A LOW-COST DATA GLOVE FOR VIRTUAL REALITY

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Abstract. *Data gloves are devices with a set of sensors for obtaining information about the movement of the hand and its fingers. In Virtual Reality, data gloves are widely used as input devices for its capability to interact with the computer for application development. Currently, there are many such devices, which are offered by specialized commercial companies at high costs. Nevertheless, in recent years low-cost solutions for construction and software development kits for data gloves have been available. This paper presents the design and development of a low-cost data glove system to be used in virtual reality applications based on finger movements. The design of the glove is presented as a prototype based on computer vision algorithms in order to determine the relative position of the fingers. The manufactured data glove requires only inexpensive materials and a simple webcam for motion tracking. In the performed tests, our solution shows good results in the task of tracking the movement of each finger in a 3D space.*

Keywords: virtual reality, digital image processing, computer vision, sensors, low-cost devices

1. INTRODUCTION

Since the beginnings of Virtual Reality (VR) technology in the mid-1980s, several researches and applications had been developed. As stated by Burdea and Coiffet [1], VR is a simulation in which computer graphics are used to create a realistic-looking world. VR technology can be usefully applied to a broad range of fields and the created synthetic world is dynamic and it responds to the input of the user (gestures, verbal commands, etc.). This feature defines the VR as a real-time interactivity approach.

In order to allow human-computer interaction, it is necessary to use devices to input the command of users into the computer and to provide some kind of feedback. In VR, there are several special devices for this purpose: 3D positions trackers, navigation and manipulation interfaces, gesture interfaces, and so on. Particularly, hand gesture interfaces measure the real-time position of the fingers or wrist in order to allow natural gesture recognition based on interaction with the virtual world.

A data glove basically contains a set of sensors to determine the position of each finger as well as the palm of the hand. Mainly, these gloves differ in factors such as type, number and resolution of the employed sensors and whether they are wired or wireless. However, data gloves have a high price and are distributed by specialized companies. This paper describes the design and development of a low-cost data glove for VR with simple materials and a webcam, using computer vision algorithms. The data glove can be easily built by the user, to be used in VR applications.

This paper is organized as follows. Section 2 presents a briefly overview of the related works in which we based our proposal. Section 3 describes our approach for manufacturing the data glove. In Section 4, we show the obtained experimental results. Finally, Section 5 presents conclusions and future work.

2. RELATED WORK

Nowadays, there are several commercial and non-commercial options to data gloves. Nevertheless, we present a subset of them, selected by their cost and their applications. The data glove *HandTutor*, developed by MediTouch Ltd. [2], is a system for rehabilitation of upper limbs based on hand exercises. On these exercises, it evaluates and treats the fingers and dysfunction of the hand movement through activities that promote the extension/flexion of fingers and wrist. The offered system is composed of the data glove with sensors to record the movements of the fingers and the wrist.

CyberGlove II (its predecessor *CyberGlove I* is now discontinued) of Cyber Glove Systems [3] offers a motion-based capture system for a variety of applications such as digital prototype evaluation, virtual reality, animation and rehabilitation. The *CyberGlove II* is composed of an elastic fabric for comfort; and about 18 to 22 sensors which capture the movements of the fingers.

At the same time, Fifth Dimension Technologies (5DT) has a few data glove models used for VR. The models vary according to the number of sensors, e.g. 5, 14. The sensors are able to capture motion in order to measure finger flexion (1-2 sensors per finger). The most basic model offered by 5DT is the *5DT Data Glove 5 Ultra* [4].

The aforementioned data gloves have an approximate cost of $1,000 for the basic models. Therefore, several low-cost solutions more accessible were created. One example is the *P5 Glove* data glove [5], which can be used for developing applications in 2D at a cost of $79. The *P5 Glove* is designed with various specialized sensors, and it is seen as an additional peripheral. There is a software development kit under the open source license for this product.

As well as there are commercial solutions, there have also been developments with a focus on scientific research. Adamovich et al. [6] developed a data glove which measures the force applied by fingertips (except the pinky). This glove was designed with such a haptic interface to interact with virtual worlds. It also has sensors in the palm of the hand for support. Also, Pamplona et al. [7] designed a prototype for a data glove for image-based interaction with virtual objects, as shown in Fig. 5. They show how to register the movements of the fingers by visual markers on the fingertips.

3. OUR APPROACH

In this paper, the development of a low-cost data glove prototype is presented. The main idea is to capture the movement of the fingers using one webcam, i.e. single-channel video. Each movement is obtained when a cord linked to the fingertips is shifted. Figure 1 shows the design of our approach. Note the five cords through the hand linked with each fingertip and the field of view of the webcam. In that field, images with 5 cords of different color are captured. Every cord offers a low resistance using small springs. Particularly, in this prototype we use as springs simple office rubber bands.

