Design and Development of a Personalized AFO Combining CFRP and Additive Manufacturing

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Summary

Ankle-Foot Orthoses (AFOs) are medical devices widely utilized to support patients with limb disorders. In this work, the design and manufacture of a personalized AFO for a child patient with mild drop foot is presented. The subject is an 8-year-old male with congenital neuropathy in the right leg due to vascular malformation. The leg and foot shape was acquired using a 3D Scanner. The gait and running kinematics were obtained with an optoelectronic system. A product development study was performed taking into consideration user needs, weighing metrics, and different ideation concepts to establish the device architecture. Computer-aided design (CAD) models were iterated and prototypes were built with 3-dimensional printing (3DP) technology. A finite element analysis (FEA) model was developed to analyse the main structural component. Finally, the device was manufactured utilizing carbon fibre reinforced polymer (CFRP), polyethylene terephthalate glycol (PETG), and thermoplastic polyurethane (TPU) as the main building materials.

Introduction

AFOs are used on patients with a wide range of lower limb abnormalities. However, commercially available solutions frequently lack adequate mechanical design and fail during their normal period of use. The use of composite materials, such as CFRP, in a device like the one presented here, offers interesting advantages. It enables the adaptation of complex continuous surfaces to the organic shape of the leg and foot, while allowing the development of slim, lightweight, yet stiff solutions that provide the necessary structural support for gait. For other components, such as the components in contact with the skin, 3DP biocompatible TPU was used as this material supports complex shapes, while, due to its compliance, has the potential to improve comfort and minimize skin rash.

Methods

The gait and running cycles of the child were acquired using an optoelectronic system with 14 cameras and 53 retroreflective markers placed on the body. The geometry of the leg and foot of the patient was obtained using a hand-held 3D scanner and the resultant point cloud transformed into a mesh. The cleaned and decimated mesh was then imported into the CAD software and converted to a closed surface. A product development process [1] was conducted to assess the desirable characteristics of the device based on the user needs. With that in mind, metrics were defined and compared with AFO designs proposed in the literature [2]. Several concepts were generated, with the best elected based on patient-specific criteria. For the selected concept, the device architecture was delineated. An initial CAD model was designed and then iterated to implement different ideas for improving the device shape and function. At each stable iteration, a 3DP prototype was created (Fig. 1) to better understand its pros and cons or to find unforeseen flaws. FEA was used to define the layup of the carbon fibre component, aiming for a targeted stiffness. The FEA model was tested for different events of the gait cycle, using the loads previously calculated in the laboratory.

Results and Discussion

The device was manufactured using different technologies. For the 3DP parts, TPU and PETG materials were used with fused filament fabrication (FFF). For the CFRP structural component, positive moulds were designed and 3DP. These moulds were then utilized in the manufacture of the negative mould using gelcoat and a glass filled epoxy moulding paste. Onto this mould, the pre-impregnated carbon fibre was laminated. The child donned the AFO and provided feedback regarding comfort. New movement data was acquired in this stage using the optoelectronic system and the results compared with those acquired initially.

Figure 1: 3DP AFO prototype ideation process.

Conclusions

The design and manufacturing process presented in this work is suggested as an engineering supported design approach to obtain personalized AFO solutions with improved performance.

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