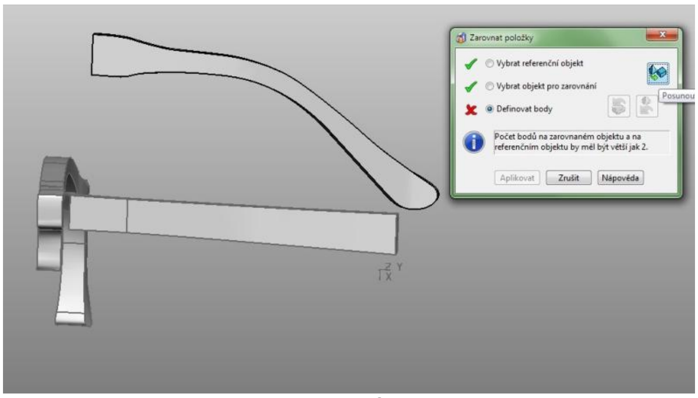

Figure 33: Displacement after scaling

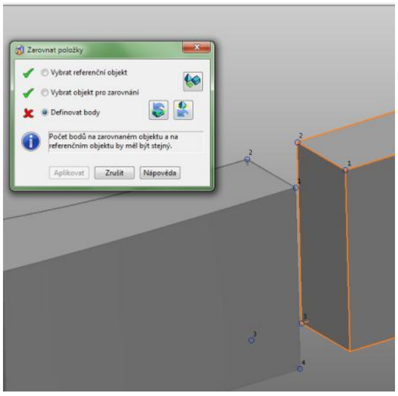

Figure 34: Connecting 3 points

There were some additional details added to the model in order to make it more personalized. It is possible to add different shapes and forms. The idea was to add typography, more precisely word “MY“, as a relief on a surface of the arm (Figure 35). Latest versions of PowerShape has the ability to make solid model out of typography, but unfortunately, available version that I had access to, cannot recreate this. This is the reason why only two letters are written, since it has to be drawn as a composite curve and then extruded to a solid. These two solid letters were then added to the existing model.

