Contemporary Engineering Sciences, Vol. 8, 2015, no. 28, 1339 - 1349
HIKARI Ltd, www.m-hikari.com
http://dx.doi.org/10.12988/ces.2015.56188

Tractor Cabin Ergonomics Analyses by Means of Kinect Motion Capture Technology

Francesco Marinello

Department of Land, Environment, Agriculture, and Forestry
University of Padua, Legnaro, Italy

Andrea Pezzuolo

Department of Land, Environment, Agriculture, and Forestry
University of Padua, Legnaro, Italy

Alberto Simonetti

Occupational medicine MD, Oderzo, Italy

Stefano Grigolato

Department of Land, Environment, Agriculture, and Forestry
University of Padua, Legnaro, Italy

Davide Boscaro

Department of Land, Environment, Agriculture, and Forestry
University of Padua, Legnaro, Italy

Omar Mologni

Department of Land, Environment, Agriculture, and Forestry
University of Padua, Legnaro, Italy

Franco Gasparini

Department of Land, Environment, Agriculture, and Forestry
University of Padua, Legnaro, Italy

Raffaele Cavalli

Department of Land, Environment, Agriculture, and Forestry
University of Padua, Legnaro, Italy

Luigi Sartori

Department of Land, Environment, Agriculture, and Forestry
University of Padua, Legnaro, Italy

Abstract

Kinect is the de facto standard for real-time depth sensing and motion capture cameras. The sensor is here proposed for exploiting body tracking during driving operations. The motion capture system was developed taking advantage of the Microsoft software development kit (SDK), and implemented for real-time monitoring of body movements of a beginner and an expert tractor drivers, on different tracks (straight and with curves) and with different driving conditions (manual and assisted steering). Tests show how analyses can be done not only in terms of absolute movements, but also in terms of relative shifts, allowing for quantification of angular displacements or rotations.

Keywords: Ergonomics, Tractor, Real-time, Sensor, Kinect

1 Introduction

Driving and control of agricultural machinery during different operations for crop cultivation is a stressing activity, from both physical and mental points of view. Specifically, with regard to tractors, the driver undergoes a number of movements which mainly involve the upper part of the body: steering, looking forward, backward, controlling the monitor or the vehicle’s dashboard, using clutch, brake, control levers or joystick [1]. In the long term such activity could generate physical health problems in different part of the body, such as arms, neck, shoulders, back or head. The cabin design, in this sense, plays an important role in the comfort during driving. Indeed, a good ergonomic disposition of the main commands and organization of the cabin room, together with adequate operating practices can potentially reduce or minimize the operator stress.
However, in order to properly characterize and assess ergonomics and comfort in a vehicle cabin, an accurate analysis system is needed. To achieve such purpose, three different methods are typically applied for the acquisition of physical/physiological parameters:

(i) Drivers' self-reporting, which is inadequate due to implementation of a subjective metric, limiting the strength of the interpretation;

(ii) use of sensors for real-time analyses of main physiological parameters, which can provide a clear feedback on driver's state without no or minimum interference with the driver's activities. Most common analyses typically include electrocardiography (for heart rate monitoring), electromyography (for monitoring muscles activity through their electrical potentials), the pneumography (for respiration control) or the skin conductivity (to measure sweat activity) [2; 3; 6; 14]. These investigations provided fundamental information on physiological parameters and health condition, by contrast sensors for real-time analyses still find limited application due to high competence requirements for the understanding and interpretation of physiological data.

(iii) implementation of sensors for real-time analyses of body movements. Such approach is clearly limited due to its focus on activity quantification rather than on body health status. On the other hand it has the merit to allow real-time measurement (in terms of distance, instantaneous speed or acceleration) as well as long term results (in terms of cumulative distances). Such analyses can be applied to different body parts (arms, hands, head, etc.) made in an absolute system as well in a body reference system: in this latter case relative angles and positions and postures in general can be recognised and recorded.

