A new approach on 3D scanning-printing technologies with medical applications

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Abstract. The 3D printer is a very much discussed subject nowadays. It has many positive aspects and its purpose is to minimize costs, streamline complex processes, and shorten implementation times. From simple applications to complex systems, almost any assembly or subassembly can be reproduced using 3D printers, either based on a design or on a 3D real-world scan. Medicine is one of the domains that has turned to these devices, achieving amazing performance. 3D scanning and printing are basic elements in the development of new processes that were not possible at the moment. Thus, there are 3D models of the external ear of the human ear, applications in the repair of the epithelium affected by certain external factors, prostheses, medical models, and heart valves. In the present paper, we aim to explore, presenting advantages and disadvantages, existing systems for 3D scanning and designing of 3D models for printing in the field of orthopaedics.

1. 3D Printing: reminding the history

3D printing is a manufacturing method in which materials such as plastic or metal are deposited together in layers to produce a three-dimensional object. Even though it's been talked about 3D printing intensely for only a few years, it has a longer history. In 1981, Japanese researcher Hideo Kodama, from the Nagoya Municipal Industrial Research Institute, presented for the first time a paper on a functional technology that could enable a 3D printer.

The technology involved the use of photopolymers (special resins that come into contact with ultraviolet light) and their stratification until they reach the desired shape. An even more important role was played by Charles Hull, who in 1984 invented stereolithography (SLA), technology that allowed the creation of 3D objects based on digital models using a computer and photopolymers.

The first industrial machine to automate the printing process was created in 1992 by Hull's company. Frequent use of 3D printers in the field of medicine began in 1999, when the first 3D printed organ was created and implanted into a person. It is a human bladder created from the patient's own cells that received the implant in a 3D matrix printer.

After this success, advances in the medicine industry have ceased to occur: kidneys, complex prostheses, and blood vessels have been created [1].
2. 3D Printing: the present days

According to several researched studies, at present, there are thousands of applications in various industries, but in medicine the results of 3D printing predict a radical transformation of this field. Custom dentures are already printed on the patient's conformation, bone density, age, and morphophysiological features. Cranial reconstructions with titanium implants have been performed and implants are produced. The American Food and Drug Administration (FDA) approved the first printed drug 3 years ago. Skin grafts are produced and tested and bones made of polymers are made frequently. Further there are presented several achievements in the medical industry that are made by maximizing the benefits of 3D printing [2].

The 3DBio Startup has printed 3D reproduction of the thyroid gland. The Fraunhofer Institute uses bioprinting of organic stem cells based inks for blood vessel production - tubes that reproduce the properties of human arteries and veins that are then "dressed" in proteins. Organovo Medical Research Company produces liver cells capable of functioning for 40 days.

All of these advances serve as a basis for other experiments, which aim at producing entirely vital organs that reduce human addiction. Until this is possible, more and more universities use customized 3D models of tumor organs (based on data from tomography) that are used by surgeons to prepare for removal [2, 3].

Princeton University created a prototype of Hi-Fi ear using a hydrogel skeleton using cartilage-producing stem cells as well as silver nanoparticles that form an antenna that detects radio frequencies that exceed the human spectrum. The University of Edinburgh uses stem cell material extracted from brain tumors of patients to observe their development and test the effect of different drugs.

The Nottingham Trent University has created, through 3D printing, biodegradable bone implants that can be used to treat bone cancer and major fractures. Synthetic bones reproduce the porous structure and are printed from a substance that contains the same minerals as human bones, which allows them to dissolve over time with the growth of organic tissue.

Following the same principle of operation, Imperial University of London uses a biopolymer obtained through 3D printing in cartilage recovery surgery. The solution is based on printing a 3D skeleton of polycaprolactone that is filled with cells; as the tissue develops, the biopolymer dematerializes, leaving the cellular structure to reconnect to the cells of the patient's body [2, 3].

3. 3D Printing: a new approach for sport medicine

The magnitude of sport nowadays is unprecedented in the history of modern society. This has been done from one geographical area to the next, and it diversifies its sporting branches and is now reaching shapes and structures of some sporting branches that could not previously be considered unfeasible.