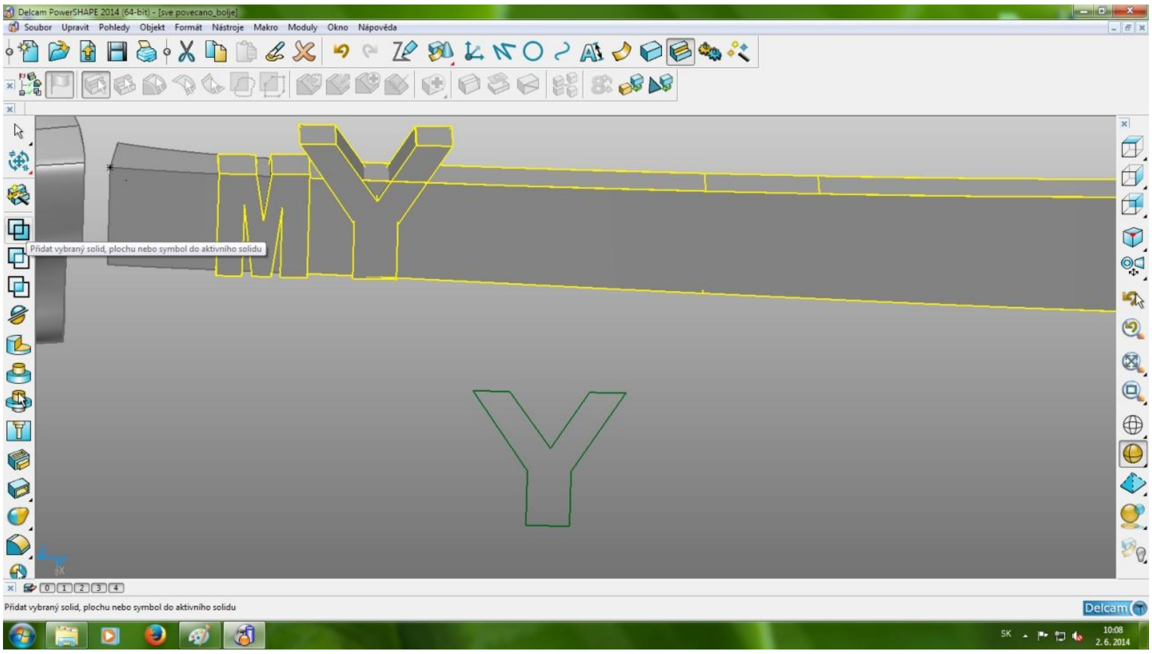

Figure 35: Adding relief to the surface of the solid

Next step was mirroring of the model in order to create full model with two sides. Mirroring has also few options depending on wanted result. Mirroring can be done as projecting wanted shape through planes (XY, YZ, ZX), in a wireframe line, by placing the input of two points that define mirror plane, or creating a multiple copies of the selected items. This model was mirrored with a wireframe line (Figure 36).

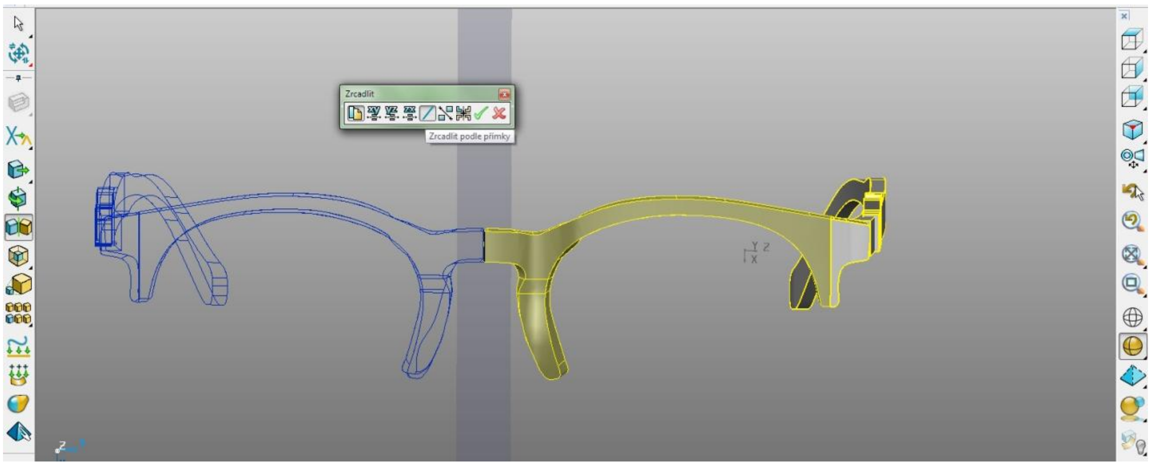

Figure 36: Mirroring

After creation of the whole model, it is neccesarry to redesign nose pads in order to make contact surface bigger, and fitting to scanned face. Surface is moved by clicking on geometry to define the direction of movement (Figure 37). When one surface is moved, other connecting geometry surfaces move along.

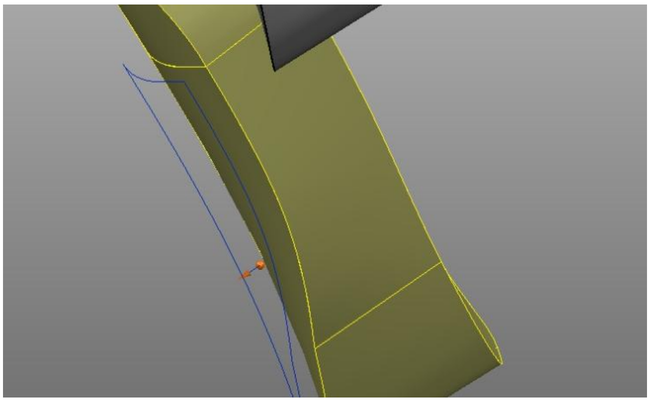

Figure 37: Extrusion

Existing shape of nosepad surface is not so important, as it will be modifyed to fit the nose surface of scanned face. In order to do this, a mould of nose surface has to be done (Figure 38). As optimal distance between the pupile and glasses is 10-12mm, surface at this distance was moulded. This was made by creating a curve on the surface of scanned face and creating a new wireframe surface by fitting. After creating the surface, it is applied to the frame model. Surface is positioned where nose surface should be, recreating the contact area (Figure 39).

