Cost-Effective Design and Development of a Prosthetic Hand

M. N. Anh, T. D. Tang, V. T. Trung, L. C. Hieu, N. H. Tu, H. L. Minh, and L. H. Quoc

Abstract

The prosthetic hand is used to replace a missing part of a hand, which may be lost through trauma, disease, or congenital conditions in order to restore the normal functions of the hand. The state of the art design and development of prosthetic hands has been well studied and documented. The modern prosthetic hands which are computer-controlled via the means of electromyogram (EMG) signals are very helpful for amputees; however, they are expensive, not always available for low-income populations. This study presents a cost-effective solution for innovative design and development of a prosthetic hand for a patient who lost both hands due to the work accident. Design concepts of the prosthetic hand were successfully developed and tested. Different strategies for cost-effective design and development of the high-value added prosthetic hand are also discussed, including mass-customization and design for additive manufacturing.

Keywords

Prosthetic arm • Rehabilitation • Reverse engineering • Design

1 Introduction

A prosthetic hand is an artificial device that replaces a missing part of a hand, which may be lost through trauma, disease, or congenital conditions, in order to restore the normal functions of the hand. The prosthetic hands can be divided into cosmetic hand, body-powered hand and electromyogram (EMG) prosthetic hand or bionic prosthetic hand [1, 2]. There has been a lot of effort working on design and development of the smart prosthetic hand which is computer-controlled by the means of EMG surface electrodes [1–5].

The EMG technology allows the amputees to conveniently control and use the prosthetic hand for the daily activities. However, most of the EMG prosthetic hands are expensive for the low-income populations. In addition, the use and maintenance issues of the prosthetic hands need to be taken into account, especially for cases where amputees have to work and use the prosthetic hands in different working environments and weather conditions.

In this study, cost-effective solutions for innovative design and development of a prosthetic hand for a patient who lost both hands due to the work accident are presented and discussed, with the focus on the meeting well the daily need of a patient, and the use of the state of the art design and product development to obtain the added-values.

The rest of the paper is organized as follows. Section 2 presents materials and methods used for cost-effective and innovative design and development of a prosthetic hand. Section 3 presents the main results and discussions about the design analysis and test of a developed prosthesis hand. Finally, Sect. 4 presents summaries, conclusions and suggestions for further studies.

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2 Materials and Methods

2.1 Data Collection and Identifications of Need and Technical Requirements

Figure 1 presents a patient who lost both hands due to the accident with the common daily activities, including driving a bike or motorcycle (a, d, h), using the computer (b), preparing the food and cooking (e), drinking and eating (c, f), and writing (g).

Both the RE and CT scanning techniques were used for the patient data collection to be sure that the obtained 3D models of anatomical parts are reconstructed with the required accuracies. The full 3D body model is used as the reference and direct inputs for designing assistive components such as Velcro straps for attachment of the prosthetic arm to the body.

The main requirement is to develop prosthetic hands used to mainly assist the daily basic activities of a patient with the reasonable price, easy use and maintenance. Both forearms were partly missing in which only the right forearm and elbow is able to move and pro-actively assist the daily work. First of all, in order to fully develop the prosthetic hand that meet well the clinical and technical requirements, the patient data in the form of 3D models of the forearm, elbow, arm and shoulder needs to be collected and reconstructed. In this study, the non-contact Reverse Engineering (RE) techniques are used with the use of RE scanner and CT/MRI images [6, 7] as shown in Fig. 2.

2.2 Concept Design, Embodiment and Detail Design

Figure 3 presents a method for innovative design and development of a prosthetic hand. Based on the identified need of a patient and technical requirements, different design concepts are proposed, taking into account the prioritized daily activities to meet well the customer need. In order to obtain the cost-effectiveness and proposed functions of a product, within the scope of this study, the selected design concept for embodiment and detailed design is the manually-controlled prosthetic hand, not the bionic EMG one which will be further developed in the next versions of the product.

State of the art design methods were applied for the design, including modular design, mass-customization [8], design for assembly, disassembly and design for manufacturability (3D printing and Additive Manufacturing). The basic design tasks are normally divided into three main groups: (i) Connection of hand-forearm- upper arm parts; (ii) Control of the hand for getting skillful jobs; and (iii) Diversification of functions of hand kits. Figure 4 presents the fully developed 3D CAD assembly of the first design concept of a body-powered prosthetic hand. This first design concept is able to allow the user do the most commonly daily activities such as picking-up and carrying objects (a) and using the computer (b) mouse via two different end-effector (action units).

