# Applied methodology for design of personalized exoskeletons

**Jakub Bukała[1a]* and Kamil Sybilski[1b]**

[1]*Department of Mechanics and Applied Computer Science, Faculty of Mechanical Engineering, Military University of Technology Kaliskiego 2, 01-476 Warszawa, Poland*
[a]*e-mail: jakub.bukala@wat.edu.pl*
[b]*e-mail: kamil.sybilski@wat.edu.pl*

Abstract

The paper presents an applied methodology for design of personalized exoskeletons. The author focused on rehabilitation capabilities of exoskeletons which allow exercise walking even when the patient muscles are too weak, thanks to reduction of the loads acting on patient's limbs. However, the exoskeleton set has to be accurately selected (considering personal features and the nature of undertaken activities) to effectively perform its duties. Such personalization is possible using newest tools from the field of geometry scanning, motion capture, and rapid prototyping. In the second part of the paper, the methodology was used to design a carpus exoskeleton which is intended to connect the hand to the forearm. In given example, the exoskeleton is designed to reduce the load on carpus and, therefore, allow the patient to use the crutch during the rehabilitation process.

*Keywords: exoskeleton, personalization, rehabilitation, design methodology*

## 1. Introduction

According to World Health Organization, human world population has reached 7 billion [6]. Nearly 15% of this number corresponds to disabled people among which the majority has movement disabilities [4,6]. Disabilities are caused by congenital disorders, injures and diseases. For example, stroke which is only one from many diseases causing movement disabilities, is diagnosed in approx. 70'000 patients in Poland annually [5]. According to estimates, approx. 400'000 people live with permanent after-effects of this disease in our country [1].

Elimination or reduction of negative effects of acquired or congenital movement disabilities is possible thanks to systematic rehabilitation. The rehabilitation process is often supported by various kinds of medical devices, in order to increase its progress and overall efficiency [2]. Nowadays, commonly available devices allow constant rehabilitation which is performed simultaneously with other activities (such as work, etc.). Among those devices, there is a separate group called "exoskeletons". Exoskeletons allow exercise walking even when the patient muscles are too weak, thanks to reduction of the loads acting on patient's limbs. What is more, exoskeletons correct the walk movements which allow for improvement in walk technic and develop the correct kinematics of movement [4]. Exoskeletons may support the movements of an entire body or any chosen element, e.g. elbow-joint.

Exoskeleton set has to be accurately selected (considering personal features and the nature of undertaken activities) to effectively perform its duties. Such personalization is possible using newest tools from the broad field of movement analysis, geometry scanning and rapid prototyping. The combination of mentioned approaches allows for providing a complex exoskeleton solution matching particular dysfunction. Therefore, it is important to develop a comprehensive methodology for design and testing of personal exoskeletons, which combines all the approaches listed above.

## 2. Methodology

The developed methodology is based on subsequent steps discussed below.

### *2.1. 3D scanning*

3D geometry data acquisition of the patient's limb (or other body part) is performed using 3D scanning tools (reverse engineering). Such devices are used nowadays by the automotive industry, police, CSI, military, and makers worldwide. The author decided to use a modern handheld scanner 4D F5 developed by Mantis Vision® company. In this system, structured light is used to create a single projected pattern (Patented-US8208719) which is then captured by the camera (1.4 megapixel resolution) at high frame rate. Due to active triangulation, instead of using two cameras and the light on the scenery, the active infrared source is used to illuminate the scenery and only single camera is used to create the real-time depth mapping. Described scanner has a range of several meters and can scan given object in just several minutes. What is more, no targets or markers are required. Scanning accuracy is closely related to scanning distance and is equal to approx. 0.5 mm per meter. Scanning data are represented by point cloud which could be relatively simply converted to triangle mesh.

### *2.2. Motion capture*

In this stage, photogrammetry system MyoVideo HD developed by Noraxon U.S.A., Inc. is used to track and quantify joint angles. MyoVideo is a video analysis and recording module operated in the multi-device platform software MR3 and provide motion measurements from infrared digital images captured by HD camera. In order to improve method accuracy, passive markers are applied on examined structure.

### *2.3. Prototypes design*

Prototype design is developed with the use of 3D parametric and synchronous solid modeling software Solid Edge ST8, based on the results from previous steps (3d scanned geometry and gathered kinematics data) as well as on available standardized components (hinges, etc.). Prototype design

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process consist of projection, fitting and morphing functions as well as Boolean operations. Final 3D model is a set of individual parts, some of which are intended to be manufactured from polymers (3D printed) and some purchased on the market.

