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The Application of Leap Motion in Astronaut Virtual Training

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Abstract. With the development of computer vision, virtual reality has been applied in astronaut virtual training. As an advanced optic equipment to track hand, Leap Motion can provide precise and fluid tracking of hands. Leap Motion is suitable to be used as gesture input device in astronaut virtual training. This paper built an astronaut virtual training based Leap Motion, and established the mathematics model of hands occlusion. At last the ability of Leap Motion to handle occlusion was analysed. A virtual assembly simulation platform was developed for astronaut training, and occlusion gesture would influence the recognition process. The experimental result can guide astronaut virtual training.

1. Introduction

With a boom of computer vision, virtual reality has been applied in many fields including games, entertainments and simulation training. Additionally, it is appropriate that using VR in astronaut training compared with expensive real simulators. There are two main parts in astronaut virtual training [1]. First significant part is to structure simulation virtual environments, and second important part is human-computer interaction. Most training task are completed by hand manipulation, so gesture interaction is one of important way of human-computer interaction in astronaut virtual training.

In order to meet the increasingly growing demands of training, gesture recognition based virtual reality training system has been used in astronaut training, such as virtual glove-box(GVX) system of NASA [2-4] and EVA astronaut virtual system of China astronaut center [5]. Both of these systems use data gloves to recognize gestures. However, data gloves are uncomfortable, complex and expensive. So advanced tools are essential for more convenient, non-contact, unencumbered interaction.

Recently many consumer-grade optic equipment for hand gesture recognition arose, which can gain hand gesture information easily without touching operators. Those advanced equipment, such as Kinect and Leap Motion, can help to realize natural human-computer interaction.

Kinect is consumer-grade depth sensor, which was designed for natural human-computer interaction. The Kinect sensor can capture depth and color images simultaneously. Kinect has been used in many fields including mapping, human body pose estimation, 3D modeling and hand gesture recognition. However, Kinect was designed for far human body recognition only with low-resolution of depth. So it is difficult using Kinect to achieve full 3D gestures.

Leap Motion controller allows the acquisition of full 3D gestures. With Leap Motion as a tool for gesture input, operator could communicate freely with virtual environments. There has been attempt combining Leap Motion with astronaut virtual training [6]. Leap Motion can provide precise and fluid tracking of hands, fingers, and small objects with sub-millimeter accuracy [7][8]. But Leap Motion could not offer steady and accuracy tracking of hands, when occlusions happen.

The main goal of this paper is to analyze the ability of Leap Motion to handle hands occlusions. This paper also presents some interesting features of Leap Motion. The main contributions of this paper are the following:

- Astronaut virtual training system based Leap Motion was structured.
- Mathematics model of hands occlusion was established.
- Ability of Leap Motion to handle occlusion was analyzed.

2. Astronaut virtual training system

Traditional astronaut ground training employs the construction of the simulation of the real scene to simulate the space environment. Generally the physical simulator is expensive, and it is difficult to simulate the distortion of the scene and the space scene. Additionally we cannot repeat the destructive test by physical simulator. Excitingly, virtual reality technology can break through the limitations above. The virtual reality technology is appropriate to be introduced into the astronaut's ground training. The astronaut virtual training system can be constructed. Depending different tasks various virtual space scenes are created using virtual reality simulator. In astronaut virtual training system stereoscopic vision is displayed to astronaut through helmet or cave. And astronaut could interact with virtual scenes using gesture. During the training process, feedback including visual, auditory and force, is provided to astronaut.

The astronaut virtual training system framework based on natural gesture is showed in fig.1. The system mainly includes virtual reality simulator and human-computer interface. The mission of virtual reality simulator is structure virtual scenes, which are presented to astronaut through helmet-mounted displays. Meanwhile head motion is tracked by sensor. Another important part is human-computer interface. Leap Motion is suitable to be used as gesture input device because Leap Motion controller is small and precise.

