# Handheld 3D Scanning and Image Processing for Printing Body Parts - A Workflow Concept and Current Results

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***Abstract*—The combination of current technical possibilities of handheld 3D scanning devices, 3D data analysis and interaction, and novel 3D bioprinting technologies has opened the way to develop workflows and scenarios for the generation of personalized human prosthesis. Specifically, using the human ear as one example to develop a cost-effective chain of methods and tools, the above mentioned combined and interacting technologies can be used to understand and demonstrate the possibilities for rapid bio prototyping. Production workflows for personalized soft-material bio-prosthesis gain significance in reconstructive and plastic surgery. This paper introduces a workflow concept, presents a list of appropriate and accessible state-of-the-art handheld scanners, followed by an image processing solution based on the MeshLab application and printing first prototypes.**

***Keywords—3D handheld scanning, 3D-printing, point clouds, mesh, workflow***

## I. Introduction

Technical developments in the synergetic fields of optical 3D scanning devices, 3D-image and data analysis, including human-machine data and point cloud manipulation and interaction, and recently the availability and use of 3D-printers with the capability to process biomaterials (cells, tissue, muscle, …) have opened new potentials to develop and establish new workflows and scenarios for the generation of personalized human soft tissue prosthesis [1]. Nevertheless, each part of this process chain (scanning, data-manipulation, printing) is often regarded separately by different research groups (e.g. physicists for scanning, computer scientists for data manipulation, bio-engineers for bio-printing), while the aspect of the complete production and adaption process including clinical specifications have only recently been in focus.

Even though research and development activities on bio-prostheses, tissue engineering, automated bio-production and 3D printing go back a couple of years, only some real major break-throughs regarding personalized bio-prostheses can be observed. 3D image techniques are widely used in dentistry. E.g. permanent and temporary tooth implants ("hard tissue prosthesis") can be printed on demand during an intervention [2]. Here it is beneficial that existing printing materials are adequate for such applications. Nevertheless, if body parts of softer material (tissue, cartilage etc.) have to be reproduced for replacement, rigid materials such as metal or plastic may not be applicable. E.g. artificial nose replicas (prostheses) have been printed using colored biologically compatible plastic material in 2012 at the Sheffield University [3-5]. These can be adjusted individually, thus making them less noticeable after serious injuries and reconstruction surgeries. A similar technique has been proposed by a group at the Université Catholique de Louvain (UCL) for pre-surgery preparation to reduce waiting prior and during surgery [6-8]. Using 3D CT scans metallic implants were designed prior to the surgery in high accuracy, and are then individually adjusted to the patient. The 3D printer used in this research was based on a low-cost paper material using so-called laminated object manufacturing (LOM) [9]. During the LOM process, layers of plastic or paper are fused — or laminated — using heat and pressure, and then cut into the desired shape with a computer-controlled laser or blade. While LOM is not the most popular method of 3D printing, it is still one of the fastest and most affordable ways to create 3D prototypes. Researchers at Princeton University have recently printed an artificial pinnae with an integrated antenna [10, 11]. The material used was composed of hydrogel, silver nano particles and mesh. Printed bionic material that can coexist with living cells and human tissue has been in focus at Cornell University and at the University in Munich. Printed artificial basis for the pinnae having small holes can be used as a "motherboard" that will be overgrown by the human living tissue. For commercial use, there exists a novel method recently applied to individually fitted in-ear-headphones [12]. Users have to take pictures of their pinnae via a software application on their smartphone, and optimally fitted headphones will be printed in 3D and shipped within two days.

In this paper the human outer ear shape and form (pinnae) is used as a study example to suggest a chain of methods and interfaces to bridge the current observable gap between various well understood, and more and more affordable 3D-scanning, image data manipulation technologies and the recently new development of 3D printers. Furthermore, results of initial experiments along this workflow are described.