3 Results and Discussions

Figure 5 presents the successfully developed prototypes of the first design concept of a body-powered prosthetic hand, evaluation and test of using a prosthetic hand to do the common daily activities.

This first design concept is used mainly to meet the basic daily requirements of a patient, especially it is used for detailed evaluations of the clinical need for further development of the next version of a product, including the bionic

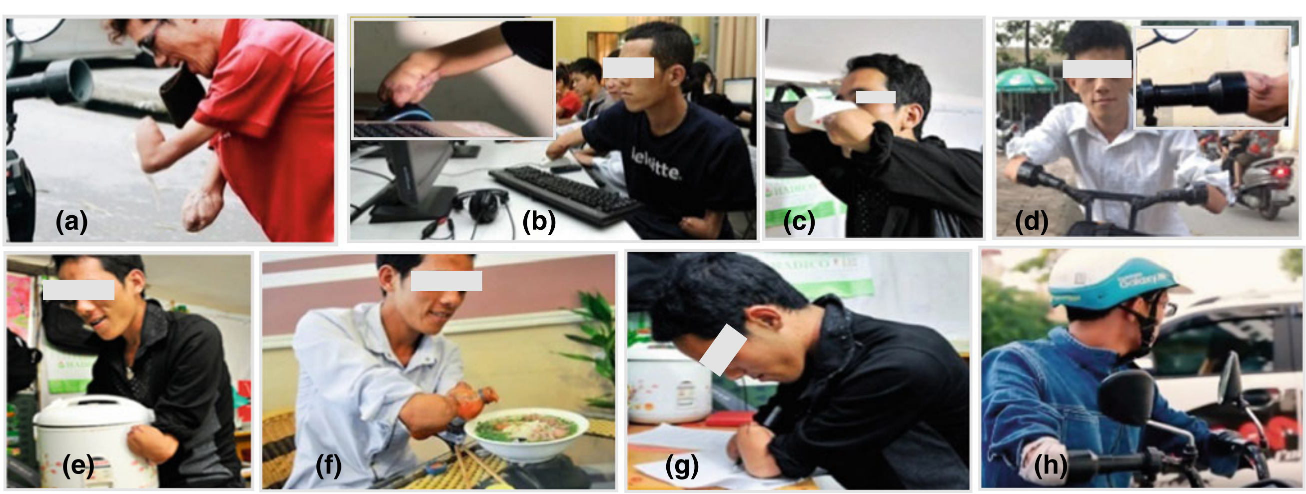

Fig. 1 Daily activities of a patient who lost both hands due to the accidents

Fig. 2 Data collection and 3D modeling of the body parts for design activities. **a**, **b** RE scanning. **c**, **e** 3D models constructed from scanned point data. **d**, **f** 3D models constructed from CT images

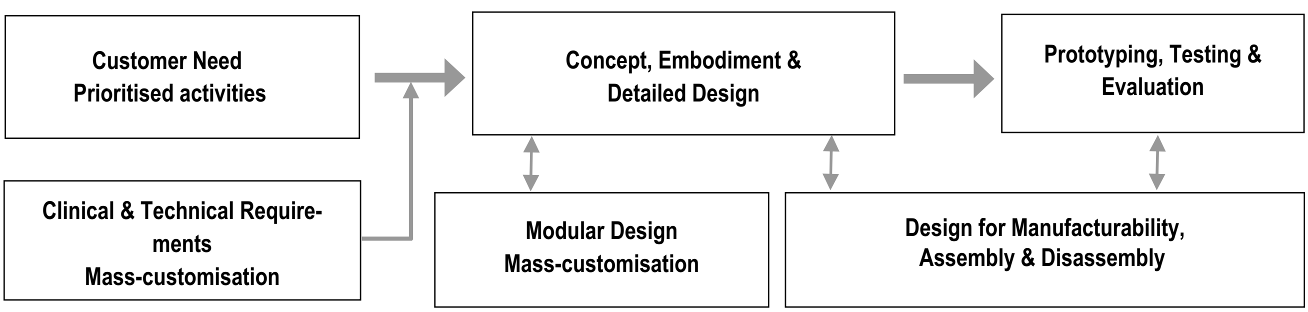

Fig. 3 A method for innovative design and development of a prosthetic hand

Fig. 4 A fully developed 3D CAD assembly of the first design concept of a prosthetic hand

EMG one, with the focus on Design for Additive Manufacturing and Design for Mass-customization.

