



Reverse Engineering for Students: Digitalization and 3D Modelling of Microstructures Using Photogrammetry and 3D Printing

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Abstract

The sense of sight is generally considered to be the most important human sense [1]. Nevertheless, the structure of many small objects is difficult to grasp, since not all special features can be seen with the naked eye. Here, lifelike models on a larger scale help very well to analyze the exact structure and to understand its functions. Using the reverse engineering method, starting with an object - virtual or physical - it is possible to deduce the structure and thus also the function. Reverse engineering methods are often needed when there is little or no information about how the object was originally designed or how it works, which is often the case with biological structures. The whole process of reverse engineering with a 3D scanner allows the transition from a physical object to a CAD model [2]. By developing a 3D scanner capable of creating a realistic 3D digital model of microstructures via photogrammetry, such objects can be digitized and scaled quickly and inexpensively. The working principle of the 3D scanner is to use a fixed camera to capture the object while two stepper motors rotate the object along two axes. The resulting photos of the object are processed into a digital 3D model using special software for photogrammetry. The microstructures can then be printed in a much clearer size with the help of a 3D printer, so that all structures can be recorded well, which has proven to be very practical, especially for teaching purposes.

Keywords: Reverse Engineering, Digitalization, 3D Modeling, Photogrammetry, 3D Printing

1. Introduction

The sense of sight is generally considered to be the most important human sense [1]. Nevertheless, the structure of many small objects is difficult to grasp, since not all special features can be seen with the naked eye. Here, lifelike models on a larger scale help very well to analyze the exact structure and also improve the understanding of its functions. Especially in the case of biological structures the way how a structure was “designed” is often not known and/or the functionality is not clear. The method of reverse engineering can be very helpful there: starting with an object - virtual or physical - it is possible to deduce the structure and thus also the function when there is little or no information about how the object was originally designed or how it works. The whole process of reverse engineering with a 3D scanner allows the transition from a physical object to a CAD model [2]. This model can be used for simulation, 3D scaling and printing or virtual reality applications.

2. Aim of the project

Enlarged models of microstructures should be created and 3D printed for courses in order to improve clarity in teaching. It should be possible to record any structures and print them scaled. By developing a 3D scanner capable of creating a realistic 3D digital model of microstructures via photogrammetry, such objects can be digitized and scaled quickly and inexpensively.

As part of a student bachelor thesis in mechanical engineering, an optical measurement method for digitizing and 3D modeling of microstructures is to be developed and a prototype built and put into operation. Ideally, surface structures in the micrometer range should be recorded and evaluated.

For this purpose, a 3D scanner is designed and further optimized in the course of the project, which is able to create a realistic digital 3D model of microstructures. The working principle of the 3D scanner is to use a fixed camera to capture the object while two stepper motors rotate the object along two axes. In addition, the integrated lighting of the object should be optimized in order to largely avoid shadows and light reflections on the surface of the object.

Subsequently, the 3D models created should also be scaled and used for the 3D printing process in order to obtain the desired enlarged models for teaching purposes.



3. Principle of 3D modeling

Figure 1 represents the measurement principle used for the project: It shows that there are two stepper motors. The first one is used for the rotation of the object and is programmed to rotate gradually 360 degrees, the second stepper motor is used to drive the first to turn the stepper motor to a certain angle so that the camera is able to capture images of the object from different angles while the hemisphere has the task of illuminating the object in order to obtain a good resolution of the images. The camera is programmed in such a way that after each rotation step of the stepper motor it takes a picture automatically. After having recorded enough pictures with a good resolution of the object, the resulting 2D photos are converted into a 3D model by inserting them into photogrammetry software [3].

