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Inverse dynamics based on occlusion-resistant Kinect data: Is it usable for ergonomics?

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Joint torques and forces are relevant quantities to estimate the biomechanical constraints of working tasks in ergonomics. However, inverse dynamics requires accurate motion capture data, which are generally not available in real manufacturing plants. Markerless and calibrationless measurement systems based on depth cameras, such as the Microsoft Kinect, are promising means to measure 3D poses in real time. Recent works have proposed methods to obtain reliable continuous skeleton data in cluttered environments, with occlusions and inappropriate sensor placement. In this paper, we evaluate the reliability of an inverse dynamics method based on this corrected skeleton data and its potential use to estimate joint torques and forces in such cluttered environments. To this end, we compared the calculated joint torques with those obtained with a reference inverse dynamics method based on an optoelectronic motion capture system. Results show that the Kinect skeleton data enabled the inverse dynamics process to deliver reliable joint torques in occlusion-free ($r = 0.99$ for the left shoulder elevation) and occluded ($r = 0.91$ for the left shoulder elevation) environments. However, differences remain between joint torques estimations. Such reliable joint torques open appealing perspectives for the use of new fatigue or solicitation indexes based on internal efforts measured on site.

Relevance to industry: The study demonstrates that corrected Kinect data could be used to estimate internal joint torques, using an adapted inverse dynamics method. The method could be applied on-site because it can handle some cases with occlusions. The resulting Kinect-based method is easy-to-use, real-time and could assist ergonomists in risk evaluation on site.

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1. Introduction

Posture and movement of workers are important information for determining the risk of musculoskeletal injury in the workplace (Vieira and Kumar 2004). Based on accurate kinematic data and external forces, inverse dynamics provides ergonomists with internal efforts, such as joint forces and torques (De Looze et al., 2000), or even muscle tensions (Rasmussen et al., 2003; Pontonnier et al., 2014) that are useful to better understand the risk of musculoskeletal injury. Inverse dynamics can be performed by isolating each body segment and using the Newton-Euler methods to retrieve the joint forces and torques (Featherstone, 2014). Another approach is to drive a dynamic model into the kinematic measurements using optimization (Damsgaard et al., 2006). In both approaches, inaccuracies in the kinematic data would strongly influence the resulting joint torques and forces (Riemer et al., 2008).

As a result, accurate motion capture systems, such as the optoelectronic systems with complex setup and calibration, are generally required. Such optoelectronic systems require placing multiple infrared cameras in the environment, positioning skin markers/sensors over standardized anatomical landmarks, calibrating the

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setup, and post-processing the data. On-site, in real work conditions, this motion capture process is not possible and could interfere with the current task the subject is performing. Recent development of cheap, markerless and calibrationless sensors, such as the Microsoft Kinect, provides an alternative to these motion capture systems in various application domains, such as clinical gait analysis (Clark et al., 2013; Springer and Seligmann, 2016; Auvinet et al., 2014, 2015), fall-risk assessment (Stone and Skubic, 2015), evaluation of the upper-extremity reachable workspace (Kurillo et al., 2013) and computer graphics (Wei et al., 2012). In ergonomics, previous works have evaluated the ability of the Kinect to measure reliable 3D positions (Dutta, 2012), individual morphologies (Bonnechère et al., 2014; Bonnet and Venture, 2015), assess postures at work (Diego-Mas and Alcaide-Marzal, 2013; Spector et al., 2014; Plantard et al., 2016), and provide real-time feedback to the workers (Martin et al., 2012).

However, recent works have shown that joint angles could be badly estimated in some situations, especially those with occlusions or with inappropriate Kinect placement (Plantard et al., 2015, 2017). These constraints generally occur in real manufacturing plants due to cluttered workstations. The resulting inaccuracies could consequently strongly impact posture assessment and further processes such as inverse dynamics.

Several methods have been proposed to enhance the quality of Kinect skeleton data delivered by the associated software (Shotton et al., 2011). Recently, several authors have proposed to reconstruct badly estimated skeleton data by more plausible one, using a database of accurately captured examples (Shum et al., 2013; Shen et al., 2014). To ensure continuity of the resulting posture sequence, recent works have proposed to organize the database of examples as a graph connecting two postures without discontinuity (Plantard et al., 2017).