To this purpose, different approaches have been proposed in the past, including implementation of gyroscopes or accelerometers [13], or the processing of video-recorded images [11]. Rotational and linear accelerometers can observe real-time situations but often expansive multiple sensors are required for three-dimensional analysis of a whole body, with the drawback of preventing or interfering with the body movement. On the other hand, motion capture cameras allow real-time acquisition of several parts of the body positions, taking advantage of body markers. Such systems are expensive and their implementation requires several points of view that are not possible when tests have to be performed in limited space conditions.
However the costs of motion capture devices could be considerably reduced thanks to recent hardware and software advances in the videogame industry [8]. The present work takes advantage of such new possibilities, proposing implementation of a new commercial motion-sensor device for tractor cabin ergonomic analysis.

2 Material and methods

2.1. The Kinect depth sensing camera technology

In the present work a commercial camera integrating depth sensing technology was implemented. Such technology is well known since some decades [9] but it is

only in the last few years that it has been rising to a wide diffusion, thanks to the important developments fostered by the videogame industry. Indeed videogames consoles are nowadays using specific peripherals allowing motion capture recognition for full-body control interface, with costs even lower than 70 €. Specifically, for the present study a Microsoft Kinect™ RGB-depth camera was implemented [5; 10]. This device, characterized by low costs and high quality, is arising curiosity and consideration in many agricultural applications [4; 7; 12]. Although this technology is the de facto standard for motion capture and is already considered in many research fields, its implementation for analysis of vehicles cabins ergonomics has only been preliminarily proposed by the Authors [8] and here is discussed in detailed for the first time.
The Kinect is a peripheral sensor of the Microsoft Xbox gaming console allowing three-dimensional reconstruction of the scene and extraction of bodies movements thanks to the integration of different sensors: an RGB camera, an infrared emitter coupled with an infrared camera, four microphones and a three-axis accelerometer (Fig. 1a).
The Kinect sensor adopts an infrared laser emitter which splits a single beam into a speckle patterns through a diffraction grating. The pattern is projected into the scene and collected by the infrared sensor: comparison between the original and the revealed distorted pattern allows definition of a disparity map, given formed by the relative shifts of all projected beams (Fig. 1b). Such map can be used to produce a three-dimensional reconstruction of the scene: the larger the shift, the farer the position and vice versa.
The 3D map is afterward processed by the sensor board to extract the body contour and skeletal joint locations. Such operation can be done both in the case of a standing or of a sitting body: the latter is particularly of interest when considering a standard driver position.
The Kinect sensor presents a view angle of about 57 degrees which allow proper upper body detection reconstruction at a distance of about 1 m.

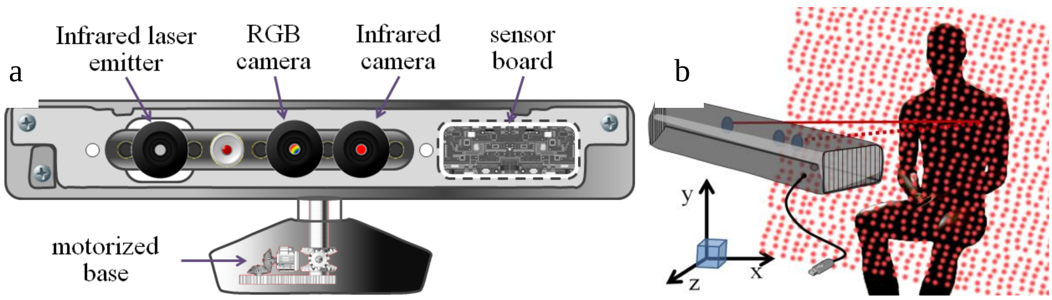

Fig. 1 – (a) Schematic representation of the Kinect sensor and (b) triangulation principle for 3D body reconstruction.

Such condition is suitable to allow ergonomic analyses in the case of large cabin tractors, or even for in the case of small cabins whenever the front glass can be removed or partially opened. Furthermore, a robust algorithm can reconstruct and

monitor hidden joints when they temporarily exit the field of view or they are covered by other body portions or external elements such as the steering wheel.
Despite the infrared laser emitter is high sensitive to an excessive exposition to the sunlight especially when it works in outdoor environments; nevertheless the tractor cabin provides normally a sufficient shading for an adequate working of the sensor.

