

Spatio-Temporal Evaluation of White Cane Maneuvering Based On a Single Video

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ABSTRACT

This study presents a method for evaluating the three-dimensional posture of white cane walking from a single camera observation and proposes an approach to evaluate the quality of white cane maneuvering through spatio-temporal analysis of the estimated results. The camera is set at a certain place to capture all the walking path. To achieve 3D posture estimation, we introduce an extended skeletal model that incorporates the white cane as part of the human skeleton. White cane maneuvering is a critical skill directly linked to the safety of visually impaired pedestrians, and certain postures are regarded as appropriate for effective and safe use. In this work, we compare walking with and without conscious adoption of the appropriate posture by applying the extended skeletal model and conducting spatio-temporal analysis of the resulting motion. For validation, we implemented a system based on the proposed method and analyzed factors such as cane swing width, the state of the stepping foot, and the position of the cane relative to the forward walking direction, thereby demonstrating the effectiveness of the approach.

Keywords: Computer vision, 3D pose, Skeleton model, Action evaluation, Walking, Human object interaction, Motion analysis, Assistive technology

1. INTRODUCTION

Proper use of the white cane is crucial for ensuring safety when walking with a white cane. It is desirable to acquire a 3D pose status of white cane gait on gait training. To achieve this, it is necessary to have a method to confirm the quality of walking with a white cane. Therefore, we believe that there is a social need for a system that can estimate the posture of a person walking with a white cane in three dimensions using only a single camera image, and that can determine whether the person is walking with an appropriate posture.

We propose a method to realize 3D posture estimation of walking with a white cane from observations made with a single camera, and a method to indicate the goodness of walking with a white cane based on spatio-temporal analysis of the results. For 3D posture estimation of walking with a white cane, we introduce a skeletal model for walking with a white cane, in which a white cane is added as a part of the skeleton to the conventional human skeletal model based on the conventional 3D pose estimation via video.¹ Our posture estimation model of a white cane walker estimates 3D posture based on 2D posture estimation results.

There are several factors that should be considered for proper white cane walking. This paper addresses the following three items among them. Regarding proper posture for white cane walking, based on literature examining teaching guidelines and accident factors, the following points are noted:

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1. The swing width of the white cane should be approximately shoulder-width.
2. Step forward with the foot opposite the direction the cane is swinging.
3. Swing the white cane about one to two steps ahead of the walking path.

These factors can be examined only when the 3D pose estimation of white cane walking is accurate. The latter half of the paper discusses it can be possible based on our 3D pose estimation method.

2. RELATED WORK

Research has been conducted on the relationship between walking posture and the white cane.² Recent assistive technologies for the visually impaired include smartphone-based systems and sensor-equipped white canes. Guerreiro et al.³ propose a system that uses the GPS on a visually impaired person's smartphone to navigate them to their destination. It provides navigation using voice and vibration cues for nearby landmarks and turns. Based on this navigation, it enables guiding visually impaired individuals to their destination even in unfamiliar environments, as long as GPS connectivity is available. Varghese et al.⁴ propose a white cane equipped with ultrasonic sensors, water sensors, GPS modules, and other components. They identified a key challenge: conventional white canes often fail to detect obstacles until contact is made, potentially exposing users to danger. The proposed cane enables earlier hazard recognition than conventional canes by alerting users to detected obstacles or dangers through vibrations and buzzer sounds. Texeira et al.⁵ proposed a white cane equipped with ultrasonic sensors to address the limitations of conventional white canes, which have a short detection range and cannot detect obstacles at head height. Using a white cane with ultrasonic sensors, they successfully detected obstacles three steps ahead, identifying hazards such as stairs, bushes, overhead obstacles, and walls, and issued warnings.

3. 3D POSE ESTIMATION WITH WHITE CANE

In this study, we utilize a human skeleton model to estimate the 3D posture of a white cane user from a single camera video. Here, we construct an extended skeleton model by incorporating the white cane as part of the skeleton. This skeleton model is referred to as the white cane walking skeleton model.⁶ For implementation, we based our approach on VideoPose3D.¹

To enable 3D pose estimation using a white cane walking skeleton model, we created a 3D pose dataset for white cane walkers through CG simulation. We acquired walking data in a motion capture studio by attaching markers to specific joint locations and tracking their coordinates using a motion capture system. Using 3D animation tools, we recreated white cane walking in a virtual space based on the acquired walking data. By filming the virtual white cane walking with a virtual camera, we acquired posture data on a 2D image compatible with 3D animation.

