ARTICLE IN PRESS

Journal of Biomechanics xxx (2018) xxx–xxx

Contents lists available at ScienceDirect

Journal of Biomechanics

journal homepage: www.elsevier.com/locate/jbiomech
www.JBiomech.com

Short communication

Estimation of vertical ground reaction force during running using neural network model and uniaxial accelerometer

Ngoh Kieron Jie-Han [a], Darwin Gouwanda [a,*], Alpha A. Gopalai [a], Chong Yu Zheng [b]

[a] School of Engineering, Monash University Malaysia, Malaysia
[b] Department of Mechatronics and Biomedical Engineering, Lee Kong Chian Faculty of Engineering and Science, Universiti Tunku Abdul Rahman, Malaysia

ARTICLE INFO

Article history:
Accepted 9 June 2018
Available online xxxx

Keywords:
Running Gait
Accelerometer
Neural Network
Ground Reaction Force

ABSTRACT

Wearable technology has been viewed as one of the plausible alternatives to capture human motion in an unconstrained environment, especially during running. However, existing methods require kinematic and kinetic measurements of human body segments and can be complicated. This paper investigates the use of neural network model (NN) and accelerometer to estimate vertical ground reaction force (VGRF). An experimental study was conducted to collect sufficient samples for training, validation and testing. The estimated results were compared with VGRF measured using an instrumented treadmill. The estimates yielded an average root mean square error of less than 0.017 of the body weight (BW) and a cross-correlation coefficient greater than 0.99. The results also demonstrated that NN could estimate impact force and active force with average errors ranging between 0.10 and 0.18 of BW at different running speeds. Using NN and uniaxial accelerometer can (1) simplify the estimation of VGRF, (2) reduce the computational requirement and (3) reduce the necessity of multiple wearable sensors to obtain relevant parameters.

1. Introduction

Vertical ground reaction force (VGRF) is an important factor in analyzing human motion in sports, especially during running. It is more than twice of a person's body weight (BW) and much greater than the horizontal and lateral ground reaction forces. Excessive VGRF has been linked to the risk of running related injuries too (Messier et al., 2008). The standard measurement involves the use of calibrated force plate. Typically, one force plate is used to measure one step. Therefore, to monitor a series of continuous steps in a gait such as running, an instrumented treadmill embedded with two force plates is required. However, such treadmill is expensive and bulky.

Several wearable devices have been developed to estimate ground reaction force. Some of them use load cells (Veltink et al., 2005, Liu et al., 2010; Faber et al., 2010), while others use pressure sensors (Howell et al., 2013) and pressure insoles (Fong et al., 2008; Crea et al., 2014). Both methods have their strengths and weaknesses. A three-axis load cell can measure the three-dimensional force interaction between the foot and the ground (Liu et al., 2010). However, it is thick and heavy. On the other hand, pressure sensor has a slimmer profile, but it only measures force perpendicular to the sensing surface and it is prone to wear and tear. Hence, it is less durable and has a shorter lifespan.

Recent study by Karatsidis et al. (2017) reported the use of inertial sensor in estimating ground reaction forces and moments. This approach produced positive results. However, it requires the modelling and kinematic behaviors of human body segments. To do so, multiple sensors will need to be fitted on the body. This may constrain subject's motion during walking or running. It may take longer time to setup too.

With wider adoption of machine learning in various applications and wearable motion sensor in monitoring human activity, it is possible to estimate running ground reaction force from a wearable sensor using neural network model (NN). NN is an efficient computational model, which has been demonstrated to be useful in gait analysis (Oh et al., 2013). It is widely used to predict and distinguish walking gait (Schollhorn, 2004). It is also used to estimate VGRF based on measurements by foot pressure sensors (Billing et al., 2006; Jacobs and Ferris, 2015). However, to the best of our knowledge, none of existing study reported the use of NN and wearable motion sensor to estimate VGRF during running.

This study aims to estimate running VGRF using NN and uniaxial accelerometer. The proposed method involves the use of algorithm presented in Chew et al. (2017) to identify the foot initial

* Corresponding author at: School of Engineering, Monash University Malaysia, Jalan Lagoon Selatan, 47500, Bandar Sunway, Selangor, Malaysia.
E-mail address: darwin.gouwanda@monash.edu (D. Gouwanda).

https://doi.org/10.1016/j.jbiomech.2018.06.006
0021-9290/© 2018 Elsevier Ltd. All rights reserved.

contact (IC) and end contact (EC) using foot forward acceleration. This allows the acceleration to be segmented and normalized from IC to EC and be used as an input for NN. The accelerometer is placed on top of the running shoe – above the third metatarsal to minimize disruption to the subject's natural running gait. An instrumented treadmill is used to validate the accuracy of the proposed method.

2. Method

The inertial sensor (Opal, APDM Inc.) was placed on the right shoe and looped together using shoe string to minimize the measurement errors due to shock and vibration (Fig. 1). This sensor can measure acceleration, angular velocity and magnetic field with measuring range of ± 6 g m/s^2, ±2,000 deg/s, and ± 6 Gauss and has dimensions of 43.7 × 39.7 × 13.7 mm^3 with weight of less than 25 g (with battery). As only the forward acceleration (Acceleration along X-axis) is used in this study, it is referred as uniaxial accelerometer.

