CHICAP: Low-cost hand motion capture device using 3D magnetic sensors for manipulation of virtual objects

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Figure 1: (a) CHICAP, hand motion capture device. (b) Hand operation using CHICAP in real world. (c) Corresponding object manipulation in virtual world.

ABSTRACT

In the research, we propose a cost-effective 3-finger exoskeleton hand motion-capturing device and a physics engine-based hand interaction module for immersive experience in manipulation of virtual objects. The developed device provides 12 DOFs data of finger motion by a unique bevel-gear structure as well as the use of six 3D magnetic sensors. It shows a small error in relative distance between two fingertips less than 2 mm and allows the user to reproduce precise hand motion while processing the complex joint data in real-time. We synchronize hand motion with a physics engine-based interaction framework that includes a grasp interpreter and multi-modal feedback operation in virtual reality to minimize penetration of a hand into an object. The system enables feasibility of object manipulation as far as the needs go in various tasks in virtual environment.

CCS CONCEPTS

• **Human-centered computing → Interaction devices; Interactive systems and tools**;

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KEYWORDS

Exoskeleton hand MoCap, Object manipulation, Virtual reality

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1 INTRODUCTION

In order to enhance the sense of reality in a virtual environment, realistic interaction between a user and the virtual contents, like object manipulation, is of importance. So far many of the researchers have focused on measuring the finger movements by using RGB-d sensors [Engel hard et al. 2011], linear or rotational potentiometers [Gu et al. 2016], or IMUs [Valtin et al. 2017]. Image or IR sensors such as Leap Motion or Microsoft HoloLens are non-contact sensors, thus there is an advantage of easy utility but it suffers from self-occlusion of a hand itself and requires a specific environment to work properly, including visibility, light conditions, etc. Motion capturing methods using linear or rotational potentiometers involve some sorts of wearable mechanism. This method lacks in accuracy, however, as it assigns 1-2 DOF for each finger and assumes a linear relationship between the finger and the measured values. Some use rotational potentiometers in the joints of exoskeletons, but disadvantages were inevitable due to the inability of the workspace coverage of the finger from the mechanism and the lack of DOFs.

In the paper, we propose a novel hand motion capturing wearable device that utilizes 3D magnetic non-contact sensors to capture all the 4-DOF motion of a finger. There are several advantages over the early attempts to enable hand interaction. First, it disregards the existence of self-occlusion during motion tracking since it reads data from magnetic sensors. Second, the mechanism fully covers the range of motion of the fingers and consequently acquires accurate finger movement data. Third, one of the aims in designing the mechanism is to provide the means of accurate hands interaction at a low cost. The sensors used in the proposed mechanism are simple magnetic position sensors that cost around 1 USD each, thus the manufacturing cost of the whole mechanism is expected to be under 200 USD.

Next, we develop a physics-based virtual interaction module that corrects the mismatch between the real hand and its virtual model due to the lack of haptic feedback. [Kim et al. 2016] proposed the object-centered status management using physics particles, but it controls the pose of virtual objects without considering the kinematic hand motion, which may result in manipulation error such as hand penetration through an object or continuous shaking of an object during contact. In this paper, we propose an algorithm that reconstructs the virtual hand pose considering the physical feasibility, and provides a multisensory feedback to support natural and sensuous interaction.

2 SYSTEM DESCRIPTION

The developed exoskeleton is a 3-finger mechanism that provides 12 degrees of freedom in total. Each finger mechanism follows the abduction and adduction of a finger with a yaw joint at the base, and an intermediate joint supports flexion and extension of the finger, as shown in Figure 2. Two 3D magnetic sensors are located at the first and the fourth joints. When a finger moves, the pose (location and orientation) of the end-effector (fingertip) of the mechanism are determined in 100Hz after initial calibration step. The error between the real length of an object and the distance between two fingertips after grasping the real object is less than 2 mm in average. Optimization process and inverse kinematics using the pose provide configurations of virtual fingers to re-generate a virtual hand. HTC Vive tracker on the back of the mechanism provides global position and orientation of the hand.

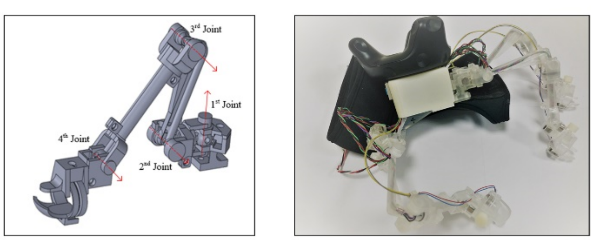

Figure 2: 3D model of a single mechanism (left). Manufactured 3-finger mechanism (right).

Physics simulation has been carried out with rendered hand motion based on data from the proposed mechanism. Especially, to provide the sense of touch, vibration actuators are attached to each fingertip of the device, and haptic feedback is generated whenever the associated object detects a collision. We use Bullet Physics for collision detection and construct a set of particle colliders on part of the hand surface mainly involved in contact with objects, for computational efficiency instead of deformable or dynamic hand mesh collider. The penetration-free hand pose is generated by solving a sequence of optimization problems to reduce the overlapping area between the hand and the object due to the kinematic motion. Temporal consistency is also considered to provide a stabilized hand pose.

3 USER EXPERIENCE

Figure 3: Hand manipulation simulation.

As shown in Figure 3, we set up a scene that focuses on objects that need to be aligned and balanced, which requires precise hand movements. At SIGGRAPH 2018, we plan to demonstrate a fine exoskeleton motion capturing device and vivid hand manipulation simulation using a HTC Vive HMD. In the future, we plan to integrate new haptic actuators and a rendering engine for more realistic simulations such as experiencing kinesthetic force.

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