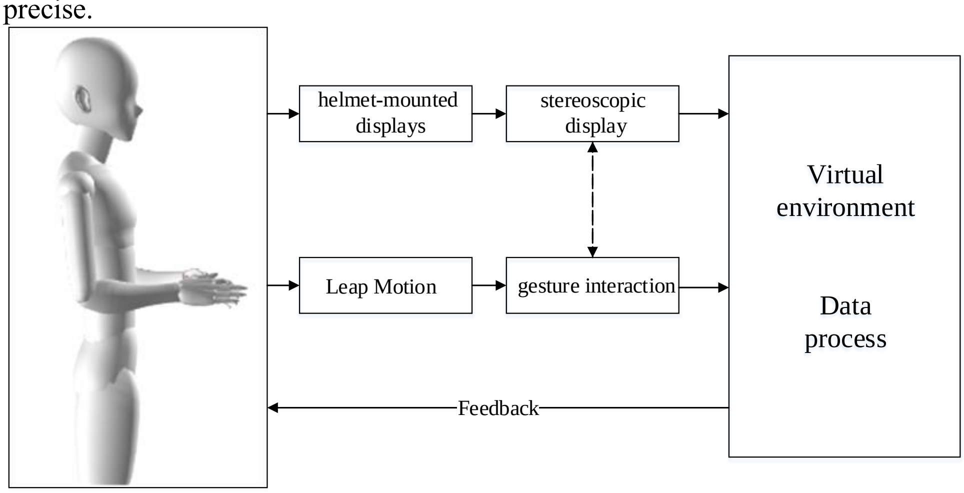

Fig 1. The astronaut virtual training system based leap motion

3. Experiment

The majority of applications for Leap Motion are gesture-based user interfaces. There are some researches about accuracy of Leap Motion, which showed high accuracy of Leap Motion for hand tracking. However, as optic equipment Leap Motion cannot resume full 3D gestures when occlusion happens. Experiment was designed to explore the features of Leap Motion.

3.1. Leap Motion controller

The Leap Motion Controller uses infrared (IR) imaging to track and recognize objects in the recognition space in real time. Leap motion sensor is located at one side of the surface. The detection region is a conical space, and the visual range is an inverted pyramid whose spire is in the center of the equipment. Detection region ranges from 25mm to 600 mm in front of the device. Leap Motion can provide precise and fluid tracking of hands. However, there hardly are details about technology because of patent and trade secret restrictions.

The coordinate system (left) and hand model (right) in Leap Motion are showed in fig.2.

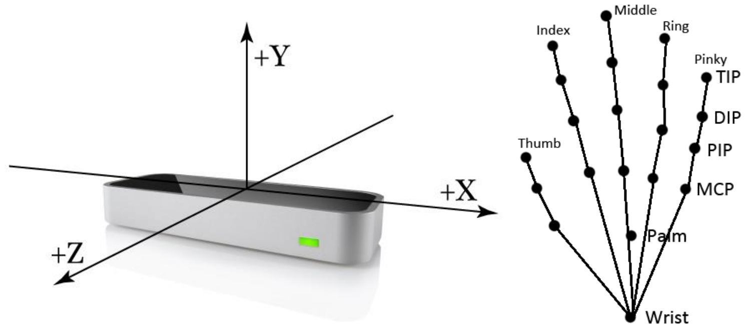

Fig2.The coordinate system (left) and hand model (right) in Leap Motion

3.2. Mathematics Model of Hands Occlusion

Human hand is composed of more than 50 bones. Complex structure and high degree of freedom are significant features of hand. When operator manipulates virtual objects by gesture, occlusion easily takes place. The occlusion of one hand includes three cases. The first case is that one finger bends, and one part of the finger is occluded by remain part of the finger. Second case is that one finger is occluded by another finger. The last case is that the finger is occluded by palm. Sometimes two hands will help finish tasks better. However, cooperative hands holding on the top of Leap Motion would interfere each other.