Model is then cut according to this surface (Figure 40). This surface simulates the nose. This could be done by placing the model in same workplane as the scanned head. The problem is in positioning the frame on head, and both files are so big it would be time consuming.Therefore, this simulation is made.

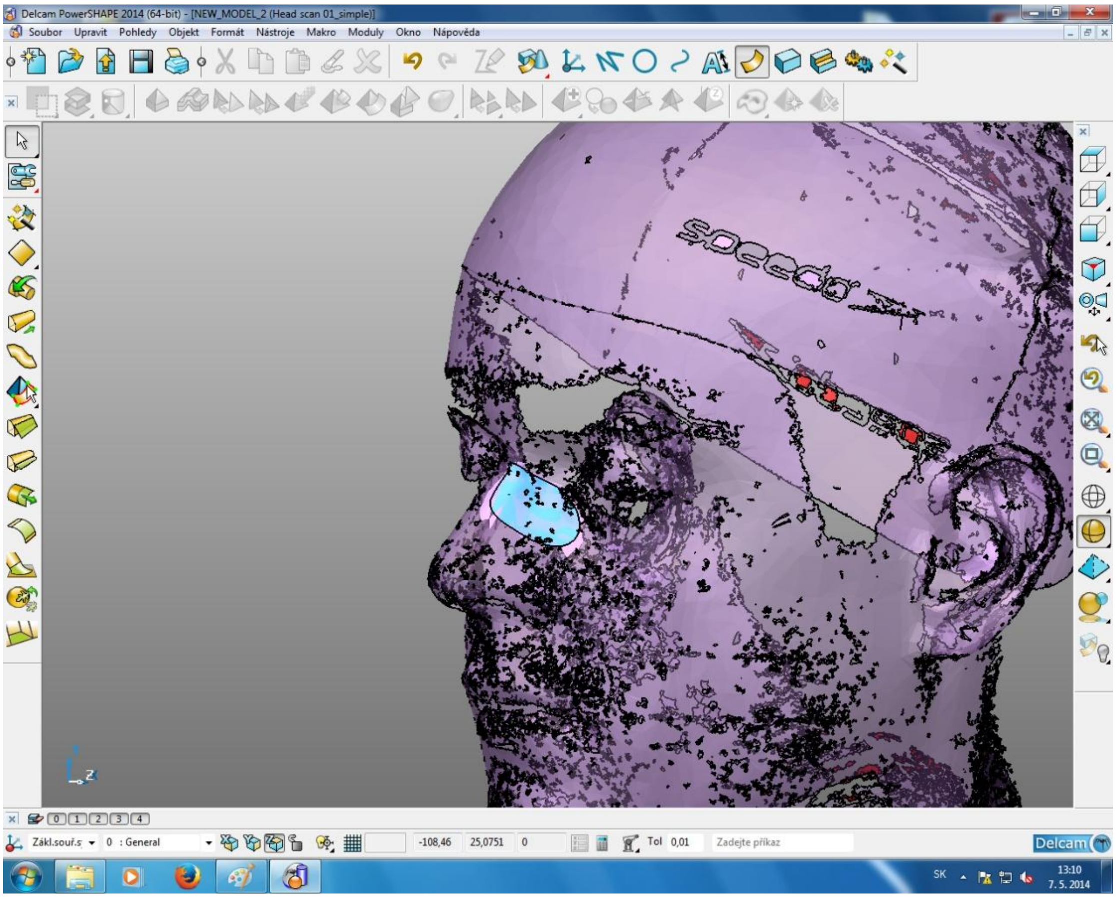

Figure 38: Creation of the mould on scanned head

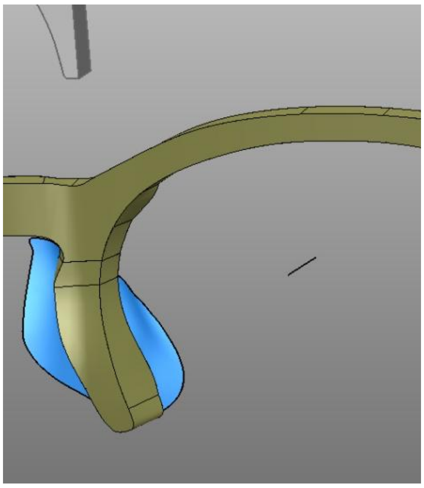

Figure 39: Positioning of the surface

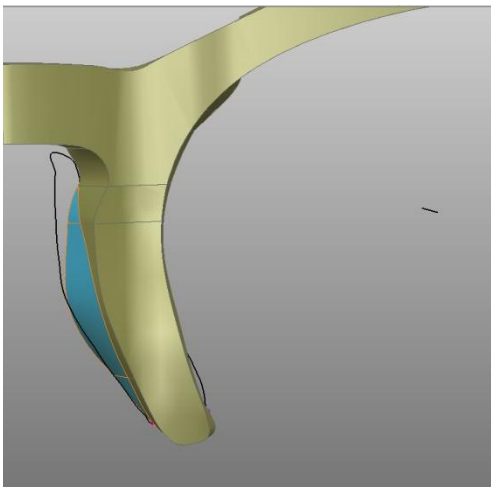

Figure 40: Cutting of the solid

After cutting a part from a nose pad, edges were sharp and one part was sticking out. In order to make it more suitable for wearing, excess part was split (Figure 41) from model and deleted, and sharp edges were smoothened (Figure 42).

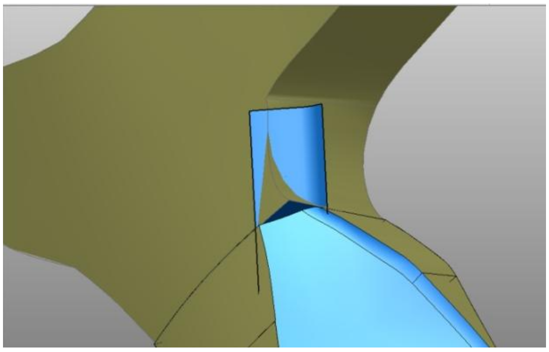