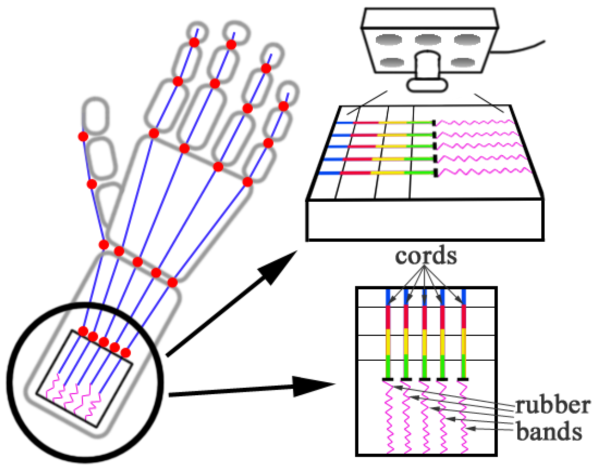


Figure 1- Design of our low-cost data glove approach.

The goal of this prototype is to capture input data from the finger movements to develop VR applications for physical rehabilitation. At present, there are several commercial devices that use finger movement sensors. In our case, each finger movement pulls the color mark linked to it and is tracked by the webcam. Each color mark is associated with a finger position between two extremes: stretched and contracted. This design of the data glove can be compared with a commercial data glove that has five high-cost fiber optic sensors.

3.1 Glove manufacturing

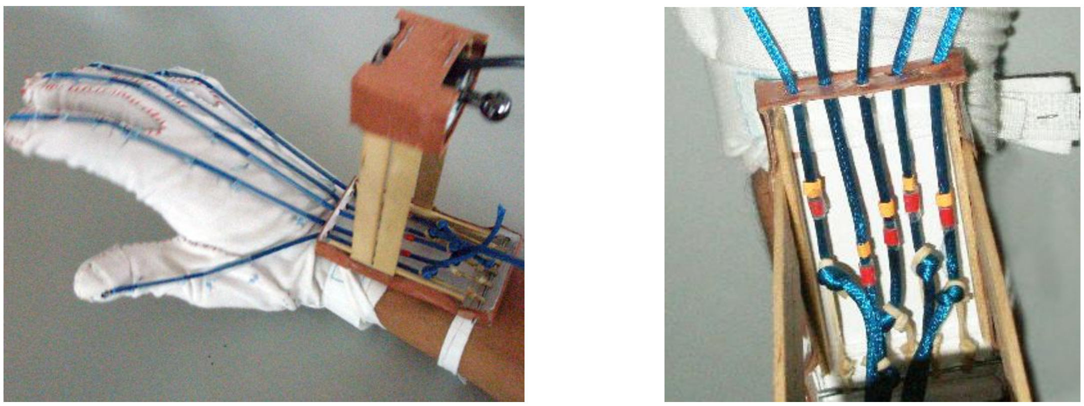
For the manufacture of the glove we propose low-cost and easy-to-access materials. Following, a list of components for the prototype is presented:

- 1 webcam connected to the computer using a USB port
- 1 small piece of white cotton cloth
- 1 board pattern of the hand (right or left)
- 14 small plastic tubes
- 5 rigid cords (one for each finger)
- 5 rubber bands (one for each finger)
- Small wooden slats
- 1 cardboard box (approximately *8 cm. x 4 cm. x 1 cm.*)
- Colored markers

One webcam of 8 megapixels with adjustable lens and a LED array of 6 lights are used. The LED lights are to ensure the good illumination and contrast at the moment of acquiring images.

Using the board pattern of the hand and a simple cotton cloth, the glove is built. The pattern has to be associated to a standard hand size for both men and woman [8]. Plastic tubes are placed along the fingers between the joints and at the dorsum of the hand (3 for each finger and 2 for the thumb). Next, the rigid cords are fit to each fingertip and passed through the plastic tubes.

On the other hand, the cardboard box is perforated with 5 holes. The cords are passed through these holes. It is necessary to hitch the cords with the rubber bands and trim them at the opposite side of the holes on the cardboard box. Then, using the wooden slats a simple base is constructed to place the webcam (approximately at *8 cm.* from the dorsum of the hand). The webcam must focus the cords in the cardboard box. Finally over each cord, a color mark should be placed. Fig. 2 presents the final result once the prototype of the glove is finished.



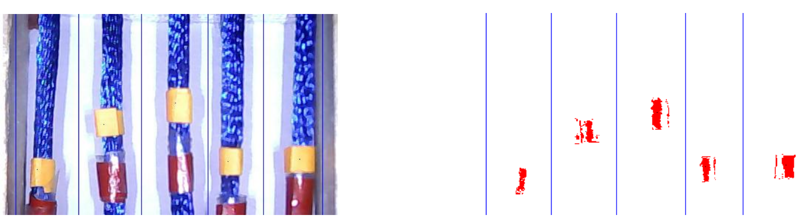
(a) (b)

Figure 2- The manufactured glove, showing the (a) complete glove and, (b) the area taken by the webcam.