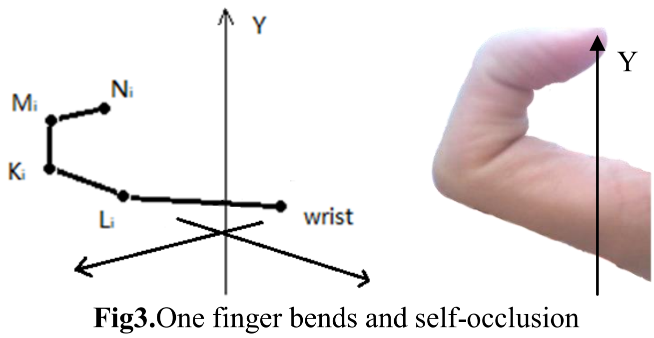

Fig3. One finger bends and self-occlusion

As fig.3 shows， finger i bends. And the bone M_iN_i is occluded by $\overrightarrow{K_iL_i}$. Mathematical expressions are as follow：

$$\begin{cases} \overrightarrow{M_iN_i}\cdot\overrightarrow{K_iL_i}>0 \text{ and } \overrightarrow{K_iL_i}\cdot\vec{y}>0 \text{ ,finger keeps bending.} \\ \text{Projection of bone } M_iN_i \text{ and } K_iL_i \text{ are same place in surface XOZ. } \vec{y} \text{ is the positive unit vector} \end{cases}$$

of Y axis.

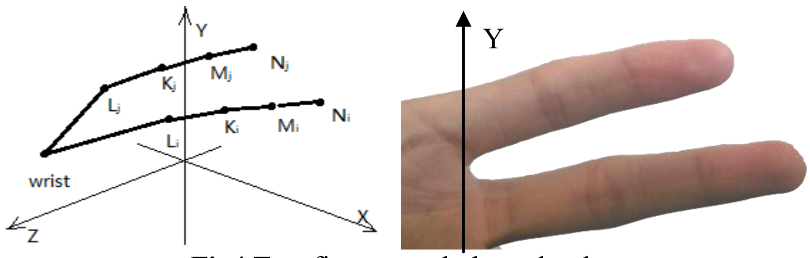

Fig4. Two fingers occlude each other

As fig.4 shows， finger i is below finger j. As an example, the surface which constructed by M_iN_i and M_jN_j, is perpendicular to the surface XOZ. And M_jN_j is occluded by M_iN_i. Mathematical expressions are as follow：

$$\begin{cases} \overrightarrow{M_iN_j}\cdot\vec{n}=0,\ \overrightarrow{M_jN_i}\cdot\vec{n}=0,\ \vec{n} \text{ is the normal vector to surface } M_iN_iN_jM_j. \\ \vec{y}\cdot\vec{n}=0,\ \vec{y} \text{ is the positive unit vector of Y axis.} \end{cases}$$

When the finger is occluded by palm, its mathematical expressions are as follow：

$$\begin{cases} \vec{y}\cdot\vec{p}>0.\ \vec{p} \text{ is the normal vector of palm.} \\ (N_{ix}, 0, N_{iz})\in S_{xz}.\ S_{xz} \text{ is projection of palm in the surface XOZ.} \end{cases}$$

The mathematics model of hands occlusion will help us to understand occlusion better. Obviously, occlusion will decrease accuracy of Leap Motion, and even hand tracking is unavailable. So we want to know tracking ability of Leap Motion when occlusion happens. The following experiment presented the performance of Leap Motion under occlusion.

3.3. Experiment design

Leap Motion Visualizer is an application SDK provides, which can display tracking results of hands in real time, as fig.5 shows. Also the SDK provides coordinate of hand joints. Table 1 showed position of fingertips given by Leap Motion We experimented with Leap Motion controller under various occlusion cases. First, operator put one hand in the recognition region of Leap Motion, and spread fingers to initialize. Then operator made designed gestures which include all case in mathematics model of occlusion. With the help of Leap Motion Visualizer, the tacking results were observed. Position of fingertips were recorded to analyse Leap Motion accuracy. The experiment process is showed in Fig 6 and Fig 7.

