Markerless Gait Analysis for Lower Back Pain: A Cost-Effective Solution to Assess Pelvis-Trunk Coordination

Mu-Hua Wang[1], Kun-Ting Tsai [1], Bo-Hung Chen[1], Liang-Wei Huang[1], Cheng-Hung Tsai[2], Chiun-Sheng Hsu[2], and You-Yin Chen[1]*

[1]Department of Biomedical Engineering, National Yang Ming Chiao Tung University, Taipei, Taiwan

[2]III Software Technology Institute, Institute for Information Industry, Taipei, Taiwan

ABSTRACT

In this study, we designed a markerless motion capture system to conduct gait analysis for subjects with lower back pain (LBP). This system provided a substantially low cost and easy-to-use protocols, aiming to overcome the implementation limitations of traditional marker-based motion capture systems like VICON in clinical settings. Our results aligned with findings from marker-based systems, demonstrating the effectiveness of our evaluation.

1. INTRODUCTION

Lower back pain (LBP) is a prevalent condition, affecting up to 80% of individuals at some point in their lives, necessitating thorough evaluation and treatment [1]. While a significant majority, approximately 90-95%, of those affected can achieve full recovery within two months, many experience functional impairments and an elevated risk of re-injury post-recovery [2, 3]. This phenomenon underscores the importance of effective assessment methods for LBP [4], as persistent functional decrements can significantly impact daily activities and overall quality of life [2, 4, 5]. Gait analysis has emerged as a valuable tool in this context, offering objective and quantifiable metrics for evaluating patients with LBP [3, 6]. However, traditional marker-based motion capture systems, such as VICON and QUALYSIS, present barriers to widespread clinical adoption due to their high costs and complex operational protocols [7].

Recent studies have highlighted the potential of gait analysis focusing on pelvis-trunk coordination to provide critical insights into the mechanics of LBP, particularly concerning the risk of re-injury and performance decrements associated with prior episodes of pain [2, 3, 6]. Despite the clinical relevance of such assessments, practical implementation remains a challenge, often limited by resource constraints in many healthcare settings [2, 6]. To address these issues, our study proposes the development of a markerless motion capture system that integrates effective gait analysis techniques while ensuring feasibility for clinical use in LBP patients. This innovative approach aims to enhance the accessibility and applicability of gait analysis in evaluating and managing lower back pain, ultimately contributing to improved patient outcomes and rehabilitation strategies [6].

2. MATERIALS AND METHODS

2.1 Markerless motion capture system

Our laboratory-designed multi-view markerless motion capture system utilizes a configuration of four RGB cameras positioned at the four corners to ensure comprehensive coverage as shown in **Figure 1**. The process begins with camera calibration, which includes intrinsic parameters (focal length, principal points) and extrinsic parameters (translation and rotation vectors) to define each camera's position and orientation. The system then estimates 26 keypoints on the human body from multiple camera views, which are used in a triangulation process to accurately reconstruct the 3D skeleton. Following calibration, object recognition and pose estimation using AI models are employed to identify and track keypoints of individuals within the captured frames. We chose the top-down method for our model to achieve better results compared to bottom-up methods. To transform the 2D prediction data captured by the cameras into 3D coordinates, we apply the Direct Linear Transforms (DLT) method, which allows for the accurate reconstruction of 3D coordinates from 2D projections. Lastly, our system filters the 3D coordinates to reduce noise, ensuring that the resulting 3D motion trajectories are both precise and reliable. The trajectories of the 3D coordinates are then used to calculate pelvis-trunk coordination, with further details provided below.

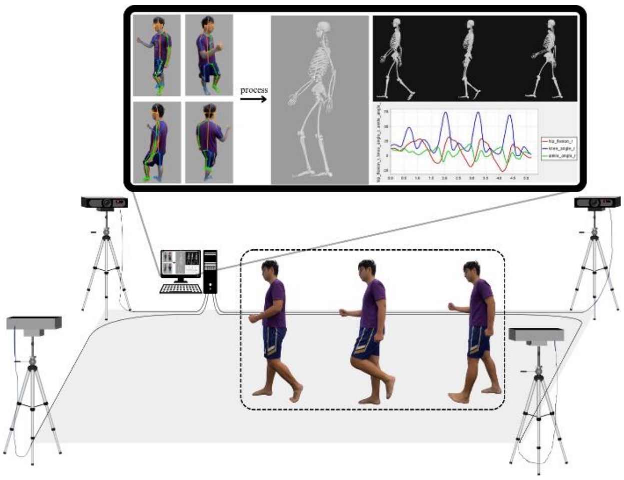

Figure 1. The system operation map.