The participants were instructed to run on an instrumented treadmill equipped with two force plates (Mercury, H/P Cosmos Sports and Medical GmbH). Seven healthy male subjects (Age: 21.3 ± 0.5 years old; Height: 174.9 ± 6.6 cm; Weight: 63 ± 6.1 kg) participated this study. Subjects were briefed on the purpose and method of the experiment, before obtaining their consent. First, the participants were required to walk at a speed of 4 km/h for one minute. The treadmill speed was then increased to 8, 9 and 10 km/h for one minute each. Lastly, participants walked at 4 km/h for another minute before stopping. The recording of the inertial sensor and the treadmill was synchronized by an external trigger.

The acceleration was filtered using 2nd order Butterworth low-pass filter with cut-off frequency of 10 Hz. Several methods can be used to identify IC and EC during running (Alahakone et al., 2010). However, the algorithm presented in Chew et al. (2017) was selected because of its simplicity and compatibility. This algorithm uses the troughs in the foot forward acceleration when foot hits the ground and lifts off the ground as the indicators (Fig. 2). The deeper

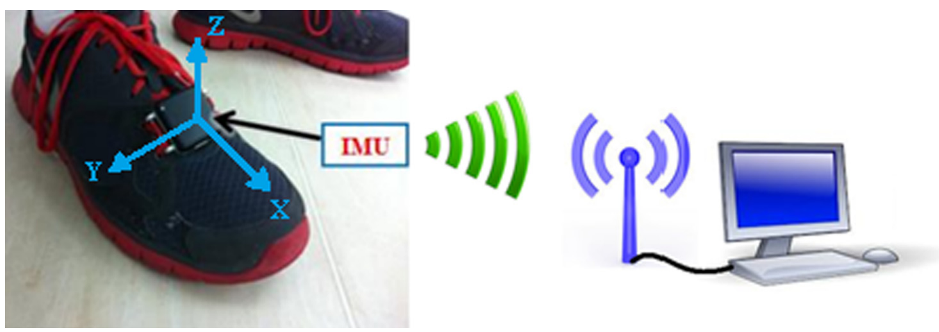

Fig. 1. Location of inertial sensor on shoe and its sensing axes.

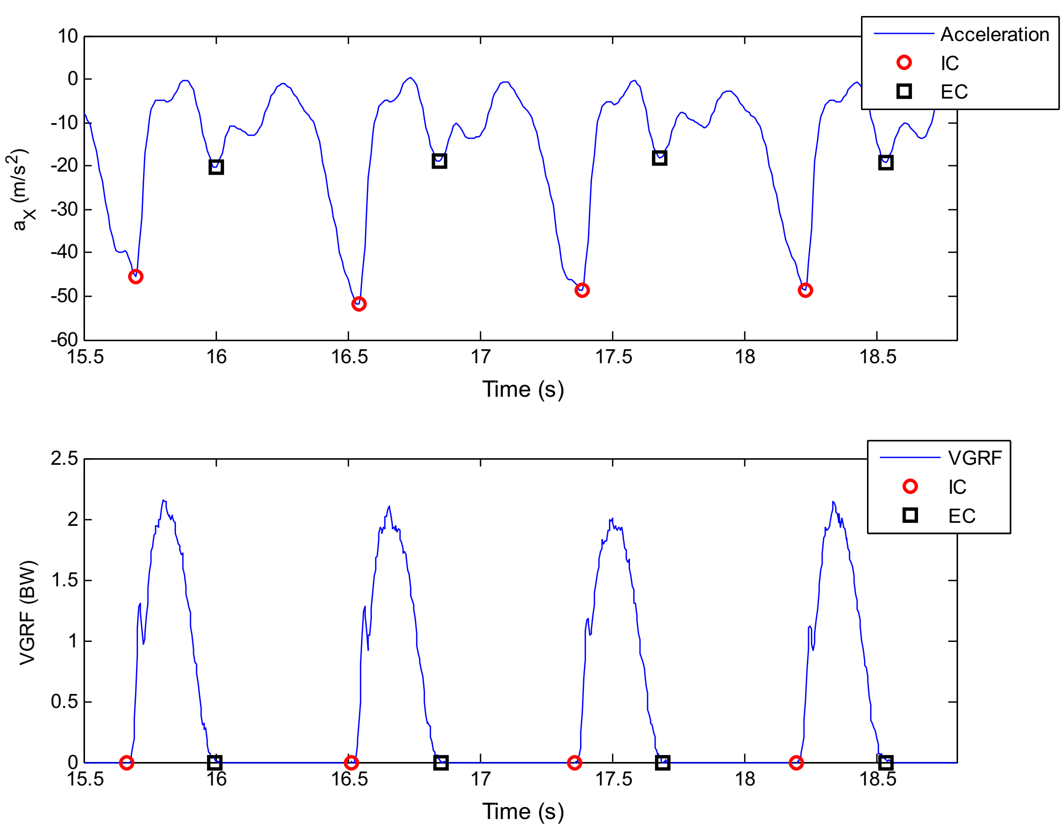

Fig. 2. Measured foot forward acceleration and the detected initial contact (IC) and end contact (EC) (Top figure) and measured vertical ground reaction force (VGRF) and the respective IC and EC (Bottom figure).

Please cite this article in press as: Ngoh, K.-J.H., et al. Estimation of vertical ground reaction force during running using neural network model and uniaxial accelerometer. J. Biomech. (2018), https://doi.org/10.1016/j.jbiomech.2018.06.006