For the technical aspects, the following are the most important specification and important points taken into account during the design: (i) Light weight, (ii) Mechanical strength, (iii) Grasping load and stability, (iv) Functionality, (v) Ease of assembly and disassembly, and (iv) Size and personalized design feature for a device to be well fitted with the forearm. In order to obtain the light weight, the forearm tube, hand, and fingers, the light materials are used such as plastic, silicon, rubber or aluminum. For the next version, the topology optimization and design for additive manufacturing will be applied to achieve both lightweight and mechanical strengths as well as personalized design [6–8].

In order to control well the grasping load and to obtain the stability when using the prosthetic hand, it is required to

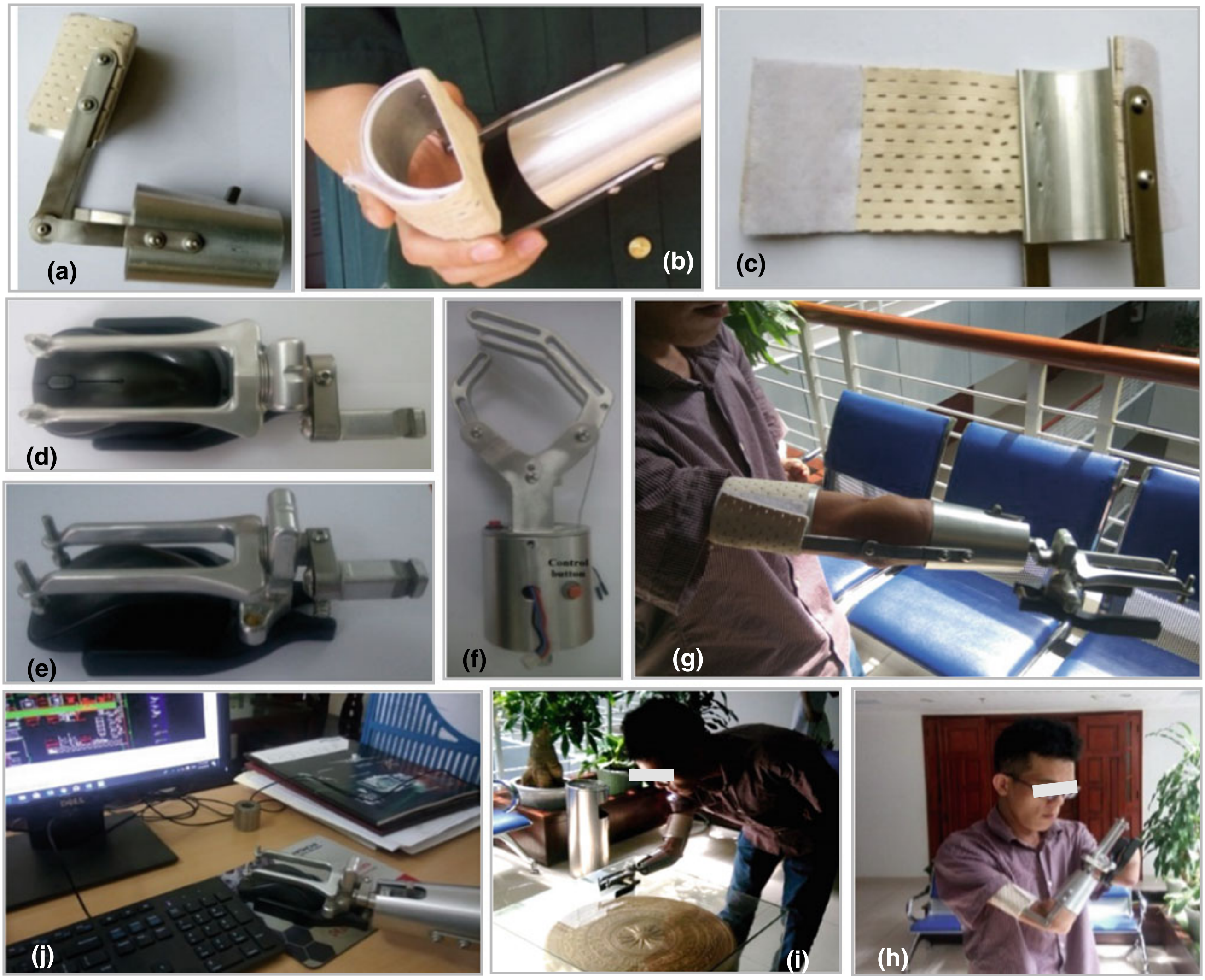

Fig. 5 **a**–**f** Successfully developed prototypes of a body-powered prosthetic hand. **g**–**k** Evaluation and testing of using a prosthetic hand for the common daily activities