## II. Workflow pipeline

Technology improvements in medical engineering target various fields of applications from administrative management, logistics, wearable and AR/VR devices to advanced manufacturing. One emerging field is the introduction of IoT, big data (of monitoring sensor information) extended by artificial intelligence and smart decision making (IoE) and cognitive aspects and human factors (IoD) [13-17]. The other current research area includes smart manufacturing, rapid prototyping and experimenting with new materials for implants and protheses.

The classical handmade manufacturing of soft tissue/material prostheses could be in the future enhanced or replaced by adequate 3D printers and thereby increase accuracy and quality, furthermore, decrease costs and manufacture (waiting) time [18-20]. It has to be highlighted that it is a driving factor here to setup a workflow chain using commercially available, accessible, relatively low-cost solutions. To do so, expensive equipment (large scanners) and bio-printers (e.g. printing living tissue) are not evaluated and taken into consideration.

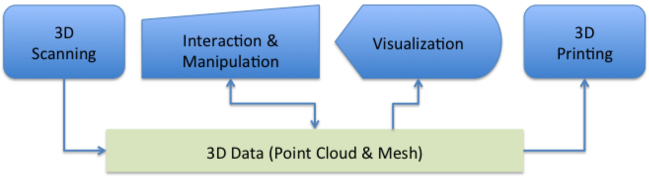


Fig. 1. Schematic of the interaction of 3D data processing modules (scanning, manipulation, visualization, printing) within a pipeline for the production of (outer ear) bio-prothesis.

The envisioned prototypic system mainly consists of a software platform (Fig. 1) being able to (a) address and read data from various scanning hardware ranging from professional scanning equipment to lower quality webcams, (b) to interactive handle and manipulate large 3D point clouds, (c) to visualize the point cloud and mesh data, and (d) to use these 3D point cloud and mesh data to address 3D-printing or manufacturing devices in order to produce soft-tissue/material prosthesis. The center point is therefore the 3D data mesh, serving both as input and output of the process.

The pipeline has the following elements:

- Handheld portable 3D scanner enabling rapid scanning of the body part(s) during medical consultation or other locations (at home);
- Importing data in standardized formats;
- Image handling and reconstruction using (open source) software solutions including
    - filling the mesh
    - cutting unwanted areas (parts of the skull)
    - correcting, resizing the mesh (if needed)
    - mirroring and/or creating the negative (if needed)
    - exporting the files to printer friendly formats;
- Choosing the appropriate printing material(s);
- Post processing of the printed samples (cutting, polishing, adjustment in size and form, allocating fixing points etc.);
- Implantation (surgery) and follow-up.

Optimum solution for each patient have to be considered individually regarding cost and time effort, intervention method, especially how to fix the ear replica on the head.

## III. 3D SCANNING

3D scanning is a process of analyzing real world objects by creating 3D models using different technologies. The most important are (contactless) structured-light scanners, LiDAR, Time Of Flight (TOF) scanners – all being able to avoid destructive testing [21-26]. Optical, laser and acoustic (ultrasound) sensors are the most common [27, 28].

The 3D model itself is a point cloud or polygon mesh (usually based on triangles). All scanners have a field of view (FOW) in which objects will be scanned and the distance of the scanned surface will be determined. Usually, multiple cameras are attached and the 3D model is reconstructed by multiple images during the „alignment" procedure. Active devices produce radiation and reflections will be detected. Figure 2 shows scanned images with the former Kinect device.

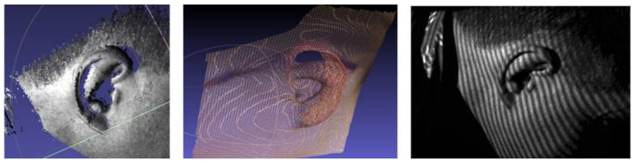

Fig. 2. Data acquired from a former Kinect-setup and so called tripe projection setup. Handheld scanners offer better quality.

