A Wireless Kinect Sensor Network System for Virtual Reality Applications

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Abstract. Currently, Microsoft Kinect, a motion sensing input device, has been developed quickly in research for human gesture recognition. The Kinect integrating into games and Virtual Reality (VR) improves the immersion sense and natural user experience. However, the Kinect is able to accurately measure a user within five meters, while the user must face to the sensor. To solve this problem, this paper develops a wireless Kinect sensor network system to detect users at several viewports. This system utilizes multiple Kinect clients to sense user's gesture information, which is transmitted to a VR managing server for the integration of the distributed sensing datasets. Different from the VR application with a single Kinect, our proposed system is able to support the user's walking around no matter whether he is facing the sensors or not. Meanwhile, we developed a virtual boxing VR game with two Kinects, Samsung Gear VR and Unity3D environment, which verified the effective performance of the proposed system.

Keywords: Kinect · Wireless sensor network · Virtual Reality · Sensor selection

1 Introduction

Tracking the skeleton of human body from RGB image and depth sensors of the Microsoft Kinect has been widely applied for the interaction between users with virtual objects in various multimedia fields, such as Natural User Interface (NUI) and Virtual Reality (VR) [1]. The kinematics researches on the Kinect, such as human action recognition and classification, have been soaring rapidly [2]. When we utilize the Kinect to acquire user's gesture, he needs to stand in front of the Kinect with a limited distance and face to the Kinect. Otherwise, weak and inaccurate signals are sensed.

To provide an interactive environment, where users are able to walk and rotate freely, this paper proposes a wireless Kinect sensor network system for VR applications. In the system, multiple Kinect sensors installed in their respective client computers detect user's gesture information at different viewports. The sensed datasets of

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the distributed clients are sent to a VR managing server, which selects an adaptive Kinect based on the user's distances and orientations of the Kinect sensors. In the sensor selection process, we apply a Bivartiate Gaussian probability density function and Maximum Likelihood estimation method to choose the most suitable one to provide accurate gesture information.

By installing multiple Kinect sensors in VR user's activity environment, the proposed method extends the motion measurements of the Kinect and solves the data lost situation when the user turns back. In our method, only small datasets including user's position and body joints are transmitted between the clients and the server, which satisfied the real-time wireless network transmission requirement.

The remainder of this paper is organized as follows. Section 2 overviews related work. Section 3 describes the proposed wireless Kinect sensor network system. Section 4 develops a boxing VR game using the proposed system. Section 5 concludes this paper.

2 Related Work

Currently, Kinect is a popular display device in VR development, which reports user's localization and gesture information [3]. A single Kinect can only capture the front side of users facing to the sensor. To sense the back side, Chen et al. [4] utilized multiple Kinect to reconstruct an entire 3D mesh of the segmented foreground human voxels with color information. To track people in unconstrained environments, Sun et al. [5] proposed a pairwise skeleton matching scheme using the sensing results from multiple Kinects. Using a Kalman filter, they skeleton joints were calibrated and tracked across consecutive frames. Using this method, we found that different Kinects provided different joints localization, because the sensed surfaces were not same at different viewports.

To acquire accurate datasets from multiple sensors, Chua et al. [6] addressed a sensor selection problem in smart house using Naïve Bayes classifier, decision tree, and k-Nearest Neighbor algorithms. Sevrin et al. [7] proposed a people localization system with a multiple Kinects trajectory fusion algorithm. The system selected the best possible choice among the Kinects adaptively in order to detect people with a high accurate rate. Following these sensor selection theories, we developed a wireless and reliable sensor network for VR applications, which enable the users to walk and interact with the virtual objects freely.

3 Wireless Kinect Sensor Network System

We developed a wireless Kinect sensor network system, as shown in Fig. 1, which integrates the user's gesture datasets from multiple Kinect client into a VR server. In the multiple wireless clients, the user's skeleton motion is detected at multiple views of the Kinect sensors. The system gathers the distributed datasets via WiFi network. The best dataset is selected using a bivartiate Gaussian probability density function. In Fig. 1(b), we develop a VR application using the two Kinect sensors integration, which enables omnidirectional detection of the user.