The dataset prepared for this paper consists of 12 walking sequences performed by 4 sighted individuals. The dataset comprises a total of 13,105 frames. In CG simulation, 11 cameras were positioned for each walking sequence to create pairs of 2D poses captured by the cameras and 3D poses in virtual space. Of the 13,105 frames, 10,356 frames were used as training data and 2,749 frames as test data.

Figure 1 shows two snapshots of the recognition result.

The results of 3D pose estimation applied to footage of white cane walking captured by cameras are shown below. Since the true values of the keypoint's 3D positions are unknown at this stage, the evaluation is qualitative. For outdoor white cane walking on the road, three cameras were set up to simultaneously capture footage from three directions. The filming directions were: front-on, side-on, and left-diagonally-forward relative to the walker's front. The footage was captured at 60fps. Figure 2 shows the 3D pose estimation results for this captured footage. From left to right, these are images taken from the front, at an angle, and from the side.

Through these experimental results, it was found that while the proposed method enables three-dimensional pose estimation regardless of the shooting direction, it is desirable to shoot from a direction where the information required for analysis can be obtained with high accuracy in order to perform subsequent high-precision analysis.

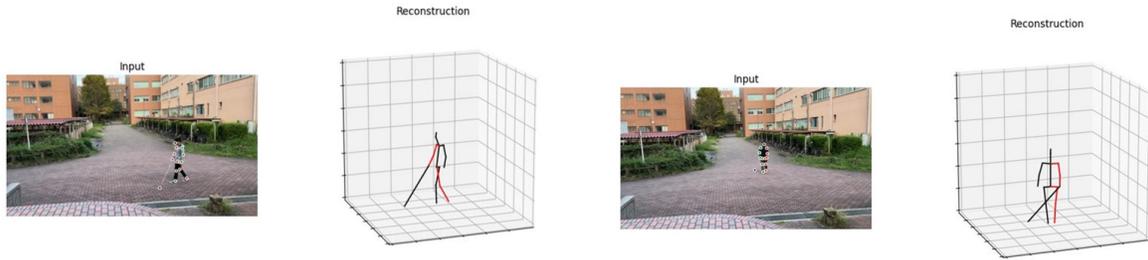


Figure 1. Two examples of 3D pose estimation using a white cane walking skeletal model.⁷