Figure 41: Splitting of the excess part

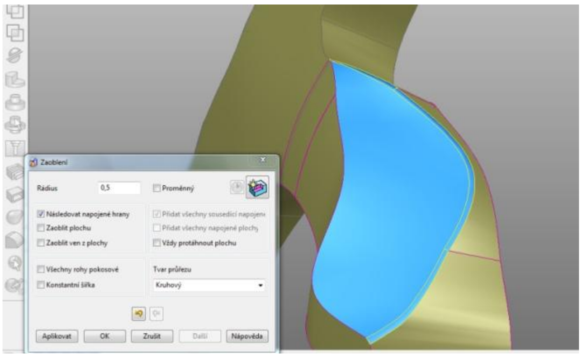

Figure 42: Smoothening of edges

Few final steps were repeated on the other side of the frame, such as „moulding“ the surface of the nose from scanned face, adjusting nose pad to the nose surface, smoothing etc. In the end, the final model with satisfying optimal dimensions was produced (Figure 43).

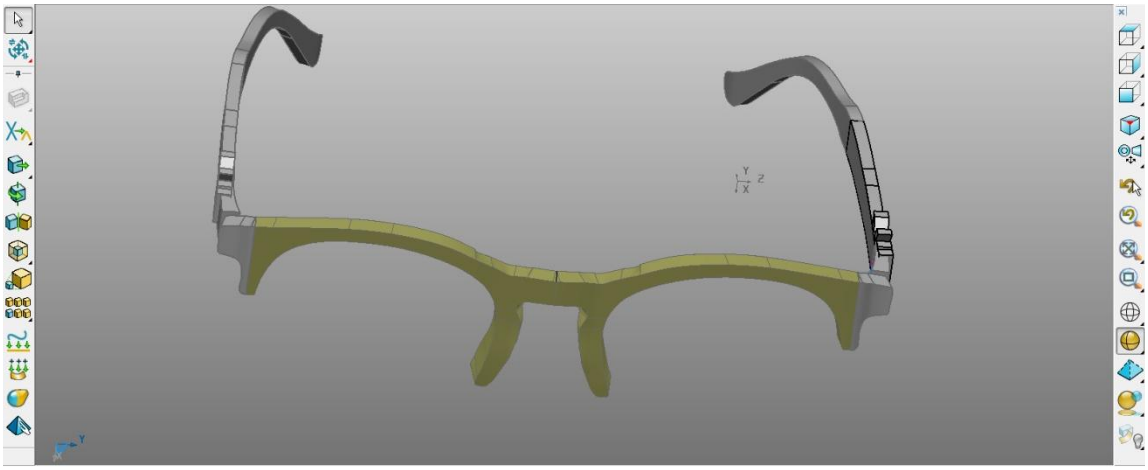

Figure 43: Final 3D model

After finishing the new, enhanced model, a comparison is made. New model has bigger glass radius (65mm), greater nose pad surface (A= 202mm^2) that is also adjusted to nose surface of scanned head and arms of the frame suited to ear position. For easier visual presentation, original model is in gray color, while new model is blue (Figure 44). Differences are obvious.

