Customization of Kayak Paddle Grips by Using Reverse Engineering, Computer Aided Design and Additive Manufacturing Tools

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Abstract. In this paper, due to the importance of maintaining a secure grip with the control hand in kayaking, a simple three phase process is presented for the massive development of personalized grips which allow the improvement of this handgrip. This process consists of obtaining the 3D geometry of the paddler's handgrip by using Reverse Engineering (RE) tools, designing the grip from the obtained 3D geometry by using Computer Aided Design (CAD) tools and manufacturing the grip by using Additive Manufacturing (AM) tools. Therefore, this paper shows that the RE, CAD and AM tools available today allow the customization of products for many applications.

Keywords: Reverse engineering · Computer aided design · Additive manufacturing · Customization · Kayak paddle grip

1 Introduction

In the world of canoeing and kayaking, the term "kayak" denotes a closed-cockpit boat that is controlled by a paddle with a blade at either end by one or more people who are sitting [1]. What could be considered the first kayaks were developed by the Inuit people of the Arctic as a means of hunting and transportation and were designed to handle the implacable environmental conditions of the Arctic [2, 3]. Today there is a wide variety of kayaks and paddles, so guidelines have been developed to help users make the correct selection [3, 4].

In any case, to achieve an optimum performance, among other points, it is important to grip the paddle correctly. For this reason, there are rules for holding the paddle [3]. Among these rules it should be noted that during any type of stroke (foward stroke, backward stroke, draw stroke, etc.) one of the hands, which is called the control hand (usually the right hand for right-handed people and the left hand for left-handed people), should never allow the paddle to rotate [3]. This way the control hand maintains the

L. Roucoules et al. (Eds.): JCM 2020, LNME, pp. 261–267, 2021.
https://doi.org/10.1007/978-3-030-70566-4_42

control of the paddle and the opposite hand allows any rotation of the paddle that is necessary. With this gripping technique, it is possible to maintain the effectiveness of each stroke and reduce the risk of injury [3].

Due to the importance of maintaining a secure grip with the control hand during navigation, in this paper is presented a procedure for the development of customized kayak paddle grips that allow to improve the secure grip of the control hand in a more ergonomic way for the users. The ability to produce individualized products with the same efficiency and cost as production is known as Customization [5].

The simple three-phase customization process presented in this paper is outlined in Fig. 1. Hence, this process consists of obtaining the 3D geometry of the handgrip (also called 3D anthropometric data) by using Reverse Engineering (RE) tools, designing the grip from the obtained 3D geometry by using Computer Aided Design (CAD) tools and manufacturing the grip by means of Additive Manufacturing (AM) tools. This technology is an emerging technology and there are many possibilities nowadays [6–8].

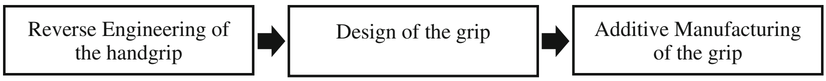

Fig. 1. The simple three-phase process for the customization of kayak paddle grips.

This process has been carried out in the DEHI laboratory (www.ehu.eus/dehi) of the Faculty of Engineering of Gipuzkoa of the University of the Basque Country UPV/EHU. As far as the authors know, although 3D anthropometry data has been used for the development of several customized products in different sectors (including sports) [9, 10], this is the first time it is used for the customization of kayak paddle grips.

2 Materials and Methods

The material resources used to carry out the three-phase procedure described in Fig. 1 are the following ones: a cylindrical sample of the same diameter as the paddle shaft, a malleable impression material (modelling clay, Jovi), a 3D digitalization system (the portable white light Go!SCAN20 3D scanner and its software VX elements 6.3 SR1, Creaform), a CAD software (Solid Edge ST10, Siemens) and an AM machine (uPrint SE FDM 3D printer, Stratasys). Now, a detailed description of how the procedure was carried out is given.