2.2 Software Analysis

Together with the Kinect, Microsoft released also a non-commercial Software Development Kit (SDK), with open access libraries, available for Windows since 2011. Then, several robust algorithms are available for processing the RGB and depth information, detecting gestures and skeletal postures, recognising audio-information, etc.
In the present work, Kinect SDK was used in order to develop and implement a software tool for monitoring of skeletal joints locations. Fig. 2 summarizes positions and names of detectable joints.
Every positions of the model is described through three coordinates x, y, z, as depicted in Fig. 1b. The positions can be monitored with predetermined frequency in the range between 0.1 and 10 Hz.
For the j-th joint, relative shifts $d_j(t)$ at a given time t can be computed according to equation (1):

$$d_j(t) = \sqrt{\left(x_j(t+\Delta t) - x_j(t)\right)^2 + \left(y_j(t+\Delta t) - y(t)\right)^2 + \left(z_j(t+\Delta t) - z_j(t)\right)^2} \quad (1)$$

The instantaneous speed $v_j(t)$ is consequently achieved deriving $d_j(t)$ as a function of the time. Relative movements are often occurring as angles shifts in correspondence of joints. The relative angles $\theta_j(t)$ on the j-th joint, comprised between adjacent joints i and k, can be computed according to equation (2):

$$\theta_j(t) = arccos\left(\frac{\left(x_i(t)-x_j(t)\right)\cdot\left(x_k(t)-x_j(t)\right)+\left(y(t)_i-y_j(t)\right)\cdot\left(y_k(t)-y_j(t)\right)+\left(z_i(t)-z_j(t)\right)\cdot\left(z_{k(t)}-z_j(t)\right)}{\sqrt{\left(x_i(t)-x_j(t)\right)^2+\left(y_i(t)-y_j(t)\right)^2+\left(z_i(t)-z_j(t)\right)^2}\cdot\sqrt{\left(x_k(t)-x_j(t)\right)^2+\left(y_k(t)-y_j(t)\right)^2+\left(z_k(t)-z_j(t)\right)^2}}\right) \quad (2)$$

As discussed above, the instantaneous angular speed $\omega_j(t)$ is consequently achieved deriving $\theta_j(t)$ as a function of the time.

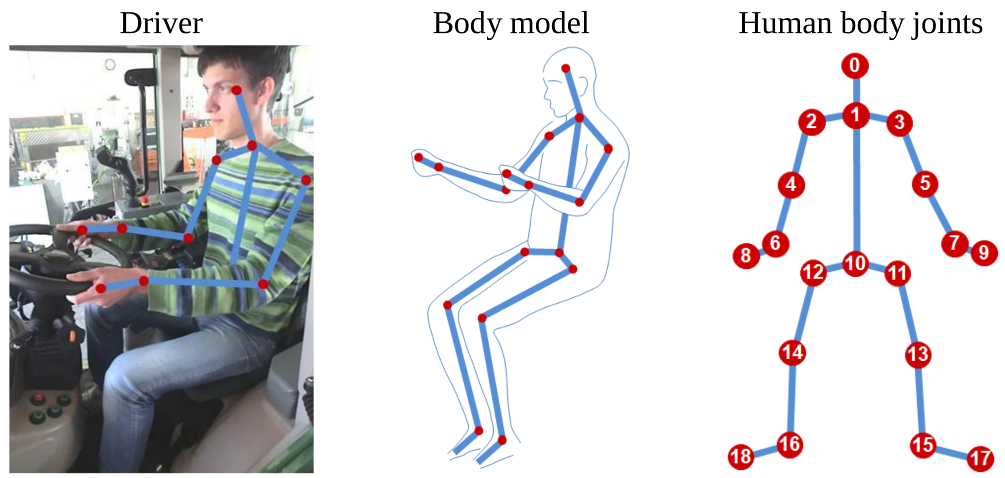

Fig. 2 – Representation of the joints and their positions as detected by the developed software tool. Joints are indicated as: 0) head; 1) shoulder median position; 2-3) shoulders; 4-5) elbows; 6-7) wrists; 8-9) hands; 10) hip median position; 11-12) hips; 13-14) knees; 15-16) ankles; 17-18) feet.