After manufacturing the glove, the processing of the captured image is performed. The main goal is to determine the movement of the cords and link them with the movement of the fingers.

3.2 Image processing

To get the corresponding visual analyzer from the glove a webcam is placed in the field of view directly over the cords. In this way, the webcam obtains an image similar to the one shown in Fig. 3(a). The webcam captures images at a resolution of *800 x 600* pixels. This image has a high contrast due to the LED lights of the webcam.



(a) (b)

Figure 3- Image captured by the webcam: (a) original, (b) after segmentation.

On every frame captured by the webcam, all color control marks should be discriminated and associate with each finger. Then, given a captured image a segmentation technique based on *thresholding* is applied. That is, for each pixel p with an intensity value of $p=(r,g,b)$, our algorithm decides that p is part of a control mark when $p=(r \geq 190, g \geq 210, b \leq 160)$. Fig. 3(b) and example of the segmentation of these control marks.

The segmentation technique explained before works correctly because the image has a good illumination, making easy the extraction of the regions using a threshold algorithm. The result is an image where each color mark control has become a pixel area. To obtain the position of each mark (in 2D), an average of all pixel positions which make up the area is performed.

Additionally to the location of each control mark, a calibration process is accomplished. This process consists in associating the mark position with the finger position. In order to do so, the position of mark i, with the hand totally stretched, is stored in $Pstart_i$. Following the same process using the hand contracted (i.e. in a fist), the obtained values are stored in $Pend_i$. Then, the position P_i of the mark i at any time can be calculated by linear interpolation between the $Pstart_i$ and the $Pend_i$ of the finger where the mark is.

In the next section, we present the results with our proposed low-cost data glove.

4. RESULTS

The experimental results performing linear movements and bending angles are very satisfactory in order to link the movement of the real fingers with a 3D model created in the computer. Figure 4 shows the low-cost data glove system moving the fingers and the image of the 3D model used for the fingers. Our software was developed in C++ using OpenGL [9] for displaying the graphics and OpenCV [10] for image manipulation.

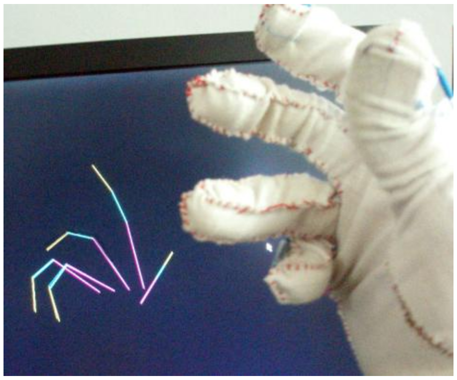


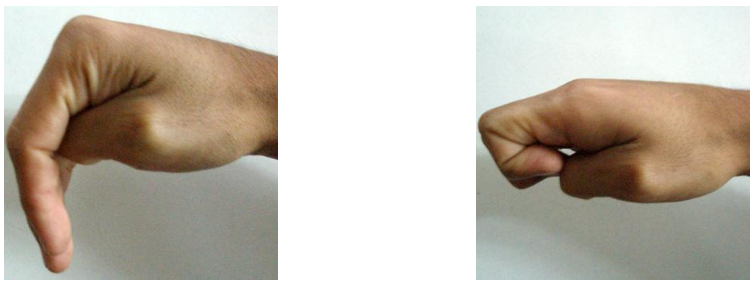
Figure 4- Image taken using the low-cost data glove and its 3D computer model.

The presented data glove is equivalent to a commercial data glove composed by 5 sensors. However, it has a low margin of error due to material weariness after prolonged use (i.e. rubber bands and cords). Nevertheless, this situation is solved applying a new calibration process.

5. CONCLUSIONS AND FUTURE WORK

In this paper, we presented the design and development of a low-cost data glove using simple materials and a single-channel video system based on image processing to reduce costs. We present an easy step-by-step procedure to develop the data glove taking into account the location and position of the webcam. Note that, the lighting condition at the moment of acquiring the images is very important to obtain the efficient *thresholding* segmentation.

We created this prototype as a first version which should be enhanced in future versions. A noticeable problem is related to the number of sensors used. As shown in Fig. 5, these two different positions are considered the same because they produce the same movement of cords. A possible solution is using more cords for tracking each finger's phalange position. Also, it is possible to change the glove design, trying to locate the webcam on a more comfortable position with respect to the hand.



(a) (b)

Figure 5- Both figure (a) and (b) result in the same cord movement.

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