The relevance of such corrected postures in an inverse dynamics process has not been tested in previous studies. The aim of this paper is to evaluate if inverse dynamics based on these corrected postures could provide accurate joint torques for an ergonomic purpose, even in bad measurement conditions: occlusions and unsuitable sensor placement. To address this question, we compared results obtained with this method with those computed with a reference method based on classical motion capture data measured with an optoelectronic system. The first part of the paper deals with the materials and methods used to develop the experimental protocol, the dynamic calculation from the two type of data and statistics. The second part of the paper presents and discuss the results of the experiments.

2. Materials and methods

The aim of this study is to evaluate the possibility to correctly estimate joint torques from Kinect data. To this end, we have carried out an experiment comparing joint torques computed with a reference method from accurate Vicon data (assumed to be the ground truth) and those computed from Kinect data. We first detail the experimental protocol used to achieve this comparison. Then, we explain how to compute the joint torques from data provided by the two systems.

2.1. Participants

12 male participants (age: 30.1 $\pm$ 7.0 years, height: 1.75 $\pm$ 0.046 m, mass: 62 $\pm$ 2.7 kg) were voluntary to participate in this study. The study was approved by the Research Ethical Committee of the M2S Laboratory from the University of Rennes 2.

2.2. Protocol

In real work conditions, one of the main constraints is the occlusion occurrences, induced by manipulation of external objects or tools. To reproduce this situation in laboratory conditions, the subjects had to perform *Getting* and *Putting* tasks, with a $40 \times 30 \times 17$ cm empty cardboard box, as depicted in the right part of Fig. 1. In this protocol, we have chosen an empty cardboard box to have a minimum weight manipulated by the subject (200 g), leading to negligible external forces but introducing occlusions. The *Getting* task consisted of a carrying box motion from initial position to the front of the hips. The *Putting* task involved replacing the box to the starting position. The box was attached in the air using a wire and a magnet with low resistance so that external forces were negligible all along the motion. The initial position of the box was set at two possible locations, in order to generate motion variability. In placement P1 the target was located on the left of the subject, aligned with the two shoulders at 1.70 m high and 0.55 m left. In placement P2 the target was located at the same height, but 0.35 m left 0.50 m in front of the subject, as depicted in the left part of Fig. 1.

The manipulated box is supposed to generate more or less occlusions according to its placement in relation to the position of the Kinect. We tested different scenarios with and without the box, and various positions of the Kinect, in order to analyse the impact of different types of occlusions:

- NB: without box condition. The subject had to mimic the manipulating motion without actually using a box, leading to a situation without occlusion. Under this condition, subjects were simply asked to reach the position with their hands where the box would normally be. The Kinect was placed in front of the subjects, as recommended by Microsoft. This scenario allowed us to test the robustness of the Kinect in optimal conditions.
- B: with box. The manipulation was realized with the box, leading to occlusions of body parts, as in real work conditions. The Kinect camera was again placed in front of the subject, as recommended by Microsoft.
- B45: with box and camera placement 45° to the right. The only difference with condition B was that the Kinect was placed 45° on the right of the subject. This type of non-recommended Kinect placement generally occurs in cluttered environments. Under this condition, the risk of occlusions was greater than in all previous conditions.

The above conditions (NB, B and B45) have therefore been combined with two target placements of the box (P1 and P2) for a total of six experimental conditions (P1-NB, P1-B, P1-B45, P2-NB, P2-B and P2-B45). These experimental conditions are summarized in Table 1. The subject repeated each task (*Getting* and *Putting*) 5 times in a unique trial, in each experimental condition.

In order to ensure that the inverse dynamic method based on optoelectronic data delivers actually accurate data, we compared recorded ground reaction forces to those predicted by inverse dynamics using Vicon data. Therefore the subjects were placed on two force plates AMTI 120 by 60 cm (frequency of 1000 Hz), calibrated regularly throughout the experiment. The subject positioned each foot on a different platform to measure ground reaction forces under each foot. The weight of each subject was measured using the two force plates. Anatomical landmarks used for marker placements were defined by the International Society of Biomechanics ISB (Wu et al., 2002, 2005).

2.3. Dynamics estimation method

In this experiment, we proposed to compare joint torques

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