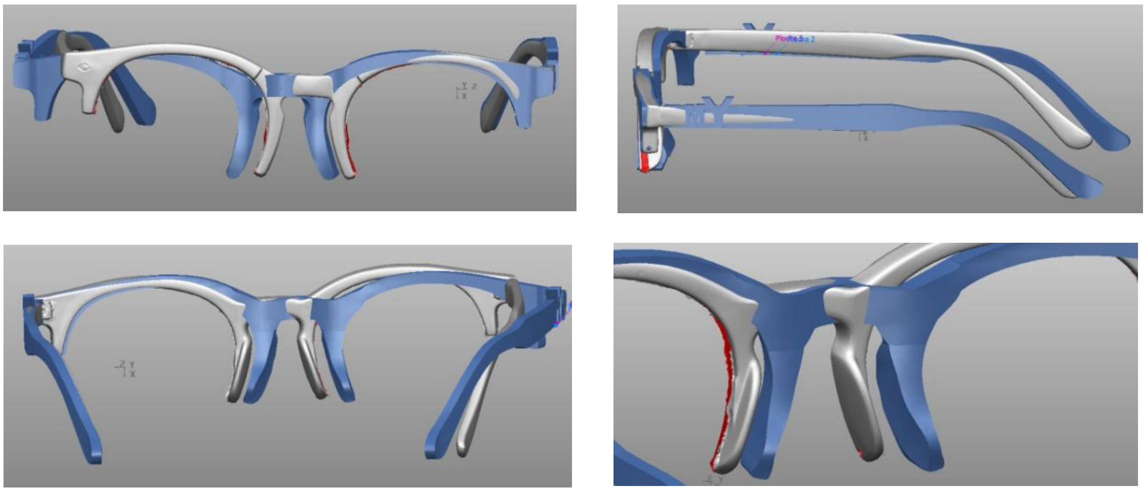

Figure 44: Comparison of the original model and modified model

The final test was placing the frame on the scanned face. This was time consuming as file with scanned face is large so every operation took some time. Screenshots were taken from few angles to make sure it fits (Figure 45).