Instantaneous relative shifts $d_j(t)$ and angles $\theta_j(t)$ can be implemented for computation of cumulative stress through the amount of operations carried out by the operator in a given time T, according to equations (3) and (4):

$$D_j(t) = \sum_{t=0}^{T} d_j(t) \quad (3)$$

$$A_j(t) = \sum_{t=0}^{T} \theta_j(t) \quad (4)$$

2.3 Measuring procedures

Thanks to the developed software tool, the Kinect sensor can perform real-time tracking of upper body (corresponding to the joints 0-10 in Fig. 2) while undergoing driving operations. The robust detection algorithms allow detection and monitoring of moving bodies in different positions of the scene, however optimization of quantitative analysis is achieved whenever the sensor is positioned in front of the driver.

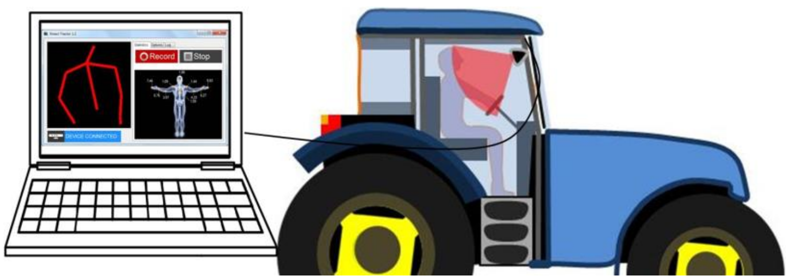

Fig. 3 – A suitable position for the motion capture sensor is in the vehicle cabin, in front of the driver, in the upper windshield in order not to reduce frontal visibility.

Vibrations and in general any relative movement of the sensor can be interpreted by the software tool as a movement of the driver. Therefore for enhancement of stability and proper execution of the tests a vibration damping rubber stage was specifically chosen.

3 Results and discussion

The developed analysis system underwent two set of experiments, respectively to:
1) analyze the potential performance of the analysis system, in terms of field of view and resolution;
2) test the applicability of the system during field operations.

3.1 Field of view and resolution

In order to understand the performance of the sensor two sets of tests were carried out. At first, the sensor was positioned opposite a human body, standing in front of a flat wall at increasing distances between 0.4 and 2.8 m, with 0.2 m intervals. The field of view was estimated as the maximum width and height covered by the moving body, while keeping active tracking through the software. Additionally, the minimum detected movement was analysed as the minimum distance revealed by the instrument between two consecutive measurements, at a frame-rate of 10 Hz. The maximum field of view width and the minimum detected movement (averaged on joints 0-10) are reported in Fig. 4. It can be noticed how resolution ranges between 6 and 22 mm and correspondingly the scanned width ranges between 400 and 1800 mm when the body stands at a distance comprised between 0.4 and 2.8 m. An ideal working condition was recognised at about 1 m distance, where, a resolution of about 10 mm can be ensured on a field of view of as large as 700 mm.
A set of tests was additionally carried out in order to verify the performance of the sensor in body motion recognition at different distances. In particular, Fig. 5 reports the result of an analysis on 5 minutes acquisitions on a moving body sitting at 4 different distances from the sensor for eleven upper joints, for a total of over 130000 points. Values were analysed in terms of outliers, missing and detected points.

