Application of Stereolithography in the Fabrication of Rehabilitation Aids

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Abstract

Free form fabrication methods have a great potential to significantly improve the design and manufacture of equipment for people with physical disabilities, such as quadriplegia through spinal cord injury, arthrogryposis, or cerebral palsy. Depending on the nature of the disability a device may need to be designed or adapted. A person with quadriplegia, for example, may benefit from an assistive device that maps existing head movements, into the movements of a spoon between a plate and his/her mouth. To be comfortable and effective a person may need a headband that can connect to a suitable linkage. Stereolithography lends itself well to the fabrication of such one-of-a-kind devices. Since the fabrication process time is considerably less than conventional approaches a greater number of iterations can be performed during the design to arrive at the most compatible device for a particular disability. Some rehabilitation devices are fabricated to establish the viability and limitations of this approach. This paper details the efforts underway to integrate stereolithography with the needs of rehabilitation engineering.

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1 Introduction

Rehabilitation (or assistive) devices require diverse approaches to design and manufacture owing to the fact that their requirements are often highly specialized. The range of disabilities and the effects of those disabilities is extremely large. Their design is often complicated because of the intimate interface between the device and the human body [1]. A number of complex biological variables need to be addressed and most often it is not possible to compile a thorough specification for a particular aid. Unfortunately, the number of people for whom the same device is suitable is small.Though there are many fabrication techniques that are suitable for large volume production, many of these are based on the fabrication of a mold from which parts are formed [2]. Depending on the complexity of the part the cost of making a mold varies significantly. Since these molds are usually very costly it is not possible to include any modifications to design until the original cost of the first mold is recovered. However, with the advent of a whole new class of manufacturing approaches called free from fabrication (FFF) it has now become possible to customize the design of a rehabilitation aid to suit the specific requirements of a particular disability. Since these FFF methods produce parts considerably faster than conventional approaches, the cost and cycle time are significantly lower.

An alternative methodology for design and fabrication of rehabilitation devices has been proposed which attempts to separate the design of the user interface from the design of supporting features like wheelchairs, large button telephones and easy grip cutlery [1]. This methodology is based on the underlying assumption that most of these supporting features can be readily obtained from traditional techniques while the user interface needs to be specifically designed for a particular circumstance. Some of the examples where this methodology is quite useful include wheelchair seating and controls, prosthetic arms and legs, and Magpie [4]. It is in the fabrication of these user interfaces that the FFF techniques become highly desirable. This study is focused particularly on stereolithography, which is one of the more highly developed FFF techniques.

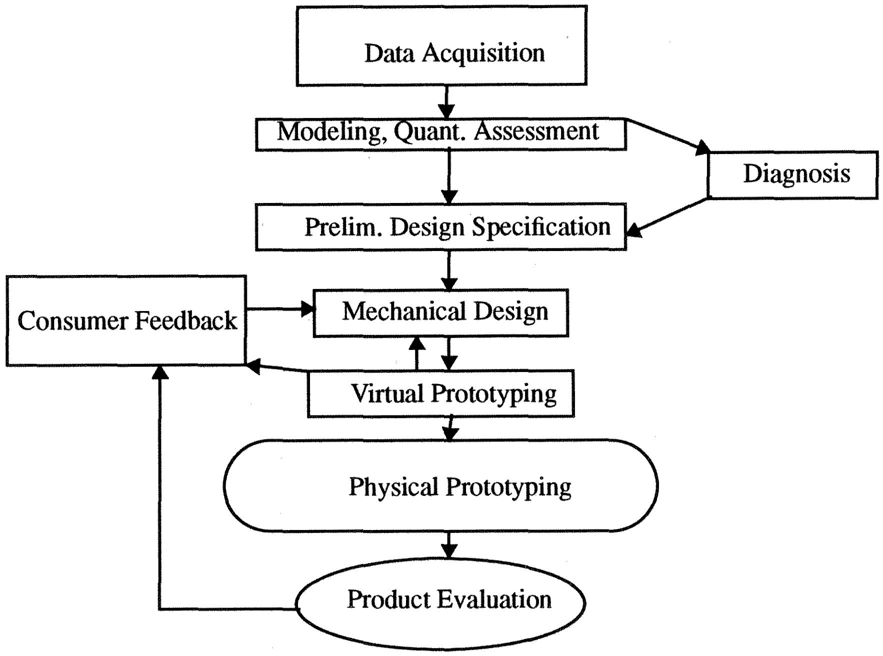

Figure 1: Design and rapid prototyping of one-of-a-kind assistive devices in rehabilitation