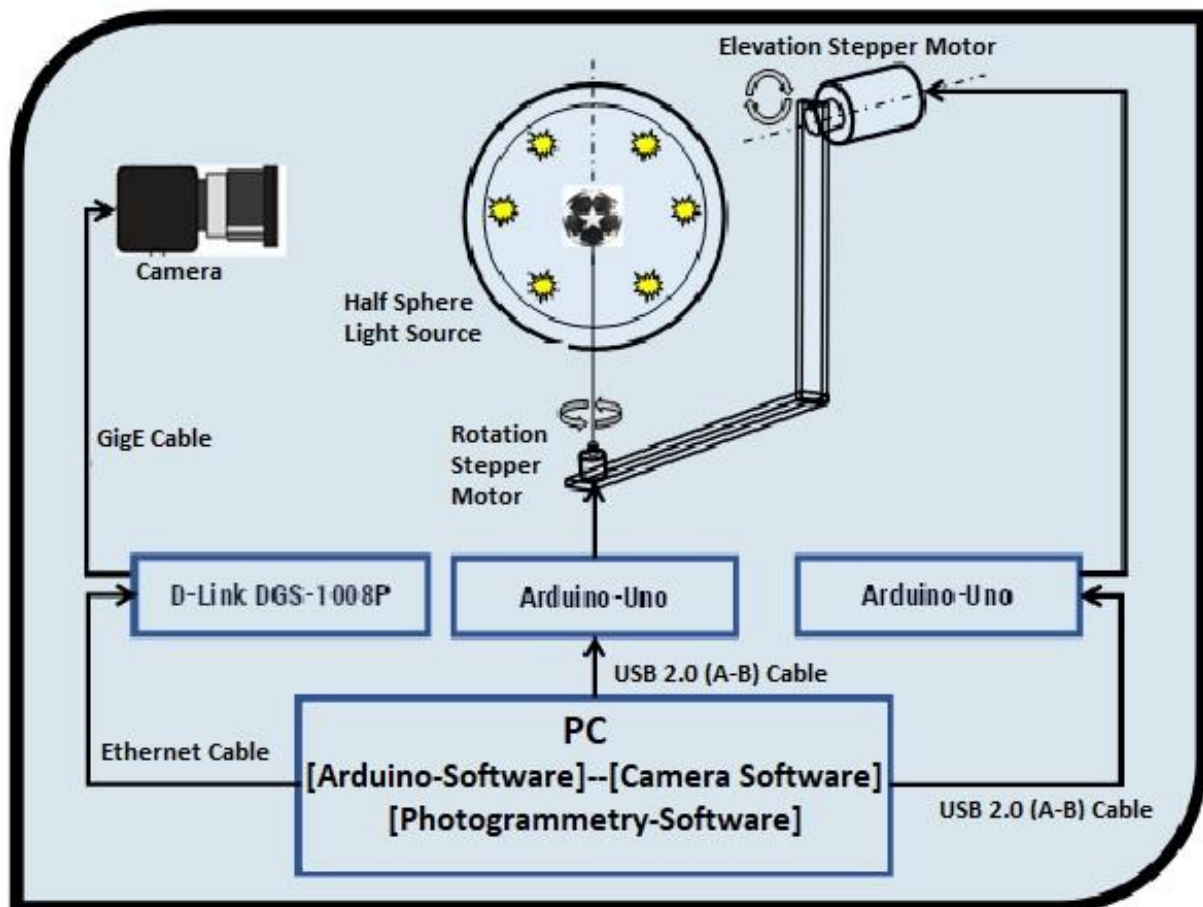


Figure 1: Structure and measuring principle of the 3D scanner [4, modified by J. Mallo, FH Aachen].

4. Practical implementation and used materials

The prototype was built according to the methodical design principles according to the VDI standard 2221 built as shown in Figure 2 [5]. During the design phase, the individual components of the scanner were represented three-dimensionally with the help of Autodesk Inventor Professional software and digitally assembled to form the system of the 3D scanner [6].