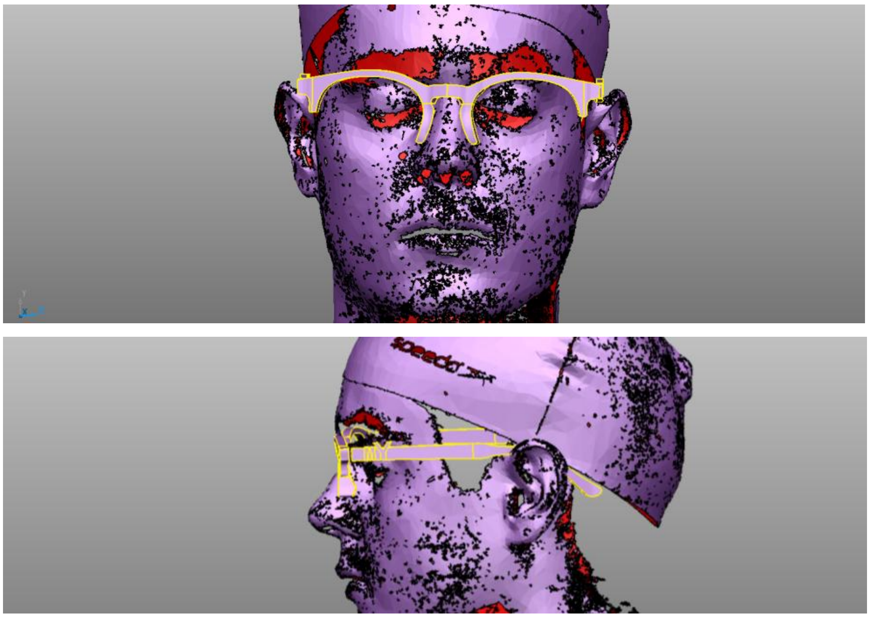

Figure 45: Fitting the frame on scanned head

12.5. 3D printing

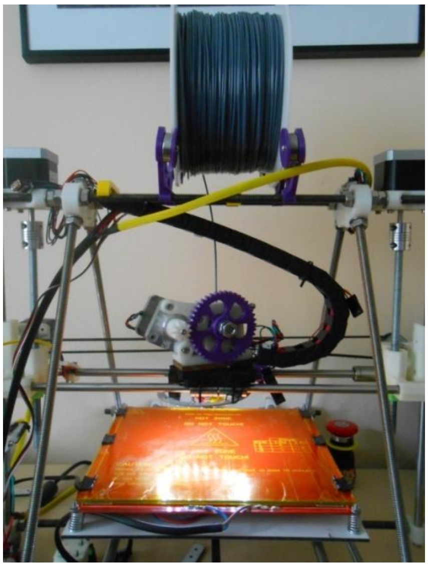

Figure 46: RepRap Prusa Mendel

3D printer that was used is named RepRap Prusa Mendel (12) (Figure 46). It is based on fuse deposition modeling contains electronic part ARDUINO with external source of energy, software slic3r and hardware. Hardware was generally described when RepRap project was mentioned, so now it is only important to mention that printers bed is rectangular with dimension 20x20cm, which means that printed models (or parts of the model) are limited in size with maximum of 20x20x20cm. Bed is made out of glass and caption tape-not heat sensitive; and is covered with “ABS juice” (acetone).
Nozzle of the printer dictates the size of piled layers. This model has nozzle opening 1,7 mm, but due to the heat and compression while piling, layers produced in the end are 0,5mm. Thickness of layers also influences the time needed for printing. For this model, contained from three parts (the front of the frame and two arms) approximately three hours will be needed (1 hour per part). As it was previously mentioned, the printer has coordinate system platform; this can be seen during the process of printing: The bed moves along Y axes, extruder and the nozzle in X axes, and layers are pilled in Z axes.

In order to make a model suitable for printing, it has to be converted into printing instructions for printer: G-code. For this was used “*slic3r”*, a tool that cuts the model into horizontal slices (layers), generates tool paths to fill them and calculates the amount of material to be extruded. The model is imported to *slic3r* where user can adjust the temperature of the room and printer bed. Since this printer is low cost startup kit, bought online average temperature of the room is not so important. In other hand, bed temperature is defined by material being used. Since ABS (Polylactic Acid or Polylactide) was used, it is necessary to set minimum temperature of 100°C.

After setting up material, temperature, nozzle dimensions etc. in slic3r; it exports G-code. These instructions for 3D printer are then imported in Pronterface- 3D printer controller software (Figure 47). During printing it shows a superposed cross section on a diagram updating image every 3 seconds. It also monitors temperature, and presents a diagram with heat and bed temperature.