use at least 3 fingers including a thumb and two others [9]. This property enables the fingers to be accurate in holding and grasping. Different functional kits for the end-effector (action unit) are used in order to obtain the multifunction (Figs. 4 and 5), with the ease of changes (assemblies and disassembly).

Based on the 3D CAD models of the arm and forearm (Fig. 2), the part for fixation of the prosthetic hand to the forearm and arm was optimally designed with the personalized features. The innovative features of the design are shown in the design of the wrist connector with a mechanical trigger. The wrist connector plays the important role of a mechanical interface to make the forearm easy to combine with different functional kits, to allow the user to manually change (assembly and disassemble) the functional kits by simply pulling the mechanical trigger. The wrist connector runs as a plug and play device and allows the user to carry out one-touch action of assembly and disassembly. Finally, the holding belt with a curved sickle shape like a crescent moon was integrated in the design to allow the prosthetic hand fixed to the forearm and arm of the user tightly and comfortably with the ease of use. Moreover, the design was simplified by the use of connection bars between the upper and low fixation parts which function as the elbow; this reduces the weight of the prosthetic hand, with reduced frictions.

In order to work on the detailed analysis and evaluation of the clinical need for further development of the next version of a product, including the bionic EMG one, the design evaluation and practical tests were implemented with the use of different functional kits for the end-effector, in which the main objective is to evaluate the performance of the comfortableness, stiffness, and accuracy as well as the functionality of the developed prosthetic hand, aimed to meet well the need of a patient (user). In this way, the following are the questionnaire and the raised issues for a feedback from a patient after the test: (a) Ease of assembly and disassembly of the functional kits and wearability without the help of others, (b) The weight of a prosthetic hand, (c) Ease of use and control and (d) Performance of the daily activities with and without the use of the prosthetic hand.

The test procedure consists of four groups as follows. The first one is to self-wear the prosthetic hand with the several times (Fig. 5g). With the short training and guide, a patient can self-wear the prosthetic hand in less than a minute. The second one is to wear the prosthetic hand as long as possible with the position shown in Fig. 5h, in order to assess the comfortability of wearing a device. The average time of wearing comfortably is about 19 min. The third one is to hold and grasp objects (Fig. 5i). The patient said that he was able to control the fingers to hold cylinder objects easily. However, the weight and the diameter of objects should not be over 5 kg and 10 cm respectively. The forth one is to use the computer mouse (Fig. 5d, e, k). The patient was able to use the computer mouse by clicking on the right and left buttons, and easily move the mouse. However, if he needs to click a button longer than a 5 s, it is a bit challenging. A patient was happy with the proposed functions and the issues related to the safety and noise during the use of a device were well-controlled.

4 Conclusion

In this study, the cost-effective solutions for innovative design and development of a prosthetic hand for a patient who lost both hands due to the work accident are presented and discussed, with the focus on the simple design concepts to meet the basic daily requirements of a patient. Basic design concepts of the prosthetic hand with different functional kits were successfully developed and tested, and it allows a patient to do the most common daily activities. The successfully developed prototype is also used for detailed analysis and evaluation of the clinical need for further development of the next version of a product, including the bionic EMG one.

The successfully developed prototypes meet the key technical requirements and basic need of a patient. The next versions of a product will be developed with the better functionality, cost-effectiveness and the ease of use, especially the following ones: (1) To apply the emerging design methods, including topology optimization, design for additive manufacturing, mass-customization and personalized design [6–8], in order to minimize the weight and to obtain a better wearability and functionality as well as added values for a device, and (2) To work on personalized design and cost-effective development of the EMG prosthetic hand or bionic prosthetic hand [1–5].

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Conflict of Interest The authors declare that they have no conflict of interest.

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