TOF uses laser light to probe the object. The so called „laser range finder" detects the distance of a surface point by measuring the round-trip time of a light pulse and calculating the distance. Only one point can be measured at a time, so the detector has to be moved (rotated) during scanning. Some ten thousand of points can be measured per second, accuracy is around 1 mm. They can be operated over large distances and used for large objects. Furthermore, high definition scans can take minutes, and movement of the object or vibrations can cause distortions. Although there exist methods for compensation, these devices are not optimal for scanning body parts.

Another popular solution is a hand-held laser scanner [29-32]. It uses triangulation, where a laser dot or line is projected onto an object from the device and a sensor measures the distance to the surface. Data is determined in an internal coordinate system, thus if the scanner is in motion, the position of the scanner must be constantly determined and updated. This can be achieved using references on the surface or by external tracking methods. Structured-light 3D scanners project a pattern of light and determine the deformation of it on the object. The pattern is projected by a stable light source. Another camera calculates the distance of every point in the field of view based on the shape of the pattern.

Structured-light scanners are fast and precise. They scan multiple points or the entire field of view at once. Scanning in less than a second reduces the problem of distortion from motion, thus moving objects can be scanned real-time. It is possible to scan (human) body parts and even dynamically deformable objects (such as facial expressions, moving hands etc.).

In medicine, computed tomography (CT) is used, where a 3D image of the inside of an object can be reconstructed based on 2D X-Ray images. MRI is similar, having greater contrast between soft tissues than CT. Industrial applications are available if non-destructive material testing is required for determining the interior of an object. However, scanning outer body parts does not require CT or MRI techniques.

## IV. 2021 MODELS

Four different models of currently available handheld scanners were tested. See figure 3 in the Appendix showing all devices for comparison.

The Creaform Go!SCAN 3D color handheld scanner offers fast measurements during product development where both the object and scanner can be moved freely during scanning. It is lightweight, has an accuracy up to 0,05 mm using measurement rates of 1,500,000 per second, ready-to-use instant mesh file outputs in various formats for various 3D modelling software solutions (see Fig. 4) [33].

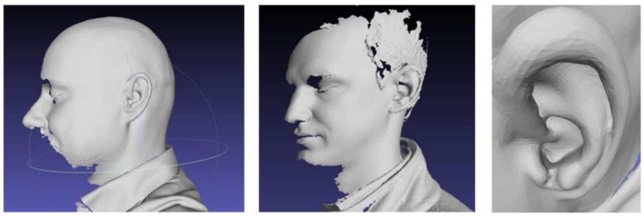

Fig. 4 .Scanned images using Go!SCAN opened in MeshLab.

The SIMSCAN 3D Scanner is a hand-sized portable 3D scanner that performs high-quality 3D scanning without any restriction of the working environment constructing the 3D model in a very short time. Under parallel blue laser mode or single line deep hole mode it is designed for scanning complex surfaces (Fig. 5). Using 11 crossed blue lasers results in 2,020,000 measurements per second and a 410*400 mm scanning area [34].

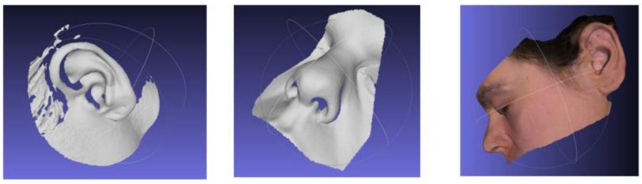

Fig. 5. Scanned images of earlobe, nose using SIMSCAN 3D and left side of a face in color using iReal 2S in MeshLab.

The iReal 2S adopts double scattering speckle technology: blue LED light and infrared light, making it totally safe and comfortable for body and face scans (even eyes and hair). This color 3D scanner features in high-definition texture capturing capacity and color reproduction, wide scan area, fast scanning speed, intelligent alignment with our without markers for irregular textures or geometric features, and fully automatic post-processing algorithm [35].

The EinScan H system is a hybrid LED and Infrared Light Source Handheld Color 3D Scanner. Based on hybrid structure light technology of LED and invisible infrared light, EinScan H is making human face and hair scanning more comfortable without strong light (Fig. 6). With a built-in color camera and large field of view it provides high quality 3D data in full color.