Fig. 1. The proposed wireless Kinect sensor network system. (a) The framework of the multiple Kinect sensors integration. (b) A scene of the VR application using the proposed system with two Kinect sensors.

A Kinect is installed at each client to detect the user's gesture information at different position, which is transmitted to an application server. From several gathered datasets, effectiveness of each sensor is generated based on the user's distance d and facing orientation θ to the Kinect. If the distance is close and the orientation is facing to a sensor, the effectiveness of this sensor is high. For example, in Fig. 2, k_1, k_2, and k_3 represent the installed Kinect; d_1, d_2, and d_3 represent the distance from the person to each Kinect; θ_1, θ_2, and θ_3 represent the orientation between the user's facing direction to each Kinect. The variables d_3 and θ_3 are smallest, so that we select the Kinect k_3 to detect the user's motion.

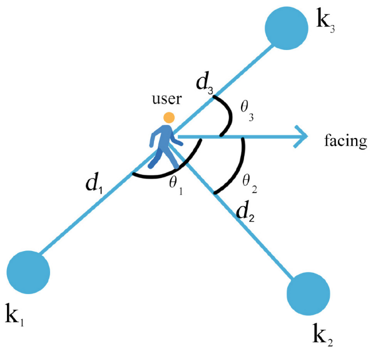

Fig. 2. An example of Kinect sensor selection.

To select the best sensor, we apply a bivartiate Gaussian probability density function (PDF) for the effectiveness estimation, formulated as follows.

$$f_{ki}(d_i, \theta_i) = \frac{\exp\left[-\frac{(\frac{d_i-d_0}{\sigma_1})^2 - \frac{2\rho(d_i-d_0)(\theta_i-\theta_0)}{\sigma_1\sigma_2} + (\frac{\theta_i-\theta_0}{\sigma_2})^2}{2(1-\rho^2)}\right]}{2\pi\sigma_1\sigma_2\sqrt{1-\rho^2}} \tag{1}$$

Here, the variables $d \in [0 \sim \infty)$, $\theta \in [-\pi \sim \pi)$, $\sigma_1 = 1$, $\sigma_2 = 1$, $\rho \in [-1, 0]$. Through the experiments, we found that $d_0 = 5$ and $\theta_0 = 0$ is the perfect position for the Kinect detection. The best Kinect is selected by determined by a maximum likelihood function expressed as follows.

$$k = \arg\max_{k_i} f_{k_i}(d_i, \theta_i) \tag{2}$$

4 Experiments

Using the proposed system, we developed a VR boxing game shown in Fig. 3. We utilized two Microsoft Kinect2 sensors to detect user's gesture on two clients, which are 3.1 GHz Intel® Core™ i7-5557U CPU NUC mini PCs with 16 GB RAM. The VR client is implemented on a Samsung Gear VR with a Samsung galaxy Note 4 in it. The Note 4 has a 2.7 GHz Qualcomm Snapdragon Quad CPU, 3 GB RAM, 2560 * 1440 resolution, and android 4.4 operation system.

Fig. 3. A VR boxing game developed using the proposed wireless multiple Kinect sensor selection system.

In the system, the user location and orientation was detected by the two Kinects. When the player was facing to a Kinect with a distance between 2 to 6 meters, the motion information was sensed precisely. By selection of effective Kinect, the user was able to take free movement and interact with the virtual boxer at omnidirectional orientation. Meanwhile, the monitor of the server rendered the game visualization result synchronously with the VR display. The processing speed of our application including data sensing, transmission, and visualization was more than 35 fps, which achieved a real-time approach.

5 Conclusions

To provide a free movement environment for VR application, this paper demonstrated an effective wireless Kinect sensors selection system via the WiFi network. Using the bivartiate Gaussian PDF, we estimated the effectiveness of each Kinect sensor based on the user's distance and orientation to it. A maximum likelihood function was applied to select the best sensor for providing accurate dataset of user's motion. Using the proposed system, we developed a VR boxing game with two Kinects, where the user was able to move and interact with virtual objects freely. In future, we will integrate some touching sensors to the system for user experience enhancement.

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