2.2 Gait analysis - pelvis-trunk coordination

Figure 2 illustrates pelvis-trunk coordination using continuous relative phase (CRP), showcasing spatial-temporal relationships in the frontal and transverse anatomical planes [8]. In the frontal plane, an anti-phase relationship occurs when the pelvis and trunk tilt in opposite directions, while an in-phase relationship emerges when they tilt together in the same direction. Similarly, in the transverse plane, anti-phase coordination involves the pelvis and trunk rotating in opposite directions, whereas in-phase coordination features synchronized rotation in the same direction. These CRP patterns capture the dynamic interplay between the pelvis and trunk, highlighting the contrast between synchronized (in-phase) and counteractive (anti-phase) movement.

The calculation of CRP is as follows: First, the angles of the pelvis and trunk relative to the transverse or frontal plane are calculated using the 3D coordinates of the shoulders and hips as shown in **Figure 3A**. Next, the angle data is segmented into a full, steady-state gait cycle as shown in **Figure 3B**. To calculate the phase angle, the angle data is converted into a two-dimensional plane, where the x-coordinate represents angular velocity and the y-coordinate represents angle position as shown in **Figure 3C**. The position-velocity plane is then scaled into a unit circle to account for frequency differences [9]. Finally, the position-velocity data is converted into polar coordinates to determine the phase angle within the position-velocity plane as shown in **Figure 3D**. CRP was calculated using the absolute values of the differences in phase angles between the trunk and pelvis. Thus, the range of CRP is between 0 to 180 degrees, with 0 degrees indicating in-phase motion and 180 degrees indicating anti-phase motion. Finally, the mean CRP was calculated to indicate the overall phase differences during a full steady-state gait cycle as shown in **Figure 3E**.

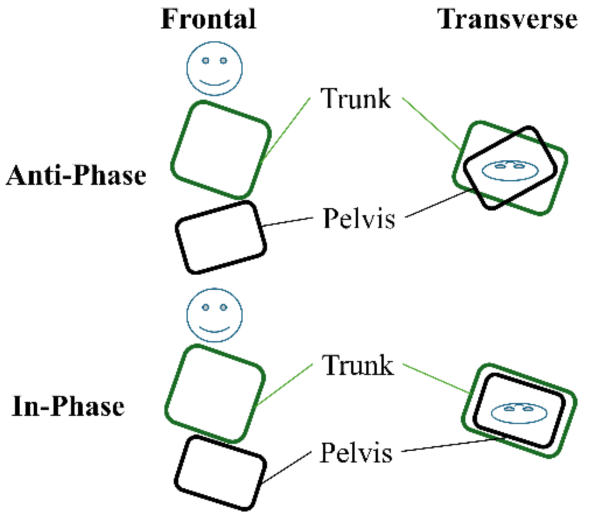

Figure 2. Anti-phase and in-phase demonstration on frontal and transverse anatomical planes.