2.1 Phase 1: Reverse Engineering of the Handgrip

This first phase consists of obtaining the 3D geometry of the paddle user's handgrip. To carry out this phase, the following steps were followed:

1. Obtain an impression of the paddle user's handgrip (Fig. 2a). To perform this task, a thick layer of modelling clay has been placed on the paddle shaft sample and then the paddle user has gripped it.

2. Prepare the impression for the digitalization (Fig. 2b). As the portable 3D scanner used employs for its positioning both the features and texture of the object to be digitalized and positioning targets, to obtain a more accurate result, several of these positioning targets were placed around the impression.
3. Digitalize the impression (Fig. 2c). To perform this task, keeping the relative position between the positioning targets fixed and changing the relative position between the 3D scanner and the impression, different captures were taken until a point cloud that completely defined the geometry of the impression was obtained.
4. Process the point cloud to obtain the polygon model (triangle mesh) of the impression (Fig. 2d). This process involves principally reducing the noise in the data collected, merging the point clouds collected in different captures and creating a unique polygon model. This process was carried out in the 3D scanner's software and was performed automatically after adjusting certain parameters such as: resolution (0,4 mm), optimize scan mesh (level 0 of 100), decimate scan mesh (level 0 of 100), automatically fill holes (level 5 of 100) and remove isolated patches (level 0 of 100).
5. Clean the polygon model (Fig. 2e). This process consists of removing from the polygon model all the unnecessary data for the design. This task was carried out in the 3D scanner's software.
6. Define the global alignment of the polygon model (Fig. 2f). To perform this task, certain geometric features must previously be created: a cylinder that best fits the paddle shaft and a plane perpendicular to it located at any point along the paddle shaft. To define the global coordinate system, the z-axis of the reference system must coincide with the axis of the created cylinder, and the x-y plane of the reference system must coincide with the created plane. The position of the x-y plane along the cylinder axis and the orientation of its axes are not important in this case.
7. Improve the polygon model to close holes, clean the edges, increase resolution on high curvature areas and minimize scanner noise (Fig. 2g) This process consists of editing the triangle mesh by using tools such as: close holes, decimate the mesh, smooth the mesh, etc. This process was carried out in the 3D scanner's software and was performed by using all the necessary tools to obtain a clean and watertight mesh by varying the values of its parameters for different regions of the polygon model depending on its geometrical characteristics.
8. Generate an organized patch layout surface model from the polygon model (Fig. 2h). This process was carried out in the 3D scanner's software and as it was an organic geometry, it was performed by using the auto surface tool.
9. Export the surface model to the CAD software in STL format.

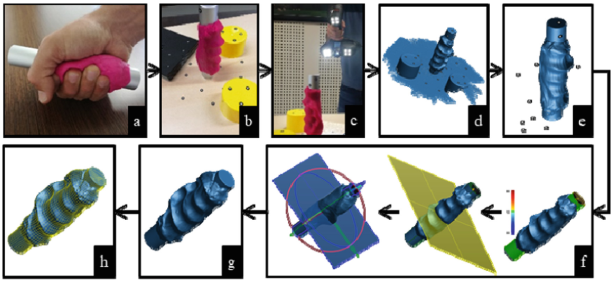

Fig. 2. Phase 1: reverse engineering of the grip.

2.2 Phase 2: Design of the Grip

This second phase consists of designing the grip from the 3D geometry obtained in the preceding phase. To carry out this phase, the following steps were followed in the CAD software:

1. Transform the surface model into a solid model (Fig. 3a).
2. Generate the paddle shaft's hole (Fig. 3b). To perform this task, a circular passing hole with the same diameter and direction as the paddle shaft was created.
3. Generate paddle shaft's sleeve (Fig. 3c). To perform this task, a thin cylinder with the same inner diameter and axis as the paddle shaft was created.
4. Design the joining system and divide the resulting solid into two parts (Fig. 3d). As a kayak paddle has a blade at either end, to enable its assembly on the paddle shaft, it must be composed of at least two parts. Also, since the grip transmits the force to the paddle, for applications where high paddle forces are expected, it may be necessary to include geometric modifications in its design to avoid both sliding and rotation onto the paddle shaft (Fig. 3d).
5. Export the grip design in STL format.