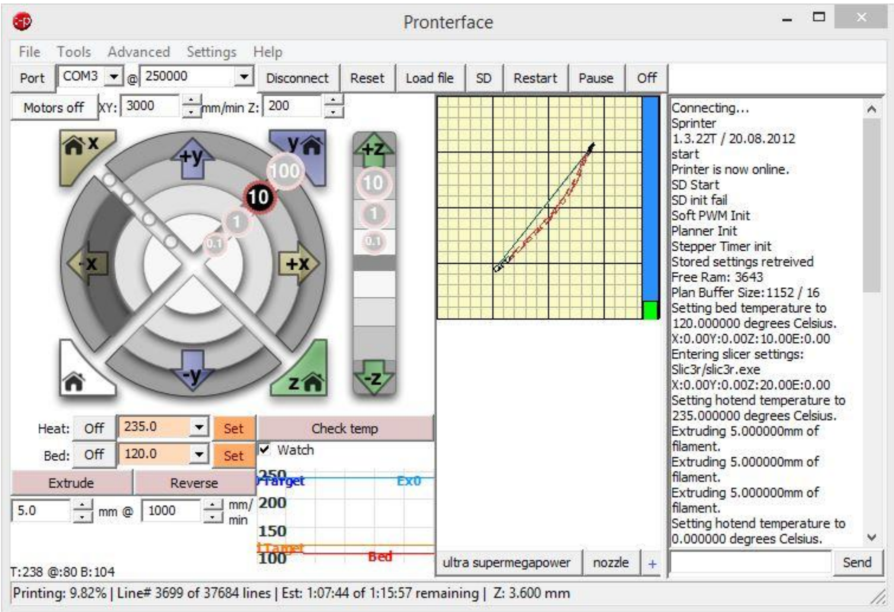

Figure 47: Pronterface

Before the printing process begins, the bed of the printer is turned on 15minutes in advance in order to heat up to 119°C. Printer then using instruction from G-code starts layering with selecting the area that will be taken (Figure 48). If needed, the support structure is built first. Images below show building of support structure for front of the frame, and the frame itself (Figure 49).

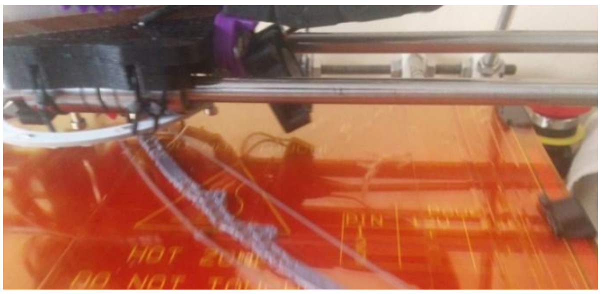

Figure 48: Building of support structure

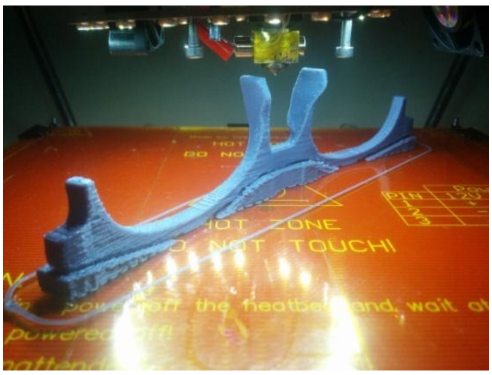

Figure 49: Layering the frame

This model was printed from three parts, both arms and front of the frame needed support structure built before layering of the object itself (Figure 50, 51). Usually support structure is made out of different material so that it can be easily removed, without damaging any of original parts. When it is out of same plastics, it leaves rough surface and some loose endings. This can then further be sanded in order to get smooth surface, but for purposes of this research, the surface of final prototype was not treated.