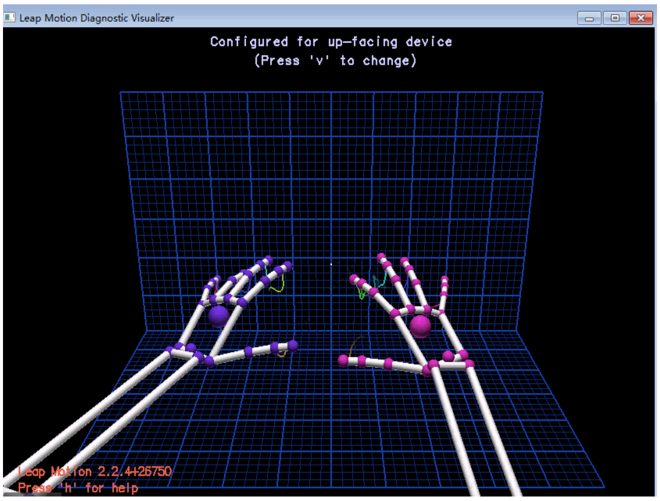

Fig5. Leap Motion Visualizer

Table 1. Fingertipsposition given by Leap Motion (mm)

Frames	195123	195138	195146
Thumb	(-12.2372, 234.425, -21.8778)	(-12.3027, 234.463, -21.8936)	(-12.4073, 234.463, -21.8259)
Index	(-3.32502,220.292, -93.3202)	(-3.56228,220.323, -93.3642)	(-3.73435, 220.222, -93.3804)
Middle	(-3.49694, 188.152, -114.144)	(-3.74823,188.109, -114.197)	(-3.96643, 188.029, -114.186)
Ring	(1.35593, 159.87, -108.419)	(1.13183, 159.93, -108.439)	(0.905643, 159.965, -108.407)
Little	(-10.9444, 117.279, -93.5915)	(-11.1747, 117.291, -93.6007)	(-11.3961, 117.382, -93.5931)