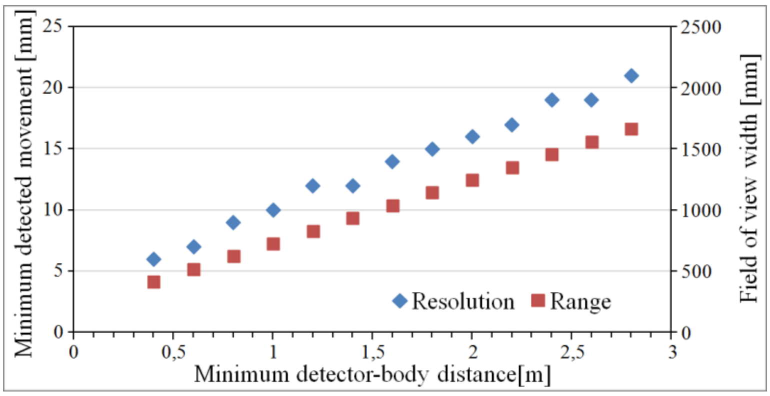

Fig. 4 – Resolution and field of view width at different distances from the sensor

It is shown how a good performance was achieved in the case of the body positioned at a distance of about 1 m from the Kinect sensor, where an optimal trade off between resolution and motion range recognition allowed detection of about 90% of the joints movements. This distance was therefore selected for execution of following field tests.

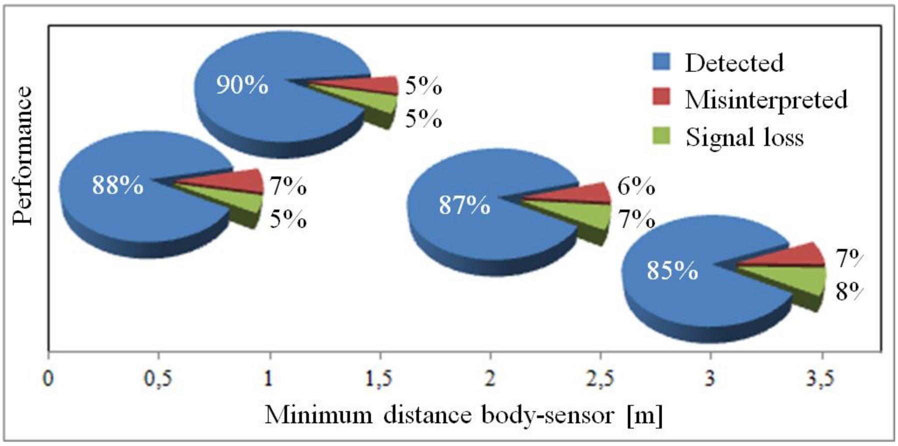

Fig. 5 – Motion capture performance at different distances of the body from the Kinect sensor

3.2 Field tests

A set of field tests was carried out in order to verify the applicability of the Kinect sensor for monitoring driver stress during driving operations. To this purpose the following conditions were analysed:
- straight track, where a tractor is driven on a straight path following a reference line;
- track with curves, where a tractor is driven on a road with a mixed route.

For the tests a continuously variable transmission tractor was implemented (a Fendt 211v) equipped with an assisted steering system (EZ-Steer by Trimble). Tests were carried out at a constant speed of about 1 m/s, considering in both cases:
- two different drivers: a beginner and an expert, respectively with less than 100 hours and more than 3000 hours driving experience;
- two operating conditions: manual and assisted steering.

In the assisted steering the tractor drives autonomously and human intervention is only for checking trajectory correctness, or for secondary controls interventions.
In order to optimize motion recognition, as discussed in the previous paragraph the Kinect was installed in front of the driver, at an average distance of 0,9 m from the head, and about 1,1 m from the hand when laying on the steering wheel. The sensor provided information on joints 0 to 10, but in the present work only joints 0 to 7 are reported. Specifically joint 0 was analysed for head, joints 2-4-6 and 3-5-7 respectively for right and left elbows angles and joints 6 and 7 for wrists tracking.

Main results in terms of average movements and standard deviations computed during 60 s acquisitions and 10 Hz frequency at different driving conditions are summarised in Tab. 1.