In parallel with this phenomenon, we see the necessity of medicine in general, and of sports medicine in particular, to keep up with the intervention as quickly as possible in the case of injuries. An important thing is also to prevent and recover injuries during sports activities.

The newest method to help sports medicine is 3D Scanning and Printing or three-dimensional printing known as "additive manufacturing" technology that overlays successive layers of material (in our case plastic) under computer control, the result being a three-dimensional object [4, 5]. These printers are used in a wide range of industries, one of them being sports medicine.

At present, the results of 3D printing predict a radical transformation of this area. Custom "prostheses" are printed based on conformation, bone density, age and morpho-physiological features of the patient, in our case, of the athlete concerned. There are several cases solved in this field, that prove that the future approaches could reach many of the particular sport related medical issues [6].

Denise Schindler, a one-legged German rider, participated in an Olympic Games edition with the first 3D printed prosthesis (Figure 1). This denture was made using the Autodesk 3D design environment that allowed a customized prosthesis to be created. The whole process of making this prosthesis lasted 5 days and has costed 5 times more than a traditional prosthesis traditionally obtained.
The ability to practice a sport despite a possible accident, such as the broken nose, is the challenge the London Cavendish Imaging Institute has managed to overcome. Using 3D equipment and software, they scanned each detail of a sportsman's face to print a customized protective mask, as shown in Figure 2. This innovation reduces the inactivity of an athlete and also prevents the injury during the healing process [6].
Another innovation was designed and created by the Austrian firm Zweikampf. The 3D printed shin guards provide better resistance to blows through three layers of protection, with weight reduced to a few tens of grams (Figure 3).

![Image of 3D printed shin guard](image)

Figure 3. 3D printed shin guard.

In addition, these shin guards are fully customizable [6].

4. Proposed solution for lower limb trauma

The most common injuries are ankle sprains, knee trauma, meniscal ruptures and collateral ligament spurs as shown in some studies. Thus, according to a clinical, observational, retrospective study on a group of 29 athletes, in which these athletes completed a questionnaire with 8 items and the data obtained were processed in SPSS20, it was observed that the most affected anatomical region was knee joint 62.1%, followed by joint elbow 17.3% and ankle 13.8%. In 17 (58.7%) of the subjects, the trauma was twisted, 7 (24.1%) suffered dislocations, 4 (13.8%) had were diagnosed with fractures and 1 (3.4%) with muscle stretch [7].

It is proposed to create orthotics through the ankle by 3D printer technology. To be able to print a 3D ankle orthosis, it is necessary to scan the respective area of an athlete's foot using a revolutionary method. This method consists of using a Kinect for Windows so set to allow you to scan the affected foot area through a specialized program. The image obtained is processed and, starting from this representation, an orthopaedic 3D design is made in an orthopaedic 3D design specific to the size of the affected foot of the athlete. Orthopaedic design is made from several constructive parts to allow for more accurate 3D printing. 3D projections are then printed using 3D printers. The pieces are connected to each other and thus the desired orthosis is obtained. The whole process is described in Figure 4.

![Diagram of the steps of achieving an orthosis using the proposed method](image)

Figure 4. The steps of achieving an orthosis using the proposed method.
The proper construction and use of these models or the creation of orthosis is guided by the needs of each patient. Once the need for a patient has been established, there are five important steps that are often linked to the 3D print process to create patient-specific prosthesis patterns and have maximum anatomical fidelity:

1. capturing the image of the area of interest
2. creating 3D geometry
3. transforming the 3D object into a ready-to-print file
4. selecting the appropriate 3D printer
5. selecting the appropriate materials for printing

The 3D scanning is a method that can generate a three-dimensional model of an object based on an acquisition system specially configured to capture images in real time that work with an interactive system based on a display device that is connected to a network interface.