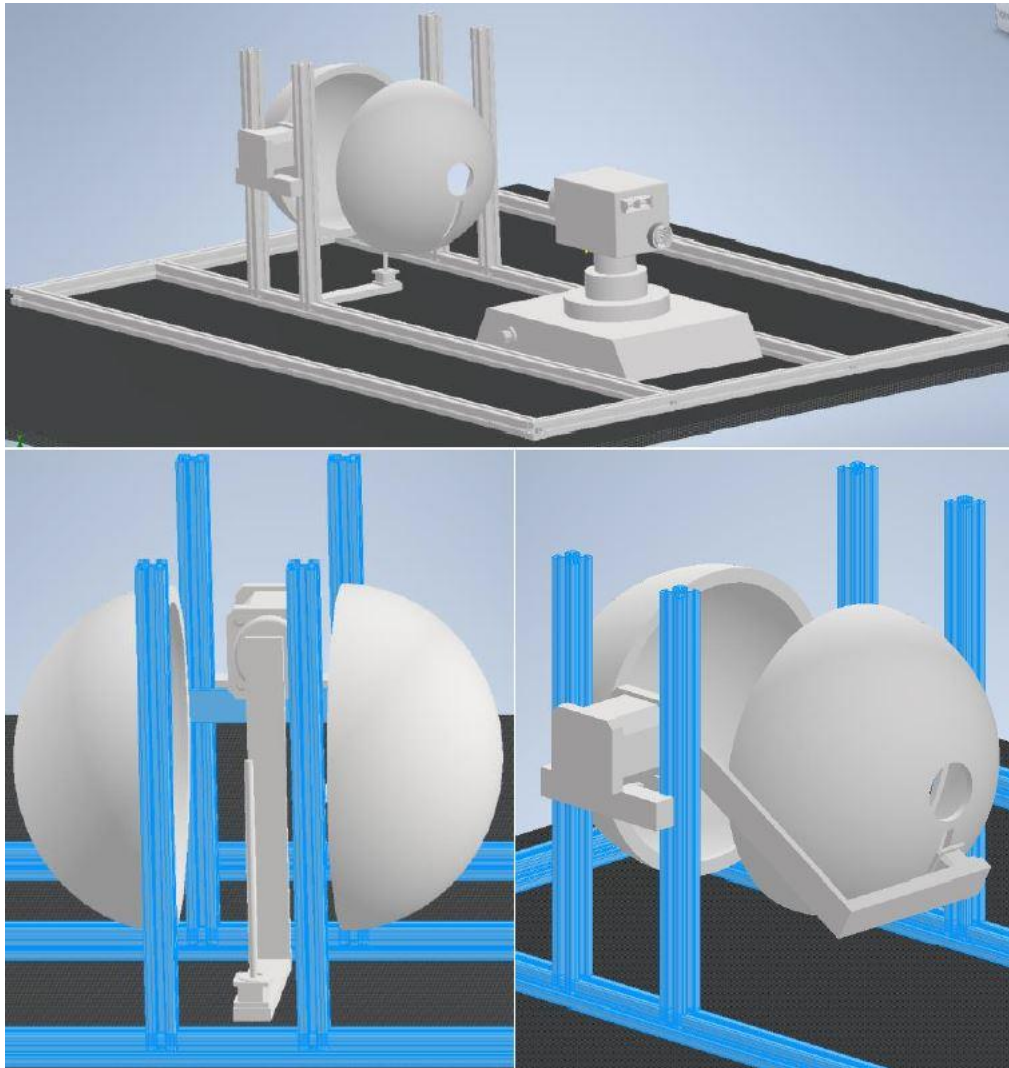


Figure 2: Overview of the structure of the scanner (above), as well as detailed views of the lighting in the two hemispheres and the position of the camera to the object (middle, left) and with a view into one hemisphere (right) [4].

The substructure (shown in blue in Figure 2) was then assembled using item profiles, since sufficient stability can be achieved with these aluminum profiles and at the same time changes can be made quickly and easily [7]. Then the stepper motors [8, 9] and the camera [10] got fixed and connected to the substructure. After that, the illuminated hemispheres are fixed and properly aligned parallel to each other to ensure optimal illumination of the object [11].