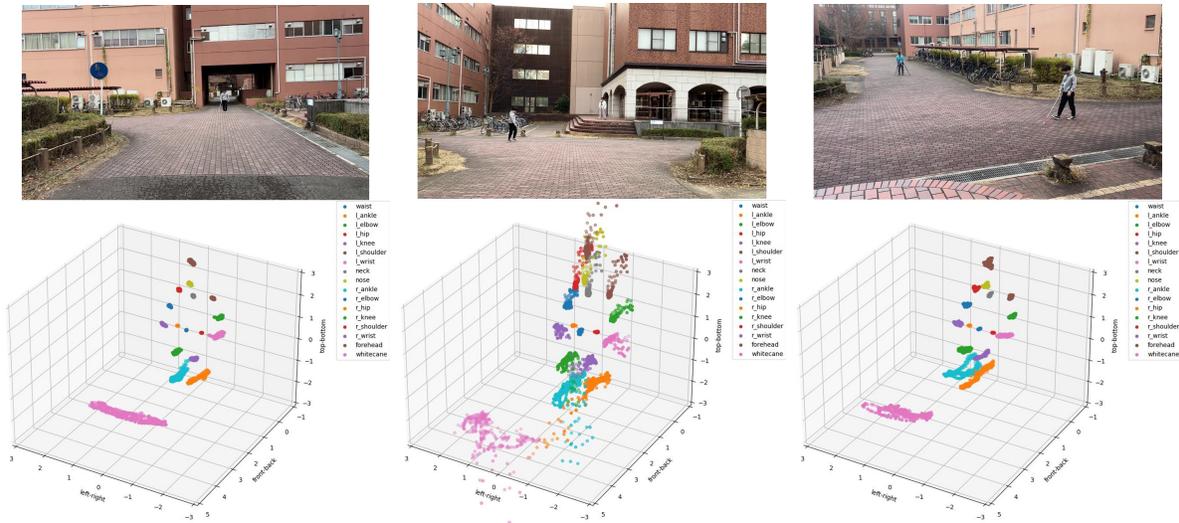


Figure 2. Analysis of walking captured simultaneously from multiple viewpoints.⁷

4. EVALUATION OF WHITE CANE MANEUVERING

Based on the above results, video recording from the front is desirable to obtain suitable footage for spatio-temporal analysis of white cane walking. The three issues of walking quality in footage captured from the front are addressed below. The three issues are listed in section 1.

Figure 3 shows the swing width of the white cane measured from the 3D pose estimation results. To mitigate the impact of noise present in the estimation results, noise reduction was performed using a low-pass filter. The dashed line indicates the data before noise reduction, while the solid yellow line indicates the data after applying the low-pass filter. The left figure shows the analysis result for walking with a swing width consciously kept to about shoulder width in the left panel. The right panel shows the analysis result for walking with an intentionally increased swing width of the white cane. Focusing on the vertical axis, it can be confirmed that significantly different values are estimated as the swing range.

Figure 4 left shows the analysis results for footage of walking with conscious attention to proper posture. It reveals that the opposite foot is stepping forward at a timing close to when the swing amplitude reaches its peak. Meanwhile, the right panel shows the analysis results for walking where the timing of foot placement is intentionally shifted. A discrepancy can be observed between the timing of foot placement and the timing when the swing amplitude reaches its peak. The left figure shows that the foot is stepped out in the opposite direction at a timing close to when the swing amplitude reaches its peak. Meanwhile, the right figure presents analysis results for walking where the timing of foot placement is intentionally shifted. It can be confirmed that a discrepancy occurs between the timing of foot placement and the timing when the swing amplitude reaches its peak.

Figure 5 shows the results of analyzing the position of the white cane relative to the walking plane. The

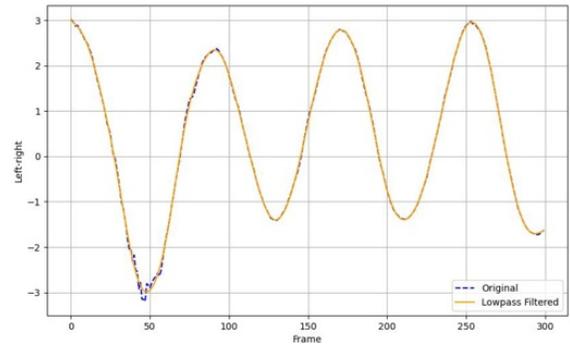
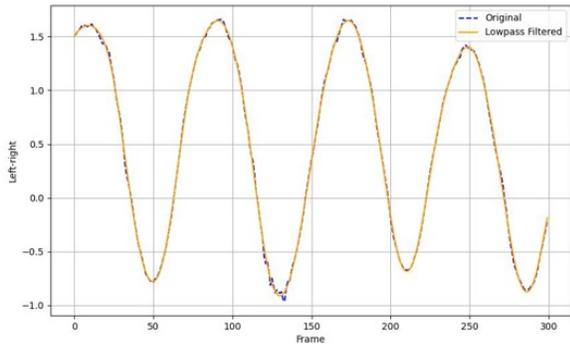


Figure 3. Analysis of white cane swing amplitude.

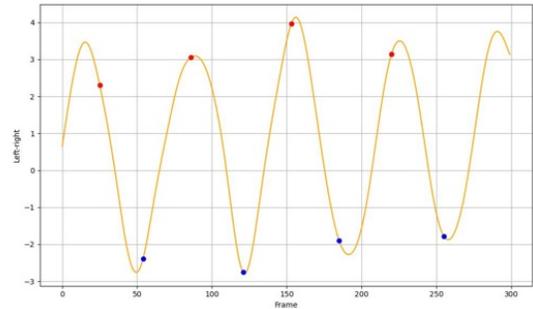
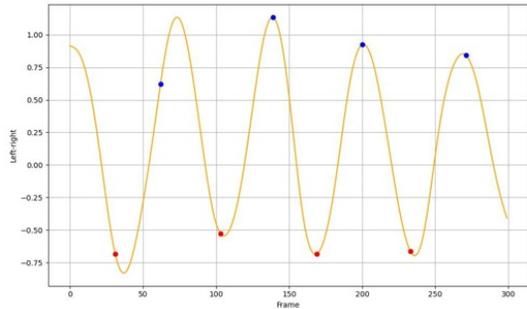


