Estimating Sit-to-Stand Dynamics using a Single Depth Camera

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***Abstract*—Kinetic and dynamic motion analysis provides quantitative, functional assessments of human ability that are unobtainable through static imaging methods or subjective surveys. While biomechanics facilities are equipped to perform this measurement and analysis, the clinical translation of these methods is limited by the specialised skills and equipment needed. This paper presents and validates a method for estimating dynamic effects such as joint torques and body momenta using a single depth camera. An allometrically scaled, sagittal plane dynamic model is used to estimate the joint torques at the ankles, knees, hips, and low back, as well as the torso momenta, and shear and normal loads at the L5-S1 disc. These dynamic metrics are applied to the sit-to-stand motion and validated against a gold-standard biomechanical system consisting of full-body active motion-capture and force sensing systems. The metrics obtained from the proposed method were found have excellent concordance with peak metrics that are consistent with prior biomechanical studies. This suggests the feasibility of using this system for rapid clinical assessment, with applications in diagnostics, longitudinal tracking, and quantifying patient recovery.**

***Index Terms*—depth-camera, rigid-body model, dynamics, sit-to-stand, biomechanics, lower lumbar loads**

I. INTRODUCTION

FUNCTIONAL assessment measures enable the quantitative assessment of patient ability. While methods such as static radiographs and goniometry quantify posture or range of motion at a joint level, functional assessments allow for insight into patient independence by gauging task level performance [1].

The clinical deployment of biomechanical motion assessment is limited by the required hardware, time, and expertise. Musculoskeletal analysis is typically performed in dedicated laboratory spaces, using specialist motion-capture and force-sensing systems. Tracked motions of surface markers are used to estimate the rigid-body motions of the underlying skeletal system. This inverse kinematics process allows for the decomposition of complex limb motions into constituent joint trajectories. A dynamic model can then be used to determine the joint torques required to produce these joint trajectories. The dynamic parameters of these models can be allometrically scaled from population data [2], [3], [4], [5], or can be estimated in vivo using identification techniques [6], [7]. This analysis can be validated by measuring the contact forces exerted by the subject. Myography techniques such as surface electro-myograpy and acoustic-myography can be used to estimate muscle activation. These activation patterns can be compared to torque estimates found through inverse dynamic methods [8], [9].

While detailed musculoskeletal models for processing motion data exist [10], [11], current clinical measures of lower limb and spine function rely on timing simple activities such as standing from sitting or walking a known distance [12]. The cost and complexity of deploying more complicated systems has resulted in a disparity between the analysis conducted in speciality biomechanics research facilities and the existing standards of clinical care.

The use of sensorised wearable devices for monitoring occupational tasks and rehabilitation has been explored as a method for overcoming this gap. Garments instrumented with Inertial Measurement Units have been developed to regulate postural control [13], track the curvature of the spine [14], or warn users of poor posture when performing lifting tasks [15]. These wearable systems offer the potential to track a set of key movement parameters. The assessment and feedback, however, is limited to angular estimates of the spine. More detailed biomechanical systems have been developed such as the Lumbar Motion Monitor [16]. This exoskeletal system tracks the kinematics and kinetics of the thoracolumbar spine during a specific occupational or assessment task [17]. The shear and compressive forces in the spine can then be estimated by combining the tracked spine movements with motion capture and surface myography [18]. This approach is limited by dedicated hardware requirements.

A number of vision-based human motion tools have been developed [19]. The Microsoft Kinect can be used to estimate joint centres from a colour and depth image using a pixel classification approach [20]. While these estimates are noisy and can be inaccurate in cases of self-occlusion [21], the system is able to provide real-time estimates which have been used for biomechanical assessments of movement [22]. There are alternative methods for reconstructing human motion from single or multiple cameras, with a number of improvements in accuracy over a wide range of real-world situations. These methods often use template surface models [23], [24] or pixel/voxel classification-based machine learning [25], [26], [27], [28]. While appearing promising, the validation of these approaches is lacking when compared to conventional biomechanical studies. Zhang [29] presented a method for estimating kinematic and dynamic states from a combination of three depth cameras and force sensing shoes. Re-projected marker

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Manuscript received XXX, XXX; revised XXX, XXX; accepted XXX, XXX. Date of publication XXX, XXX.

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This work was funded by SBIR: 1R41AR068202-01A1