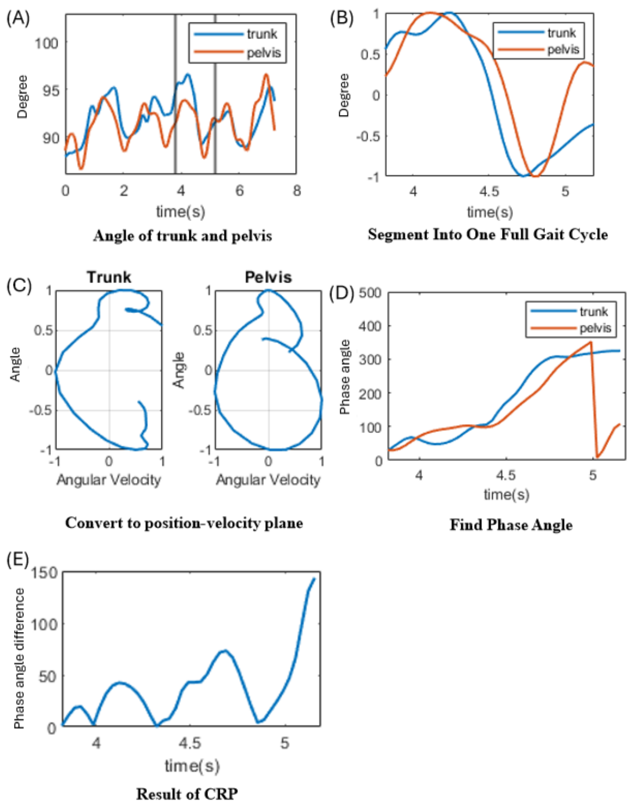

Figure 3. Full workflow for calculating CRP

3. RESULTS & DISCUSSION

Five tests were conducted for both healthy and LBP subjects using two-sample t-test for statistical analysis. A significant difference was observed in the frontal plane ($p = 0.0014^{**}$), while no significant difference was found in the transverse plane ($p = 0.1464$), as illustrated in **Figure 4.** These results suggest that LBP subjects exhibit more in-phase motion in the frontal plane during walking, which is consistent with findings from marker-based motion capture studies [8].

Anti-phase coordination during walking helps to generate elastic recoil between the thorax and the pelvis and may also contribute to minimizing total body angular momentum in the axial plane. However, the tendency for frontal plane in-phase motion in LBP subjects is attributed to the stiffness caused by lower back pain, which results in the difficulty of dissociating movements between trunk and pelvis. Thus, the in-phase motion related to stiffness of LBP subjects can cause higher risk of re-injury and performance decrements as elastic recoil and body angular momentum are constrained [1].

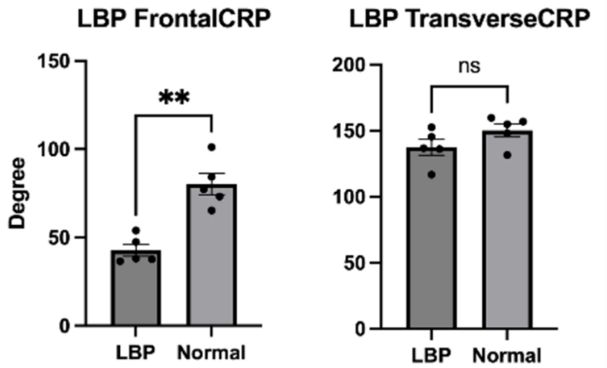

Figure 4. Analytical result for frontal CRP and transverse CRP comparing normal subject and LBP subject.

In conclusion, our markerless motion capture system can perform gait analysis on LBP subjects as an effective assessment tool for clinical practice, addressing the challenges associated with the implementation of gait analysis equipment in traditional marker-based motion capture systems.

4. REFERENCES

1. Hoy, D., et al., A systematic review of the global prevalence of low back pain. Arthritis & rheumatism, 2012. **64**(6): p. 2028-2037.
2. Araújo, S.P., L.N. Carvalho, and É.S. Martins, Lower back pain and level of disability amongst construction workers. Fisioterapia em Movimento, 2016. **29**: p. 751-756.
3. Seay, J.F., R.E. Van Emmerik, and J. Hamill, Low back pain status affects pelvis-trunk coordination and variability during walking and running. Clinical biomechanics, 2011. **26**(6): p. 572-578.
4. Khodadadeh, S. and S.M. Eisenstein, Gait Analysis of Patients with Low Back Pain Before and After Surgery. Spine, 1993. **18**(11): p. 1451-1455.
5. Meucci, R.D., A.G. Fassa, and N.M.X. Faria, Prevalence of chronic low back pain: systematic review. Revista de saude publica, 2015. **49**: p. 73.
6. Kanko, R.M., et al., Assessment of spatiotemporal gait parameters using a deep learning algorithm-based markerless motion capture system. Journal of Biomechanics, 2021. **122**: p. 110414.
7. Hulleck, A.A., et al., Present and future of gait assessment in clinical practice: Towards the application of novel trends and technologies. Frontiers in Medical Technology, 2022. **4**.
8. Smith, J.A., et al., Do people with low back pain walk differently? A systematic review and meta-analysis. Journal of Sport and Health Science, 2022. **11**(4): p. 450-465.
9. Peters, B.T., et al., Limitations in the use and interpretation of continuous relative phase. Journal of biomechanics, 2003. **36**(2): p. 271-274.