5. Data processing for 3D printing

In order to calculate a 3D model of the object from the photos taken from different angles, the photos are read into the Agisoft Metascape software and the 3D model is created with it [3].

The digital model can then be scaled and used for 3D printing. To do this, the geometric information of the object must be translated into a file that tells the 3D printer which movement, executed in which order, creates the desired structure. This requires further data processing: the file of the digital model is imported into the CAD software Autodesk Fusion 360 [12] in order to convert the CAD model into an STL file so that it can later be imported into the software Repetier Host [13]. can be read. Also built into this software is a slicing software component that is used to digitally “slice” the object into appropriate thin layers. This information is sent to the 3D printer as a G-code, which translates it into suitable movements.

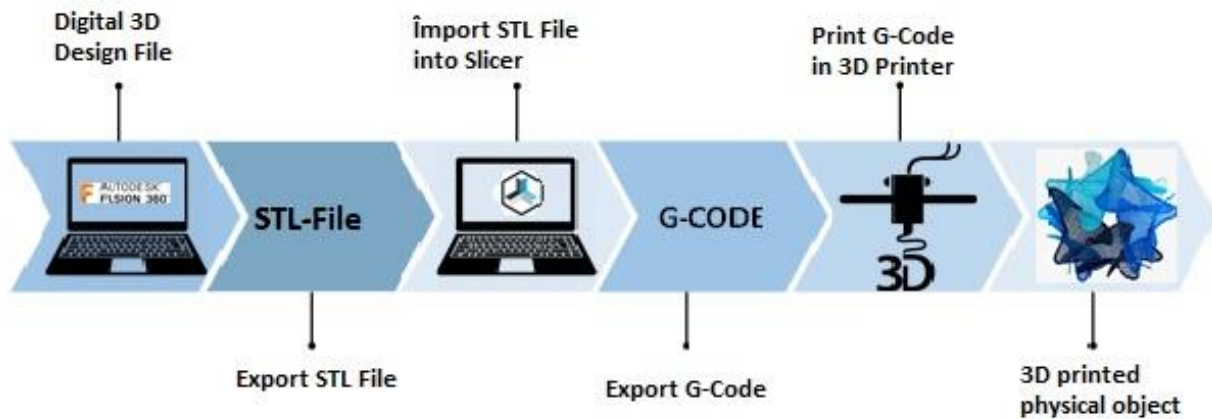


Figure 3: Overview of the data processing process from the digital 3D model over slicing and G-code creation to the 3D printed object [4].

6. Results and Conclusion

After the 3D scanner is ready to use, a complicated object is searched for, that has as many variables as possible in its shape and surface. The reason for this is to test the 3D scanner to see if it is actually capable to scan complex objects. A small wooden shoe was chosen because it has the needed characteristics: small dimensions, different surface colors, complicated shape and damaged surfaces. In parallel, the scanner should also be tested with a complex biological structure. The choice fell on a fossil shark tooth.



Figure 4: Realistic objects and the new 3D printed scaled models [4].

The results of scanning the objects with the 3D scanner show how successful the project was, where the 3D scanner was able to create realistic high-resolution 3D digital models. You can see how much detail the scanner can capture, creating 3D models that are actually even more useful than the actual object. Creating a 3D digital model of an object is important because the model can be enlarged to analyze the model and to see the microstructures on the object's surface that are not visible without the digital model. The results obtained with the 3D scanner show that the scanner is capable of scanning any object, regardless of its size and shape.

One of the main advantages of the 3D scanner is the ability to create a realistic 3D digital model of unknown objects to analyze and share with others. In addition, the 3D models created were of high enough quality to be used in the 3D printing process. With the help of the enlarged models, the students can now better grasp and understand the structure and function of complex micro-objects.



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