### *2.4. Rapid prototyping*

The "polymer" parts of the prototype are manufactured using additive manufacturing processes (3D printing). Prototype 3D design files (.stl) are processed in Zoltrax® Z-SUITE software, considering given manufacturing properties, such as layer thickness, fill type, etc. Received code is interpreted by printing machine Zortrax® M200. Filament material utilized on this stage is Z-ABS (acrylonitrile butadiene styrene).

## 3. Example usage

People who suffered from multiple trauma, such as multiple fractures handle the recovery much slower than patients with only one, even comparable, injury. The main reason for that is the impediment to performing effective rehabilitation of one limb due to the weakness of other limbs which suffered in the same incident [3]. For example, a person who suffered a femoral fracture and also carpus damage of any kind, is not capable of effective rehabilitation due to problems with using the crutch. Development of a personalized exoskeleton reducing the load on carpus will allow the patient to use the crutch at earlier stage of the rehabilitation and, therefore, increase its overall effectiveness.

### *3.1. 3D scanning*

The results of the patient's 3D scanning survey and subsequent data processing steps are presented in Fig. 1. as a triangle mesh.

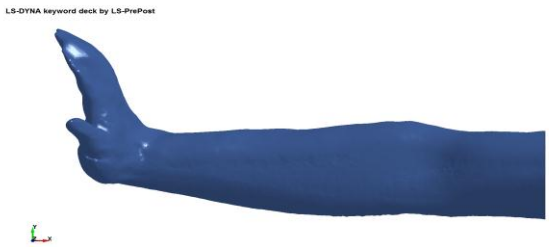


Figure 1: 3D scanning results (triangle mesh)

### *3.2. Motion capture*

The motion capture procedure overview and an exemplary results set (chosen angles change over time – min and max bending of carpus) are presented in Fig. 2.

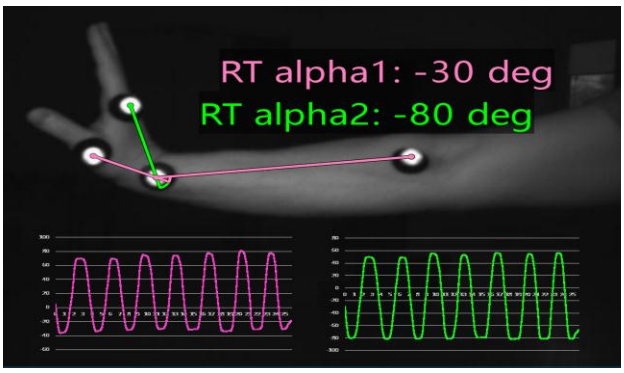


Figure 2: Motion capture: procedure overview and results

### *3.3. Design*

A preliminary 3D model of personalized carpus exoskeleton is presented in Fig. 1. The presented model based on individual geometry of the patient's forearm. The preliminary design includes: two clamping half tubes (their task is to hold the forearm), two bearing assemblies and the handle (mounted to the bottom half tube by two bearing assemblies).

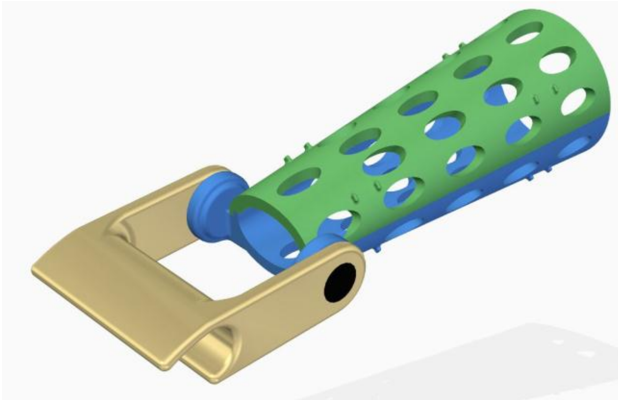

Figure 3: Preliminary 3D model of personalized exoskeleton

### *3.4. Rapid prototyping*

At this stage, a set of 5 individual parts has been manufactured using 3D printing technique. The emphasis was put on quality and mechanical properties of the prototype, therefore, the basic parameters were set to the following values: layer thickness 0.09 mm, fill type: maximal. Such an approach resulted in relatively long manufacturing time (196h in total).

After the assembly process (together with externally purchased components) the exoskeleton is ready to use.

## 4. Conclusions

The paper presents a successful attempt to develop the methodology for design of personalized exoskeletons using newest tools from the field of geometry scanning, motion capture, and rapid prototyping.

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