2 Design Methodology

A rehabilitation device that can assist in tasks of daily living need not be complex or have a universal function to be successful. Simple designs have the attraction of increased reliability, lower costs and a more ready acceptance. In fact two of the most widely used rehabilitation devices namely, Handy II [3] and the Magpie [4] are quite simple in design, perform many tasks and are suitable for a wide range of disabilities. However, the main disadvantages of these devices are lack of provision for significant adaptation, long manufacturing time and high cost of the product. The design of rehabilitation equipment requires the quantitative assessment and measurement of the disabled person's performance and a methodology to quickly design and prototype assistive devices based on performance goals. The approach adopted for the fabrication of aids is illustrated in Figure 1. The approach involves,

- a quantitative estimation of the form and performance requirements of the assistive device based on the specific requirements of a disabled person,
- the design of the assitive device,
- evaluation of the device using simulation and virtual prototyping,
- feedback from the consumer and the therapist or physician,
- actual prototyping of the assistive device using **free form fabrication** methods,
- evaluation of the function and performance of the device and,
- redesign based on the performance.

The basic objective here is to quantitatively assess the capabilities of a disabled individual which will in turn lead to the design problem specifications. For example, a person with a high level spinal cord injury may have limited shoulder and elbow movement with no ability to grasp objects in the environment and limited capabilities to supply adequate force to a telemanipulator. We can characterize his or her range of movements and the torques/forces that are applied during these movements. From this information a telethesis linkage can be designed to fit to the person - one that will harness his or her movements and force capabilities in an optimal fashion.

3 Discussion

The eventual goal of this study is to fully integrate the fields of rehabilitation engineering and free form fabrication through the design methodology described above. One of the primary advantages of this approach is the ability to involve the end-user in the design process. Since the end-user of the device is the person with disability, the design optimization is essentially based on

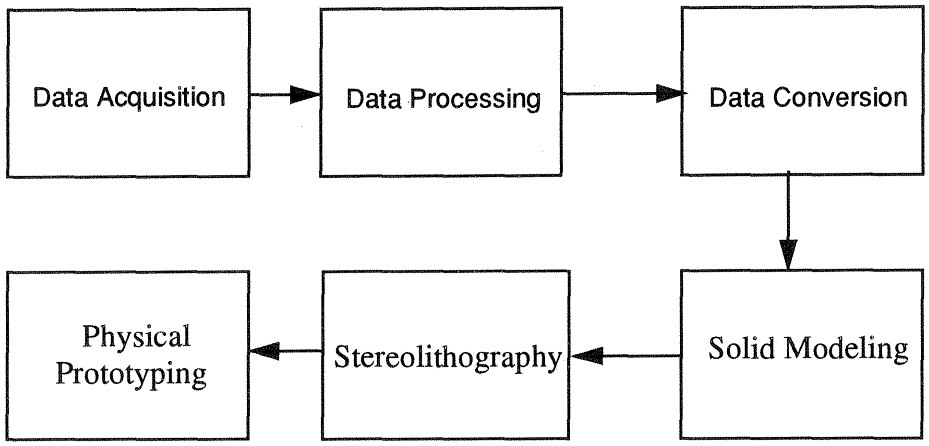

Figure 2: Path from Data Acquisition to Physical Prototype

the feedback from that person. This paper establishes the feasibility of the approach by actually fabricating specific assistive devices. Stereolithography is the FFF technique adopted in this study. Two devices namely,the headband and the mouth-stick are presented here. The head-band is designed to be part of a head-controlled telethesis for feeding a person with disability. Such a head-controlled feeding device is especially useful for people with quadriplegia.[3] These serve as two generic examples to validate the proposed design methodology.

Figure 2 shows the various steps involved in the process, starting from data acquisition to generation of the physical prototype. To begin with, the image of the head was obtained by scanning the head from different angles and registering the different images. Subsequently, the image is subjected to a series of data filtering algorithms in order to extract a rectangular strip of the image along the contour of scan, passing through the forehead. The image thus obtained is coverted to a neutral format such as IGES using customized software and later filtering algorithms are used to refine the image. The extracted surface feature is later imported into Pro-engineer and ex-

[3]When quadriplegia is a result of a spinal cord injury, depending on where the lesion occurs the upper extremities and even the torso may be impaired. But the quadriplegic generally has good control over his/her head and neck movements.