Fig. 6. Scanned images using EinScan H.

Hybrid structure light source technology integrating LED structured light and invisible infrared light into one device and adding advanced smart presetting in different scan modes allows 3D scanning in a broad range of applications.

The high accuracy of scanned data up to 0,05 mm and volumetric accuracy 0.1 mm/m improves the precision of 3D modeling in a dense points cloud or polygon meshes. Scan speed up to 1,200,000 measurement per second and large scan field of view of 420*440 mm ensure fast 3D scanning of large size objects. The larger member of the family called EinScan Pro HD delivers even more efficiency of high-quality 3D modeling, high resolution for fine details, an inherited multi-functional and modular design. By adopting a new structure light projection modular, the stripe pattern scanning which was traditionally used in Fixed Scan Mode is now utilized to Handheld HD Scan Mode. It is processing up to 3,000,000 measurements per second under handheld scan mode [36].

## V. Image Handling

The 3D model itself is a point cloud or polygon mesh (usually based on triangles) [37]. *MeshLab* is a 3D polygon mesh processing, editing and management system [38]. It is a free, open-source platform widely used with 3D scanners and printers. *Autodesk Fusion 360* is another cloud-based 3D modelling platform for product design and manufacturing, offering also free licenses given the proper conditions.

The main task is to import scanned point clouds, editing (cutting, resizing), correcting errors (filling the leaks), mirroring (if needed). Furthermore, creating the negative of the scanned object can be printed for molted materials.

Point cloud formats can be binary or ASCII stored in different file formats. The three file formats commonly used in 3D printing are STL, OBJ, and PLY. In STL files, the tiles used are triangles covering the surface of a 2D shape. It is universally recognized, files are simple and small allowing faster processing in rapid prototyping and 3D printing. The files describe only the surface geometry of a three-dimensional object without any representation of color, texture or other common CAD model attributes. It can be ASCII and binary. An OBJ file can be also both binary and ASCII. It is widely used for 3D graphics applications. It can store color and texture information suitable for advanced 3D printers. Similarly, PLY was designed to store three-dimensional data from scanners. The format is a simple description of a single object as a list of nominally flat polygons. Color, transparency, surface normals, texture coordinates and data confidence values can be also stored. Furthermore, the PTX format can be both ASCII and binary, but in an ASCII format, it is specifically designed for saving point cloud data from laser scanning systems.

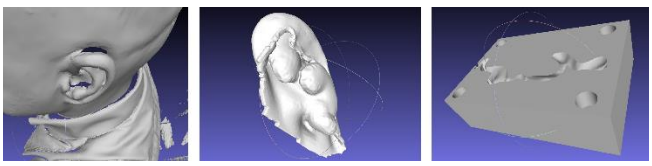

Fig. 7. Incomplete scanned image showing deficiencies in the mesh behind the earlobe (left), backside of the reconstructed model ready for printing (middle), and a mold-box model for hard material print (right).

Figure 7 shows a “leaky” mesh of a scanned ear resulting in an incomplete reconstructed print model that is too small and insufficient for an implant. Another solution could be to create a mold-box structure around the ear model that can be printed using hard material. However, cutting it to halves for filling it with congealing material is difficult.

MeshLab handles, writes and reads the most common 3D triangle mesh data formats such as OBJ, PLY and STL. All these formats are supported by the scanners mentioned above. Although these formats can store color information, this is not required for our purposes.

## VI. 3D PRINTING

3D printing has been introduced to medical application for a long time. First, temporary and permanent hard tissue prostheses were used in dentistry, where individual shaped parts could be printed and implanted. Existing printing materials are adequate for such applications. On the other hand, metal and hard plastic materials cannot be used where soft tissue has to be replaced (cartilage, moving body parts etc.).

