Lecture Notes in Mechanical Engineering

Filip Gorski
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Advances in Manufacturing III

Volume 5 - Biomedical Engineering: Research and Technology Innovations, Industry 4.0

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Volume 5 - Biomedical Engineering: Research and Technology Innovations, Industry 4.0

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Preface

This volume of Lecture Notes in Mechanical Engineering gathers selected papers presented at the 7th International Scientific-Technical Conference MANUFACTURING 2022, held in Poznan, Poland, on May 16–19, 2022. The conference was organized by the Faculty of Mechanical Engineering, Poznan University of Technology, Poland.

The aim of the conference was to present the latest achievements in the broad field of mechanical engineering and to provide an occasion for discussion and exchange of views and opinions. The conference covered topics as follows:

- mechanical engineering
- production engineering
- quality engineering
- measurement and control systems
- biomedical engineering.

The organizers received 165 contributions from 23 countries around the world. After a thorough peer-review process, the committee accepted 91 papers for conference proceedings prepared by 264 authors from 23 countries (acceptance rate around 55%). Extended versions of selected best papers will be published in the following journals: *Management and Production Engineering Review, Bulletin of the Polish Academy of Sciences: Technical Sciences, Materials, Applied Sciences.*

The book **Advances in Manufacturing III** is organized into five volumes that correspond to the main conference disciplines mentioned above.

Advances in Manufacturing III – Volume 5 - Biomedical Engineering: Research and Technology Innovations, Industry 4.0 presents current research and technology trends in the young, yet exciting field of biomedical engineering. Chapters were carefully selected to highlight important advancements in the field of design, digital analysis, and 3D printing of medical devices. Current challenges related to the application of medical imaging and 3D scanning are discussed, as well as the application of finite element analysis in bioimaging. Additive manufacturing technologies used for developing personalized medical devices are also

discussed. Further, the application of production and quality management tools in medical engineering is described. This book gathers 13 chapters prepared by 40 authors from five countries.

We would like to thank the members of the international program committee for their hard work during the review process.

We acknowledge all people that contributed to the staging of MANUFACTURING 2022: authors, committees, and sponsors. Their involvement and hard work were crucial to the success of the MANUFACTURING 2022 conference.

May 2022

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Contents

Evaluation of a Prototype System of Automated Design and Rapid Manufacturing of Orthopaedic Supplies

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Abstract. The aim of this study was to evaluate the AutoMedPrint system, which is used for automated design and rapid production of orthopaedic and prosthetic devices based on anthropometric measurements. The system was tested on a group of 21 patients. Research has been conducted to determine their needs and expectations. In the first step, anthropometric data was collected using a 3D scanner. The obtained data allowed to automatically design wrist-hand orthosis using an intelligent CAD model. Patients customized their orthoses using interactive product configurator available in the system. Some orthoses were manufactured using the necessary machines by 3D printing, and then handed over to selected patients for their opinion. The paper presents the results of usability tests and the evaluation of the technical aspects of the system. Based on these results, the main problems were characterized and ways to improve the system were suggested. Modifications are designed to improve patient satisfaction, usability, ease of use, and the enjoyment of interacting with a system or product.

Keywords: Additive manufacturing · Customization · Design automation · Medical 3D printing

1 Introduction

The rapid development of additive manufacturing technology in recent years has allowed a significant reduction in costs and time needed to implement a new product. Additive manufacturing processes make it possible to obtain physical, 3D shapes of almost any complexity, directly from a digital representation of the product (usually a model made in a Computer Aided Design - CAD system) [1]. There is no need to use any specialized tooling besides the production machine equipment. These technologies are invaluable when there is a need to quickly manufacturing of a physical prototype of a designed part [1], which is especially important in personalized medicine [2–4]. Using of 3D technology also allows to show the expected product to the patient before its production and provide him/her with flexible design options, which can be used in the process of designing and rapid production of orthopaedic devices. This allows the patient to be

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involved in the process, improves communication with the patient, and also allows to receive feedback about the device during the design phase, even before manufacturing. This makes it easier to improve the product in order to increase the satisfaction of its user. The 3D printing processes can also be useful in the field of foods and nutrition [5], patient education [6] and teaching of resident physicians [7].

A wide spectrum of additive manufacturing varieties makes it possible to manufacture products from many types of materials [8, 9]. Additive manufacturing in relation to traditional technologies (casting, machining and plastic molding) has certain limitations related to the efficiency, quality and physicochemical properties of the manufactured products [10]. However, as of 2019, the production of finished parts is much higher than in previous years [11]. One of the most widely used additive manufacturing technologies for industrial purposes is fused deposition modeling (FDM), which can be used to obtain parts from thermoplastic materials. The most commonly used building materials are acrylonitrile butadiene styrene (ABS) and polylactic acid (PLA), which provide relatively good strength and acceptable thermal shrinkage and allow for further processing of the obtained elements. From year to year, the range of available materials that can be processed with the FDM method is constantly growing [9]. FDM machines are quiet and clean, and compared to other additive manufacturing technologies, they have small dimensions and are easy to maintain, so they can be used in design offices, hospitals or medical facilities [2, 3, 12].