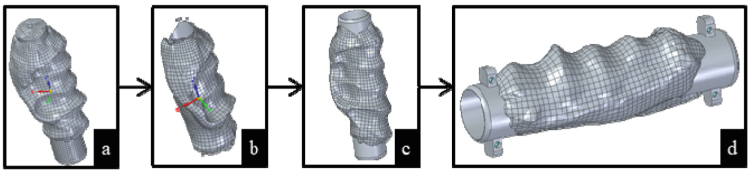

Fig. 3. Phase 2: design of the grip.

2.3 Phase 3: Additive Manufacturing of the Grip

This phase consists of manufacturing the final design of the kayak paddle grip by using an AM machine. Today there is a wide variety of AM technologies available, which allow manufacturing parts with different materials [11]. But in any case AM allows a direct translation from the design to the part, without having to program (the STL file of the design is enough). As an example, one of the designs was manufactured with the uPrint SE FDM 3D printer (Stratasys) (Fig. 4c).

3 Results and Discussion

The following two designs were generated: the design for activities that involve a small paddling force (e.g., touring kayaking) (Fig. 4a) and the design for activities that involve a high paddling force (e.g., whitewater kayaking) (Fig. 4b). The difference between the two designs is that the first one restricts the sliding and rotation of the grip onto the paddle shaft by the pressurized assembly of its two parts while the second one restricts this movement by the modification of the geometry of both the sleeve and the paddle shaft.

Therefore, the first design would be able to avoid the movement between the paddle shaft and the grip at low paddling forces and the second design would be able to avoid it at higher paddling forces. However, taking into account that the position of the hands on the paddle is different for each user [3, 4], the first design would allow sharing the same paddle between different users, while the second one, as it requires modifications in the paddle geometry, would restrict this possibility. Therefore, before selecting the design, it is necessary to determine the specifications that the grip must satisfy. In any case, as reflected in this paper, both designs could be developed in a massive way.

As for the duration of the development of these personalized grips, this depends on factors such as the hardware and software used in each phase, the experience of the developers and the geometric characteristics of both the paddler's hand and the final design. In the case of the prototype developed in this study, it was as follows: 0.5 h for phase 1, 0.75 h for phase 2 and 12 h for phase 3. The high duration of phase 3 is due to the printing time required by the 3D printer used. Finally, in order to calculate the cost of the development process, it would have to take into account, among other things, the labor costs, the raw material costs (in this case 15 €/kg) and the amortizations, which are completely dependent on the development company.

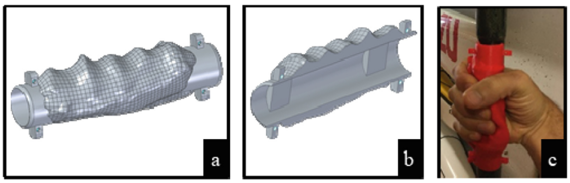

Fig. 4. The two designs generated (a,b) and the result of the AM of the first design (c).

4 Conclusions

This paper shows that the RE, CAD and AM tools available today allow the customization of kayak paddle grips. Although some designs involve modifications in the paddle's geometry, the development process of the customized grip is still massive. The process presented in this document can be easily adapted to any other similar product from any other sector.

Acknowledgments. The authors of this paper thank the Faculty of Engineering of Gipuzkoa forlocating the DEHI laboratory in their facilities and the study was supported by the Gipuzkoa Country Council (grant number 70/19) and MINECO Ministry of Economy and Competitiveness (grant number PID2019-108975RA-I00).

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