This system is specially designed based on the acquisition system to capture a multitude of images of the object and compute them in depth maps. A depth map is generated for each pose of the object and it is combined to a point cloud into a 3D mesh model [8]. In order to obtain a full scale scanned 3D model, which includes the 3D geometry of the foot ankle of a test subject, we used a Microsoft 3D Kinect scanner, presented in Figure 5, based on two key components: an light projector that is able to emitting an infrared light pattern with 830 nm wavelength and a video camera with same wavelength to receive the pattern emitted by the light projector [9].

![Figure 5. Kinect 3D scanner.](image)

The Kinect can reconstruct the image pattern based on a pseudo-random location that uses the active triangulation to obtain the position for each 3D point by combining the points resulting from the intersection of the optical rays in the pixel projector of the colour camera. [9]. So, the Kinect can acquire 3D colour image with 640*480 depth at a frames rate of 30 frames per second [10].

The result of 3d scanning presented in Figure 6 has been processed into a 3D computer-aided design software based on which it has been determined the dimensions of the foot of the test subject represented in millimetres.

![Figure 6. The 3D scanning result.](image)
The orthosis of the ankle joint was 3D designed in SolidWorks computer assisted design software that allows designers to project 3D objects from 2D sketches [11]. In the designing process of the conceiving 3D orthosis (Figure 7) was taken into account the anatomical parameters of the test subject such as: the subject weight, the foot shape and the foot paw size, all obtained in the 3D scanning process.

![Figure 7. 3D orthosis sketch with dimensions.](image)

Regarding the functional structure of the orthosis, it consists of 3 elements (Figure 8): the shank section which has a role in immobilization of leg, the strut rails section to support the weight of the use and to ensure foot mobility and foot section zone that ensures the holding of the foot paw.

![Figure 8. The 3D foot ankle orthosis design.](image)
Based on the use of the foot ankle orthosis by the subject is followed to correct the ankle posture to improve the pathological gait of the patients and to supports weakened muscles around the ankle during rehabilitation process.

In Figure 9 is presented the ensemble of the scanned 3D foot positioned inside the designed 3D ankle orthosis to ensure the fitting of the solution. The 3D assembled model result based on the linking together the 3D model of foot ankle orthosis with the 3D scanning model of test user foot.

![Figure 9. 3D foot scan and 3D orthosis.](image)

It is noticed that using relatively inexpensive 3D scanning and printing solutions along with 3D modelling solutions can produce highly reliable and accurately designed products for the needs of some subjects [11-13].

5. Conclusions
The future of society seems to be very closely related to the future of 3D printers. Currently, they are constantly being used in medicine and we are always seeing revolutionary 3D prints, but also various attempts to make aiding devices to ease our life’s.

Almost all today’s devices are undergoing a prototype process that includes 3D scanning and printing, but, in the future, we may see the same objects and mass-produced devices done with 3D printers.

This paper presents an innovative method of achieving a sports orthotics designed using 3D scanning equipment as a device Kinect for Windows. Using this 3D scanning device is extremely easy with a relatively low cost. Also eliminates the possible radiation that can affect an athlete when using equipment specific to the medical industry (X-ray scanning). Then, starting from the scanned 3D image of the traumatic foot area, 3D modelling of a orthotics is performed according to the anatomical dimensions of the scanned area. The 3D orthopaedic design in a specific design environment is divided into several pieces so it can then be 3D printed using a 3D printer after choosing the required materials. In this paper, it was attempted to highlight the fact that very simple orthopaedic devices can be made using 3D scanning and printing. This has been exemplified by an ankle orthosis because it
has been noticed that in the case of athletes the most common injuries are those suffered in the ankle. The use of this method of producing such medical devices brings, besides the low costs and an increase in the precision of taking the data necessary to obtain a 3D model specific to each possible patient. The method can also be applied to other traumas suffered by patients. The entire system also has extraordinary portability because it is necessary to work in optimal parameters only a laptop that has installed a 3D scanning program and a 3D design environment and the Kinect for Windows device. This eliminates the need to use, in particular for scanning, the devices such as CT scanners.

6. References
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