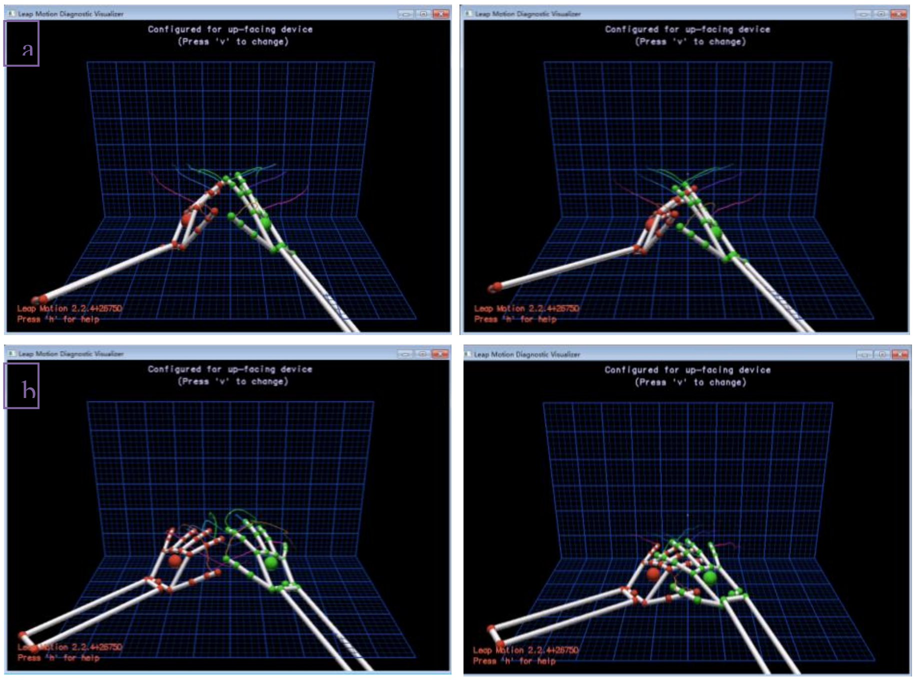

Fig 6. Two hands form non-occlusion to occlusion

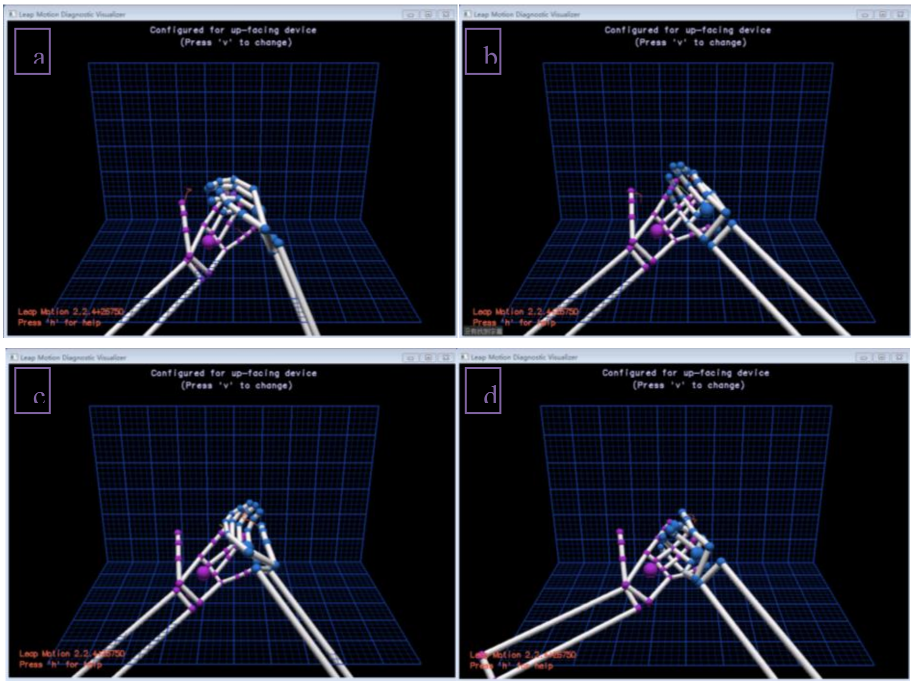

Fig 7. Two hands keep continuous occlusion

3.4. Application
We combined Leap Motion with astronaut training program, as input equipment. And a virtual hand was constructed in virtual environment, which was driven by hand pose data from Leap Motion. Rules were designed to catching and moving virtual components. So a virtual assembly simulation platform was developed to carry on test. Virtual environment was constructed by Unity 3D, which concluded virtual some work pieces and a virtual hand. The virtual hand was driven by data form Leap Motion.

Fig 8. Virtual hand moves to work piece and grab

We designed grab gesture to catch and move work piece like in real world, as Fig 8 shows. And as Fig 9 shows, bounding box was used to judge if hand has capture the virtual work piece, which materially is collision detection. When the bounding box of virtual gets in touch with bounding box of component, they collide each other.

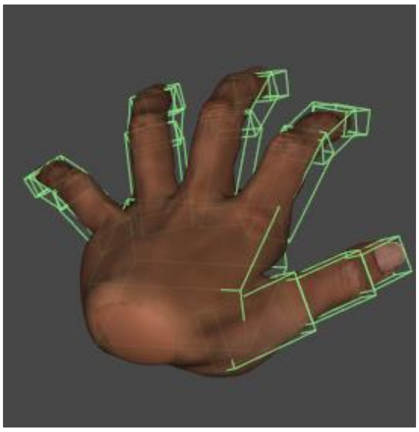

Fig 9. Bounding box of virtual hand

As Fig 10 shows, an integrated process of grab task concluded: a. click and choose a correct part; b. grab the part and move it; c. move the part to appointed position.