Figure 4. Analysis of the stepping foot.

solid yellow line indicates the position of the white cane relative to the walking plane, while the dashed red line indicates the average stride length. It shows the analysis results for footage of walking while consciously maintaining proper posture (left image). In contrast, the right image shows the analysis results for footage of walking while consciously keeping the white cane as close to the foot as possible. Even with footage captured from the front, it can be seen that depth estimation is being performed.

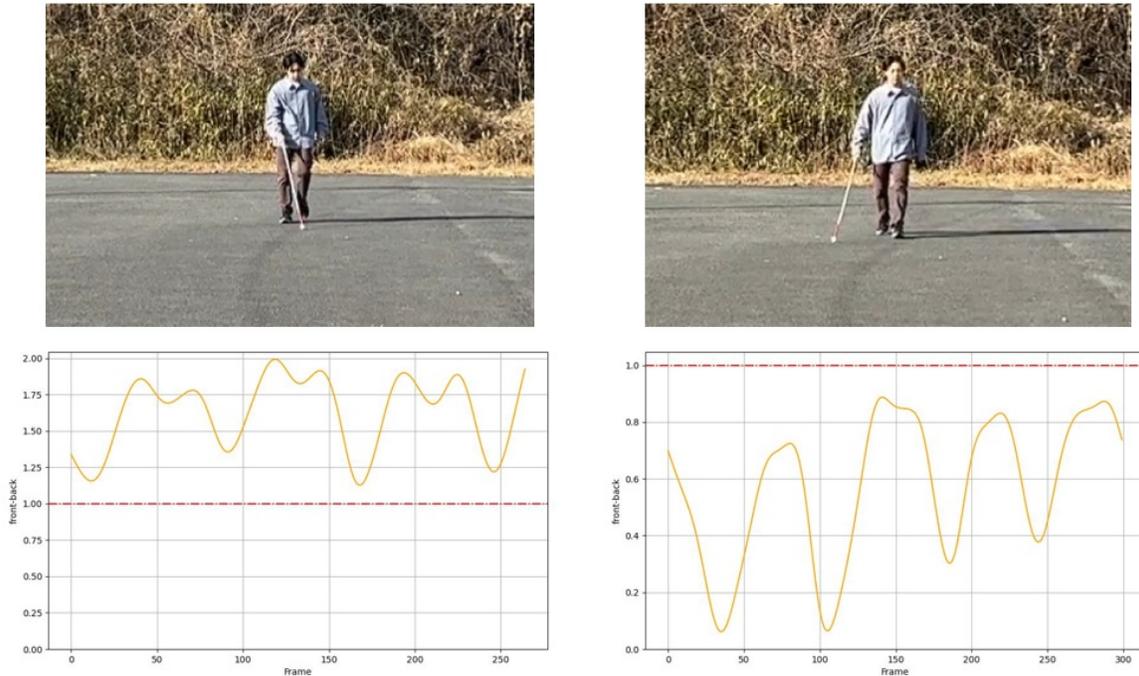


Figure 5. Analysis of the position of the white cane relative to the front line of the walking.

5. CONCLUSION

This study proposes a method for three-dimensional pose estimation of white cane users using a white cane walking skeleton model that extends the white cane as part of the skeleton. It also proposes a method to realize spatiotemporal analysis that can evaluate the quality of white cane walking based on the results of this three-dimensional pose estimation.

We introduced the following criteria to represent the quality of white cane walking: The swing amplitude of the white cane is approximately shoulder-width. The foot steps in the direction opposite to the swing direction of the white cane. The white cane is swung about one to two steps ahead relative to the walking front. The experimental results suggest that our 3D pose estimation method based on the white cane walking skeleton model can analyze the quality of white cane walking using a single camera, provided it captures the walker from the front.

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