International Conference on Artificial Reality and Telexistence
Eurographics Symposium on Virtual Environments (2017)
T. Huang (Editor)

Poster

3D Ground Reaction Force Visualization onto Training Video for Sprint Training Support System

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Abstract
We propose a method for visualizing 3D ground reaction forces for sprint training. Currently, sprinters can check their 3D ground force data using a 2D graph representation. In order to check the relationship between 3D ground force and their sprint form, they must check the 2D graph and a training video repeatedly. To allow simultaneous observation of the 2D graph and the training video, we use a mixed reality technology to overlay 3D ground reaction force onto the training video. In this study, we focus on 2D-3D registration between the image sequence and 3D ground reaction data. We achieved 2D-3D registration by using a constrained bundle adjustment approach. In the experiment, we apply our method to the training videos. The results confirm that our method can correctly overly 3D ground reaction force onto the videos.

CCS Concepts
•***Computing methodologies** → **Mixed / augmented reality;** •**Human-centered computing** → Visualization;*

1. Introduction

In sports training, information technologies such as motion capture systems, force sensors, and heatbeat sensors are gradually being adopted to improve performance by analyzing the athlete's form. Currently, several types of training data can be acquired by sensing devices. Athletes can analyze results that are visualized as either a 2D graph that depends on a time sequence or 3D computer graphics of joint skeleton motion [BHCK13, ITM*13]. In order to analyze the relationship between the obtained data and their form, athletes must check the training video independently. In many cases, the obtained data is displayed in parallel with the training video. Athletes and their coaches must separately check different information. We believe this type of visual feedback method is not an optimal strategy for sports training activities.

To improve the effectiveness of sports training activities, we use a mixed reality technology that can display the training data and sensor data simultaneously. Mixed reality is a technique that can merge real world and virtual world information. For example, we can overlay the obtained sensor data onto the video sequence. In order to overlay the obtained sensor data, all data should be represented in the same coordinate system.

In this research, we focus on the sprint training activities of track and field sports. The use of force plates, which measure the 3D ground reaction force of a sprinter's foot, has increased in recent years. In the literature [RDS*15], they reported a sprint speed is related to ground reaction forces. Currently, after running the track

with embedded force plates, the sprinter can check sequential 3D ground reaction force data displayed as a 2D graph.

In order to confirm the feasibility of visualizing 3D ground reaction force data using mixed reality (MR) technology, we interviewed sprinters at the National Institute of Fitness and Sports in KANOYA. They concluded that MR-based visualization would be useful for their training. In addition, we interviewed them about their actual training activity. They use a video camera to check their form. Usually, the camera is mounted on a tripod, and they do not use the camera's zoom feature during video capture. Primarily, they use a panning camera movement to capture the sprinter. Based on the results of the interview, we note the following assumptions for registering the 3D ground reaction force data onto the video sequence.

- The camera is mounted on a tripod.
- The camera primarily rotates in one direction.

2. 3D Ground Reaction Force Visualization Framework

In order to overlay geometrically correct 3D ground reaction force onto the video sequence, geometric relationship between the force plate coordinate system and the camera coordinate system is necessary. In other words, camera motion must be estimated in advance. In our framework, camera motion is estimated in two stages. In the initial estimation process, we assume pure rotational motion as a camera motion model. In the parameter refinement process, we assume rotational motion and small translation. Using these two pro-
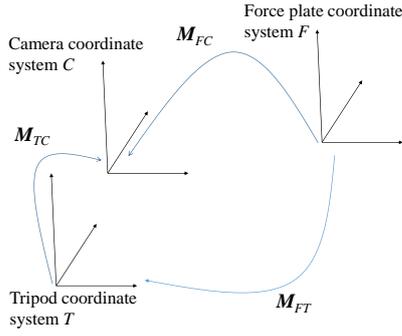
Figure 1: *Relationship between the force plate coordinate system, camera coordinate system, and tripod coordinate system.*

cesses, we can obtain accurate camera motion for overlaying 3D ground reaction force. The details of the camera model and the cost function for the refinement process are described in the following sections.

2.1. Camera Model

We consider the three coordinate systems shown in Fig. 1. In order to visualize the 3D ground reaction force in the camera frame, the transformation matrix $\boldsymbol{M}_{FC}$, which is conveyed from the force plate coordinate system to the camera coordinate system, is needed. According to Fig. 1, $\boldsymbol{M}_{FC}$ can be represented as follows.

$$\boldsymbol{M}_{FC} = \boldsymbol{M}_{TC}\boldsymbol{M}_{FT} \tag{1}$$

where $\boldsymbol{M}_{FT}$ represents the transformation matrix from the force plate coordinate system to the tripod coordinate system, and $\boldsymbol{M}_{TC}$ represents the transformation matrix from the tripod coordinate system to the camera coordinate system. Eventually, to estimate the transformation matrix, we must estimate the rotational component of the geometric relationship between the force plate coordinate system and the tripod coordinate system. In this case, the degrees of freedom of the matrix $\boldsymbol{M}_{FC}$ is three.

2.2. Energy Function for Refinement

In this process, translation matrices $\boldsymbol{M}_{FT_j}$ for each frame and 3D positions of feature points $\boldsymbol{P}_i$ are updated using the bundle adjustment approach. We use the following cost function E_{bundle} for refining the parameters.

$$E_{bundle} = \frac{1}{|\boldsymbol{N}|} \sum_{j \in \boldsymbol{N}} (E_{p_j} + E_{l_j}) \tag{2}$$

$$E_{p_j} = \frac{1}{|\boldsymbol{P}_j|} \sum_{i \in \boldsymbol{P}_j} w_i \left| \boldsymbol{x}_{j_i} - proj\left(\boldsymbol{M}_{FC_j}, \boldsymbol{X}_i\right) \right|^2 \tag{3}$$

$$E_{l_j} = \frac{1}{|\boldsymbol{L}_j|} \sum_{k \in \boldsymbol{L}_j} \left| dist\left(s_{j_k}, \boldsymbol{S}\right) \right|^2 \tag{4}$$

where $\boldsymbol{N}$ represents the set of camera frames. w_i represents a weight for the feature point. At the first frame, several feature points with 3D positions are detected. These 3D positions are measured using a total station. The weights for these points have large values. On the other hand, we set the weights for other feature points at 1.0. $proj()$ represents the function for projecting point $\boldsymbol{X}_i$ onto the

image. $dist()$ represents the function for calculating the distance between reprojected track line S and extracted track line s. $\boldsymbol{L}_j$ represents the number of control points in the projected line in camera frame j. The non-linear minimization technique is applied to cost function E_{bundle} to refine the parameters.

Figure 2: *An example of visualization for the sprinter.*

3. Experiment

To demonstrate the effectiveness of the proposed method, we confirmed the results of visualization of 3D ground reaction forces. Fig. 2 shows the results of the visualization of 3D ground reaction forces. The results confirm that the proposed method can correctly overlay the 3D ground reaction forces onto the foot positions. In addition, a brake force can be confirmed in the bottom left image. By using our visualization framework, this type of inappropriate 3D ground reaction force can be checked using the sprint form. We believe this intuitive visualization technique can help increase the efficiency of sprint training.

4. Conclusion

We proposed a 3D ground reaction force visualization framework for a sprint training support system. By using the proposed method, the 3D ground reaction forces were overlaid onto the video sequence with reasonably high accuracy. In the future, we are planning to confirm the effectiveness of this visualization framework for improving the performance of sprinters.

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