Kinematic and Kinetic Validation of an Improved Depth Camera Motion Assessment System Using Rigid Bodies

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***Abstract*—The study of joint kinematics and dynamics has broad clinical applications, including the identification of pathological motions or compensation strategies and the analysis of dynamic stability. High-end motion capture systems, however, are expensive and require dedicated camera spaces with lengthy setup and data processing commitments. Depth cameras, such as the Microsoft Kinect, provide an inexpensive, marker-free alternative at the sacrifice of joint-position accuracy. In this work, we present a fast framework for adding biomechanical constraints to the joint estimates provided by a depth camera system. We also present a new model for the lower lumbar joint angle. We validate key joint position, angle, and velocity measurements against a gold standard active motion-capture system on ten healthy subjects performing sit to stand (STS). Our method showed significant improvement in mean absolute error and intraclass correlation coefficients for the recovered joint angles and position-based metrics. These improvements suggest that depth cameras can provide an accurate and clinically viable method of rapidly assessing the kinematics and kinetics of the STS action, providing data for further analysis using biomechanical or machine learning methods.**

***Index Terms*—Depth camera, rigid-body model, kinematics, sit-to-stand, biomechanics, lower lumbar angle.**

I. Introduction

MUSCULOSKELETAL disorders of the spine and knee lead to approximately 39 million visits to clinical care facilities each year in the United States [1]. Despite the prevalence of these conditions, there remains a lack of scalable, accessible, and quantitative assessments for whole body biomechanics in clinic. The current clinical gold standard for documenting functional spine impairment is the measurement of Cobb angles in flexion and extension [2], [3], or the Sagittal Vertical Axis (SVA) from radiographs [4]. Such radiographs are inexpensive and offer a precise measurement of vertebral range of motion, but they only assess static postures. During daily functional activities such as sit-to-stand (STS), the strategy used to stand can vary [5]–[7], potentially changing the loads experienced by the joints. This results in both inconsistencies in patient care throughout the recovery process and challenges in understanding the relationship between static observations and functional abilities.

Full-body motion analysis can provide insight into pathological motions and compensation strategies. This analysis is performed in biomechanics labs using gold-standard techniques such as motion capture, force platforms, and surface electromyography. This data can be processed using full-body biomechanics software such as Anybody [8] or OpenSIM [9]. While these systems are a staple in obtaining high resolution kinematic, force, and muscular measurements, their application to regular clinical practice is limited by the time required to setup these measurements, the cost of the equipment, required expertise, and the need for a dedicated motion-capture space.

This has resulted in a dichotomy in analysis, with patients assessed with static measures focused at a particular body segment, while biomechanical labs are able to track and analyse the dynamic motion of the whole-body. Some researchers have explored the used of specialised wearable sensing systems for tracking spine function. Marras developed an exoskeletal tracking system for the lumbar spine to identify motions during occupational tasks, and to identify differences in individuals with low back pain [10], [11]. This system was shown to provide a quantitative kinematic measure of dysfunction based on a specific set of flexion tasks. Taylor and Consmüller developed a system for non-invasive back measurement using flexible strain gauges to measure the curvature of the spine [12], [13]. This system was shown to provide a reliable quantitative assessment of spine shape and range of motion when compared to X-ray. While these systems have been shown to provide good estimates of spine motion and can discriminate between pain and asymptomatic subjects, as they only track spine motion, they are not able to assess changes in full-body motion.

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This paper has supplementary downloadable material available at http://ieeexplore.ieee.org, provided by the authors. This includes an MP4 format movie clip, which compares the raw and processed depth-camera data against active motion capture. This material is 616 KB in size.

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