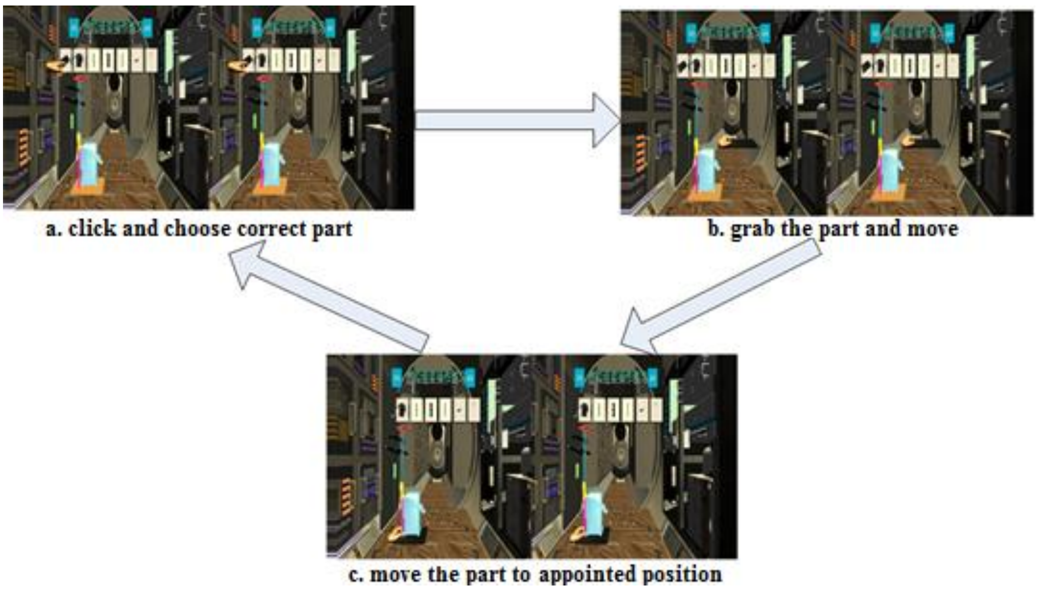

Fig 10. An integrated process of grab task

4. Results and analysis

Through the experiment in 3.3 we found the following direct results:

- The current frame of hand image Leap Motion drew was relevant to the state of the previous frame. The state of virtual hand can be kept a state before occlusion happened.
- The motion of the fingers is restricted by physical movement rules.
- When the finger is blocked, Motion Leap cannot identify the occluded part. At this point the virtual hand cannot truly reflect the real hand pose.
- When hand continued to move and occlusion disappeared, Motion Leap could immediately recovery exact tacking.
- When two hands are separate, the tracking process is similar to the process of one hand. When two hands occlude each other, Motion Leap would lose tracking to hands.

At the same time, we performed grab task using two different gesture: a. index finger and thumb knead, and the rest of fingers were straight; b. index finger and thumb knead, the other fingers were curled, in which self-occlusion took place, as Fig 11 shows.

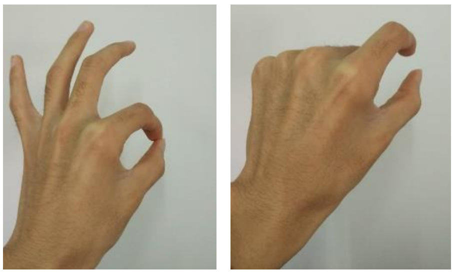

Fig 11. No occlusion (left) and self-occlusion gesture (right)

We recorded the time required to grab and move one work piece to the particular location. The result was showed in Table 2. Averagely 4.41s was cost to complete an integrated grab task using self-occlusion gesture, which spend more time compared with using no occlusion gesture.

Table 2 Time of succeed catching and moving the work piece to appointed position

Time	Average Time	Standard Deviation
No occlusion gesture	4.41	3.36
Self-occlusion gesture	3.32	2.91

The experimental results indicated that self-occlusion would influence astronaut's performance. So when carries out a training task, astronaut should try to avoid perform self-occlusion gesture. In other words, appropriate operating gestures should be designed in astronaut virtual training.

5. Summary

The experiment results showed robustness of Leap Motion, no matter hand self-occlusion or two hands occlusion. We guessed that Kalman filtering is used to predict hand motion and smooth tracking process. But it was powerless when long time continuous occlusion happened. Therefore, to use Leap Motion in astronaut virtual training we can simplify the operation of tasks.

We also developed a virtual assembly simulation platform combining Leap Motion and VR. And in future, appropriate operating gestures should be designed in astronaut virtual training.

Additional equipment or method can be used to assist in solving hand occlusion problem. For example, we can use multiple Leap Motion controllers which are placed in different viewpoints. We believe that there must be more advanced tools in future.

6. References

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