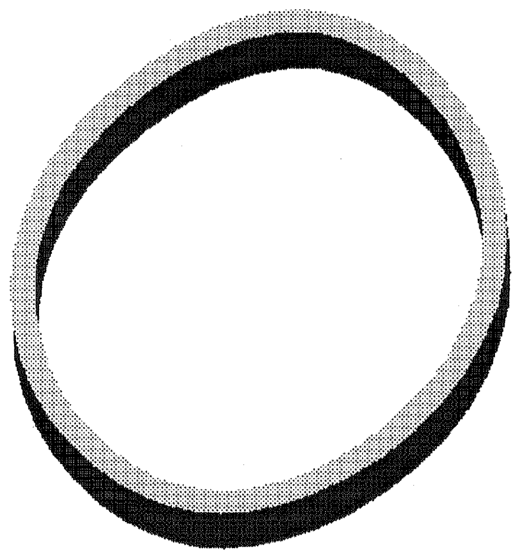

Figure 3: Profile of the Head-Band

truded to created a solid strip of uniform cross-section. However, in order to overcome the inherent unevenness built into the surface, an elliptical curvature was fitted to closely follow the contour of the scanned image. This elliptical feature was later extruded to create a solid model of the head-band. In order to fabricate this solid model a tesselated representation (.STL format) is generated. This .STL formatted representation of the solid model is then used to prepare the part for fabrication in an SLA machine. Figure 3 illustrates the contour of the head-band obtained from interpolating a elliptical curvature to a range scanner image of a subject's head obtained using a Cyberware 3030PS scanner. Figure 4 shows the geometry of the mouth-stick which was obtained by remodeling and modifying a customized design. The cad model thus developed will be used prototype the mouth-stick in a SLA machine. The main thrust here is to develop a simple device which addresses the routine tasks like lifting sheets of paper on a table. The slit seen in mouth-stick is intended to meet this purpose. A series of iterations will be performed to establish a design loop that produces the mouth-stick best suited for the person's needs. The next step in the development of this device is the interface that rests against the upper jaw of the person and allows easy

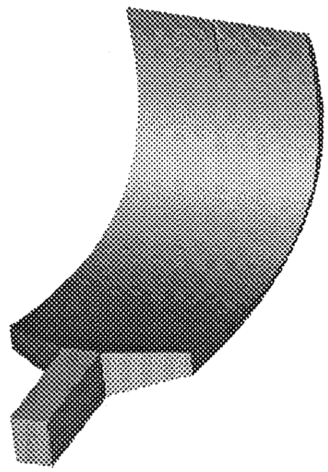

Figure 4: Profile of the Mouth-Stick

manipulation. Here, to ensure that the interface is non intrusive the contour of the upper jaw needs to be scanned and the interface developed to rest comfortably against the jaw bone. The eventual goal of this whole approach is to arrive at the most optimal design solutions and to develop algorithms which will streamline the whole design phase into a series of routine steps.

4 Future Direction

Currently the work is focused on specific assistive devices with a view to establishing the feasibility of this approach in the design and fabrication of such devices using the free form fabrication approach. Eventually, however, the goals of this research are the following.

- The development of new computer-integrated design tools for the quantitative assessment of function and performance requirements of assistive devices.

- The integration of all relevant tools and technologies into a practical rapid prototyping environment.

- The development of mechanisms for the systematic evaluation of the final product.

5 Conclusions

Though the stereolithography approach to fabricate rehabilitation devices is quite efficient it is yet to become cost effective. The high cost involved in employing this technology is a major bottleneck in the widespread use of this approach. Another major difficulty that needs to be overcome is the toxicity and other material related issues involved in the use of photopolymers in contact with the human body for prolonged periods of time. A lot of rehabilitation devices involve fabrication of small or even tiny parts and hence there is need for accurate desktop machines which could quickly be used to verify new design formulations. With continuous improvements in the machine accuracy as well as ever increasing class of photopolymer materials it is hoped that the approach outlined in this study will eventually become widely used in the rehabilitation industry.

References

[1] Roger D. Orpwood, Design Methodology for Aids for the Disabled, Journal of Medical Engineering and Technology, vol. 14, p2-10, 1990.

[2] Albert M. Cook, Assistive Technologies: Principles and Practice, Mosby 1995.

[3] John R. Hegarty and Mike J. Topping, HANDY1 - a low cost robotic aid to eating, 2nd International Conference on Rehabilitation Robotics, p17-25, Georgia Institute of Technology, Bioengineering Research Center, Atlanta, Georgia, June 1991.

[4] Mervin Evans, Magpie - It's Development and Evaluation: Internal Report, Oxford Orthopeadic Engineering Center, Nuffield Orthopeadic Center, Headington, Oxford, England OX3 7LD, 1991.