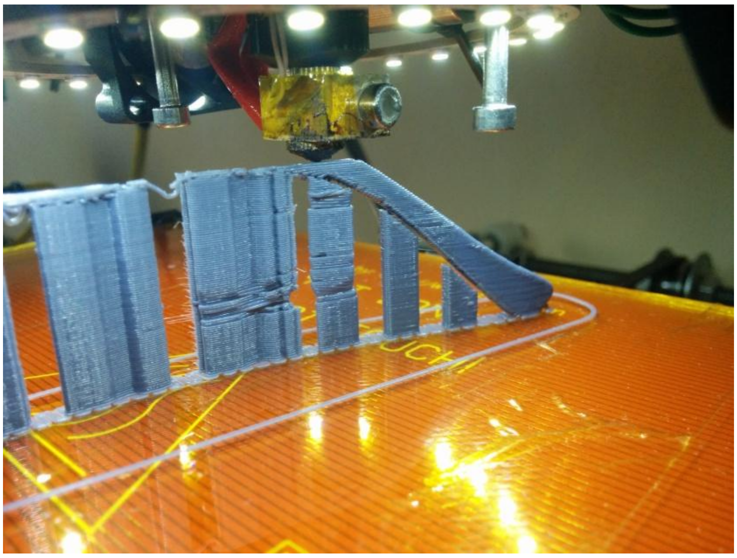

Figure 50: Layering the arm of the object

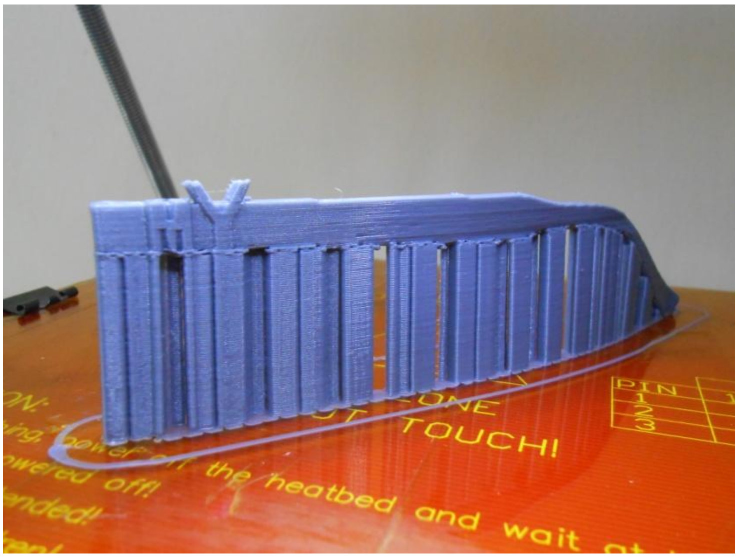

Figure 51: Complete arm of the frame

Discussion:

Analyzing the work and produced prototype can lead to several conclusions. Work in the end consisted from 3 stages: 3D scanning, modeling and 3D printing.

Most time consuming was process of modeling, and introduction to the new software. While analyzing the printed object, previous knowledge as well as availability of software's and devices has to be taken into consideration. PowerSHAPE 2013. CAD software was recommended from the faculty as the only CAD software that can be provided with license. There are newer versions on the market available that are more user-friendly and have more updated tools that make modeling easier. Few steps and modifications were improvised.

The same condition of availability influenced the choice of 3D printer. This kit was bought online and made in student's room. Still, main goal was to see the complete process of a product, from scanning to printing. Therefore, in this case even visible layers and traces of supporting structure are welcome.

Finally produced object is rough, firm, has visible layers, opaque in color and a perfect fit for a head that was scanned. From opticians approach, all optimal standards were respected. It may lack in design, but it is acceptable as a prototype.

13. Conclusion

Nowadays, advanced 3D scanners can produce spectacular results in quality and realism of 3D models. Required effort for producing such models is no less. After seeing what can be done, challenge is in making 3D scanning practical. This technology will bloom as soon as digitizing a physical object becomes equally demanding or even easier than modeling a virtual model in a 3D editor.

The real challenge is not in actual scanning process, but in converting digital data gathered with scanning to a readable format for CAD software. This problem appears because of one simple reason: CAD systems and 3D digitizers define geometry in different way. Most CAD systems define a straight edge with start and end points and center point and radius (diameter) define the edge of a cylinder or a hole; while digitizers define edges by placing a big number of points. Converting this automatically doesn't always produce satisfying results. In this case, available version of CAD software didn't even provide option of automatic conversion. Therefore, one of alternative solutions was used to use obtained .STL model of scanned frame and create a CAD readable format. This solution is based on creating a new geometry over the top of the digitized data, essentially using the scanned data as a template. This process is time consuming but can produce excellent results. For purposes of learning and introduction to new technology as well as software's, created model of spectacle frame is functional and therefore satisfying. The model could be additionally altered in terms of design, but for purposes of this research work it was not so important.

In this research work, Reverse Engineering was used as a learning tool, in the end producing a new, modified frame with 3D scanning. Used 3D printer was chosen solely because of its availability and low cost which left its toll on the quality of produced prototype. The frame could be enhanced if a 3D printer that can use a combination of materials was used. That way, supporting structure could be produced in different material than rest of the frame, making it easier to remove. More important, the screws could be produced out of metal, instead of bought in optics like in this case.

3D scanning is reserved for prototyping (for now) because of its limitations in production time. Time needed is dependent on the number of layers to be printed, as well as speed of the printer head at which it can extrude material. The idea of 3D printing evolving from prototyping to mass production raises a lot of eyebrows regarding intellectual property rights.

Another future goal for 3D printing is implementing integrated electronics of the physical object.

Already present is 4D printing which uses multi material technology that can address each particle of the designed geometry different material properties, allowing it to posses' different water-absorbing properties that can activate the self-assembly process.

This technology is still not commercially available but it is a beginning of a whole innovative world of manufacturing.

14. LITERATURE

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15. APPENDIX

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