State-of-the-art high tech solutions offer biologically compatible plastic materials, materials for Laminated object manufacturing (LOM), hydrogel, silver nano particles etc. [4,5,11,18]. Printed bionic material can coexist with living cells that overgrows printed material. Although these methods highlight straightforward solutions for the future, accessibility, costs, time are critical issues, thus, not optimal for everyday clinical use yet.

On the other end of the technology, handmade manufacturing of implants are used in reconstruction surgery, where surgeons are sculpting implants prior and/or during surgery resulting in individually shaped replicas, but also in long manufacturing and surgery times.

Recent technologies offer methods filling the gap between these solutions and offering fast manufacturing time using 3D scanning, 3D image processing and printing in high accuracy in reasonable time frame and costs limits. Plastic surgery is one of the main fields that can benefit from this technology, especially where functionality and aesthetics play a significant role (nose, earlobes) [39-46].

There are a few technologies regarding 3D printing known as Additive Manufacturing (AM) or Rapid Prototyping (RP). Within AM there exists inkjet basis 3D printing, FDM (fused deposition modelling), SLA (stereolitography) and SLS (selective laser sintering), all of them can be used for healthcare services, personalized prosthesis manufacturing etc. [47-50].

Fig. 8. (a) first print (b) second print.

As a first result of a prototyping printing, two earlobe replicas were printed (Fig. 8). For scanning the HandyScan3D was used, for printing the Objet Pro printer with FullCure 705 photopolimer. The raw scanned data were optimized during post-processing using MeshLAB. For printing only white and black materials were available, but there exist several other colors imitating skin colors as well. The ear replicas have an accuracy of about 1 mm, are relatively flexible, similar to real human tissue.

The main motivation behind these tests was to design and legitimate a workflow pipeline, a well-defined series of steps and recommendations from the beginning to the end. This has to be time and cost effective, simple, individually customizable, beneficial for both medical personnel and patient.

Analyzing the outcomes of the tests, currently available handheld scanners can be purchased, implemented and operated easily. They deliver the required accuracy and resolution for scanning outer body parts supported by various standardized data formats for the meshes. A free software is accessible for post processing using its basic functions to create printer-friendly files. The most critical step is the printing itself, as it could be time-consuming and a variety of different materials exist. Furthermore, outsourcing of the printing task to third-party service providers can cause time delays. Nevertheless, in case of hospitals, purchasing both scanner and printer would be reasonable.

Future works include printing further replicas for surgical purposes, testing for stitches and sterilization as well as informal questioning of possible patients' feedback. Furthermore, the emerging field of 3D total body photography - that is able to create 3D models based on a series of 2D images - can be explored and compared. This technique has been used for early detection of melanomas, however, it has limitations (accuracy, resolution, reliability) [51-54].

## VII. CONCLUSION

A 3D image processing workflow was proposed, focusing on current handheld scanners, image handling methods and prototype printing of earlobes. Handmade manufacturing of surgical implants of soft materials should be replaced by cost-effective accurate manufacturing procedures in the future. Nowadays, both scanning and printing systems allow producing of replicas and implants within reasonable time and cost frames. The presented pipeline is put for further research to assist reconstruction and plastic surgery – in this case – in the field of outer ear replicas (earlobes). Our recommendation would be the SIMSCAN device using exported PLY and/or OBJ formats that can be easily adopted by the open-source MeshLab. Prototypes of soft plastic materials will be printed, tested and implanted.


## ACKNOWLEDGMENT

This research was supported by the Ministry of Technology and Innovation in the bilateral technology and scientific cooperation framework program "2019-2.1.11-TÉT-2020-00199".

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## APPENDIX


The Creaform Go!SCAN plug and play system with 99 white light scanning lines (price around 36,000 EUR).

The iREAL 2S system with double scattering technology (price around 12,000 EUR).

The SIMSCAN 3D system with blue laser mode (price around 30,000 EUR).

The EinScan Shining 3D and Pro HD system with hybrid LED and Infrared Light Source (price around 6.000-12,000 EUR).

Fig. 3. Comparison of handheld scanners used for tests based on technology and price.