One of the most popular classes of 3D printed medical devices in wide use are orthopaedic supplies, primarily limb orthoses, which are medical devices designed to maintain the rigidity and safety of a selected part of the patient's body during healing or convalescence [13–15]. This is mostly achieved by immobilizing and protecting the area around the joint from deformation and physical damage. Orthoses can also be used to force a specific position and mutual orientation of different body parts [16]. The limb orthoses might be universal, which are relatively inexpensive, or personalized, much better but also a much more expensive product and made based on the patient's anatomical measurement [17].

One of the biggest problems with 3D printing custom orthopaedic supplies is engineering expertise. In the modern design process, the patient's anthropometric data are collected and digitally processed, mostly manually, which can generate many inaccuracies [20]. Many hours of advanced surface modeling in CAD systems are required to obtain the shape [18]. 3D-printing of thermoplastic products with satisfactory accuracy and strength values is difficult. The process parameters significantly affect the properties of the obtained parts [21]. Consequently, traditional plaster casting processes have not been replaced by 3D printing yet. Research is regularly conducted to facilitate data collection, processing and production in general medical practice [18, 19, 22].

Due to the problems in the subject of traditional manufacturing of individualised orthopaedic supplies, a completely new automated system, under the name of AutoMedPrint (shortly AMP) has been developed, allowing for automatic design and manufacture of orthopaedic products - limb orthoses and upper limb prostheses. This study was conducted to evaluate an upper limb orthosis using this system with a group of twenty-one

people, to present detailed problems regarding the use of the system from the user-patient and user-operator perspectives, and to propose solutions to these problems and other improvements to the system [23].

2 Materials and Methods

2.1 The AutoMedPrint System

The AutoMedPrint system is used for automatic design and additive manufacturing of selected orthoses and prostheses based on patient anthropometric measurements. The system (Fig. 1) consists of a station for 3D scanning and design, a user interface station with applications supporting the scanning process and product configuration, and a station for rapid manufacturing.

Fig. 1. The AutoMedPrint system prototype, a) 3D scanning rig; b) operator interface; c) user interface; station for 3D printing not shown

The design and manufacturing of products is based on data from the process of scanning the patient's limb. Not counting the time it takes to make the product, the whole process takes up to several dozen minutes. The time required to produce a finished product can take up to several dozen hours, depending on the type of product. The system allows defining the type of product the patient needs, taking anthropometric measurements using a non-contact 3D scanning technique, automatically designing the product based on the patient's anthropometric data, designing and visualizing the product by the recipient, and preparing and executing the rapid manufacturing process. The system's scheme of operation is shown in Fig. 2.

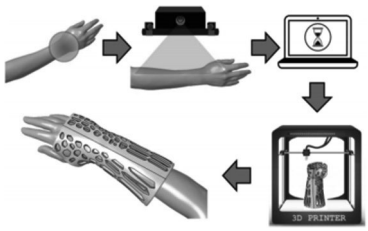

Fig. 2. Scheme of work of the proposed AutoMedPrint system [24]

2.2 Plan of the Experiments

The evaluation of the prototype AMP system was a part of its studies, performed within a scope of an R&D project. Full detailed description is presented in the work [23].

In the first stage of the research, a plan was developed, in which a method for conducting usability tests with users of the AutoMedPrint system was selected and a test course was designed, consisting of the stages of 3D scanning, design and rapid manufacturing. In the next step, a set of questionnaires evaluating particular parts of the system was developed and a leaflet was designed, handed out to the participants beforehand. Then a test group of 21 people was assembled to participate in testing the system and tests were conducted on them in the laboratory, according to the designed plan.

In the next stage, for 6 selected patients, orthoses were manufactured using 3D printing. Once all stages of the study have been completed, survey results were collected and compiled. This allowed to evaluate the system in division into the 3D scanning process, the design process, the rapid manufacturing process, the user interface and the finished product. In the final step, an overall assessment of the whole system was performed.

2.3 Methodology of Experiments

The first step of the study on the evaluation of the manufacturing system was to invite the patient to the laboratory and then hand out an information leaflet on each of the stages of testing the AutoMedPrint system. Once the participant was familiar with the study, the facilitator introduced the different parts of the system and discussed the tasks awaiting the patient and answered any questions.

The next step was the 3D scanning process. Before starting the process, it was necessary to complete the basic data on the patient. The scanning process consisted of two parts. In the first part, the participant uses an interactive application of scanning assistant, providing visual, animated information about the 3D scanning process. In the second part, the participant's upper limb was measured using a 3D scanner to create a 3D model and then a CAD model of the wrist-hand orthosis. If there was a mistake in the 3D scanning process that prevented correct results from being obtained, the process was repeated.