Driver	Track	Steering	Joint 7 Left wrist [cm/s]	Joint 6 Right wrist [cm/s]	Joints 3-5-7 Left elbow [°/s]	Joints 2-4-6 Right elbow [°/s]	Joint 0 Head [cm/s]
Expert	Straight	Manual	13.7 (6.5)	9.5 (5.8)	3.4 (2.1)	3.7 (2.3)	3.2 (0.7)
		Assisted	0.9 (0.3)	1.1 (0.2)	0.1 (0.1)	0.1 (0.1)	2.3 (0.5)
	With curves	Manual	8.5 (3.9)	7.4 (4.8)	4.6 (3.7)	4,8 (3.9)	3.7 (0.9)
		Assisted	1.0 (0.2)	1.2 (0.2)	0,1 (0.1)	0.2 (0.1)	3.0 (0.4)
Beginner	Straight	Manual	5.4 (3.4)	5.8 (3.4)	3.6 (1.8)	3.2 (1.7)	2.2 (1.1)
		Assisted	1.0 (0.1)	1.2 (0.2)	0.2 (0.2)	0.1 (0.1)	2.9 (0.7)
	With curves	Manual	9.1 (2.7)	9.2 (2.6)	4.7 (2.9)	4.5 (3.2)	4.2 (1.0)
		Assisted	0.8 (0.2)	0.7 (0.4)	0.2 (0.1)	0,2 (0.2)	3.1 (0.6)

Tab. 1 – Average measurements for joints 0-7 in different testing conditions (standard deviations in brackets)

Due to lack of experience, the beginner driver exhibited a certain rigidity, with movements which in general were computed to be 20% lower if compared to the expert driver. Indeed the expert operator moves arms and head more frequently in order to put the tractor in the right position. Results highlight how values quadruplicate in the case of the manual steering (average wrists movements of 6.8 cm/s) if compared to the case of the assisted steering (1.6 cm/s).

Similar considerations can be done with regard to elbow angle: angular movements are higher in the case of curved tracks because of steering wheel rotations, while variations are almost negligible in the case of assisted driving where the automatic control takes care of vehicle orientation. Nevertheless values are not null due to small movements of the driver, or to some background noise arising during measurements because of sensor vibrations.

The tests show that how the sensor can be implemented to quantify the impact of different driving conditions on driver’s body. Therefore, the new technologies and new kind of cabins can help the drivers to reduce the physical fatigue.

4 Conclusions

Implementation of the Kinect sensor for analysing body relative movements during driving operations is proposed. This device allows monitoring of human body movements both in standing or in seated position. In the present work, the system was specifically applied for monitoring tractor driving operations and in particular to quantify the impact of different steering conditions on driver’s body.

It is shown how over 10 joints associated to the upper body parts can be simultaneously monitored with a sampling rate as high as 10 Hz, with a performance of about 90% of the movements captured. Monitoring can be done not only in terms of absolute movements, but also in terms of relative shifts, allowing for quantification of angular displacements or rotations. Its performance can be reduced and limited in the case of intense sunlight exposure, but its low cost makes it attractive for monitoring of working places in closed or shadowed spaces. Agricultural operations and driving in particular are often very stressing especially after many working hours: implementation of quantitative ergonomic tools can be of help to recognise most stressing manoeuvres and to help a simplification of activities. Indeed often redesigning or reorganizing the working space, can reduce the total movements done by head, hands or arms. By way of example, in the specific case of a tractor cabin, simply optimizing the position of the seat can help reducing the overall activity of a driver, while introduction of assisted steering systems can minimize body movements with a positive impact on overall fatigue. This is an important result, since occurrence of incidents is often correlated to high stress levels. A low cost systems such as the Kinect sensor can be widely implemented to monitor different activities and to spread knowledge on ergonomic impact of different working places.

Acknowledgements. Dr. Massimiliano Rinaldo and Diego Gattolin are acknowledged for their assistance in the development and coding of the software implemented for tracking and analysis of the Kinect sensor data.

References

[1] B. Bashiri, D.D. Mann, Automation and the situation awareness of drivers in agricultural semi-autonomous vehicles, *Biosystems Engineering*, **124** (2014), 8-15. http://dx.doi.org/10.1016/j.biosystemseng.2014.06.002

[2] K. Boubaker, A. Colantoni, E. Allegrini, L. Longo, S. Di Giacinto, D. Monarca, A model for musculoskeletal disorder-related fatigue in upper limb manipulation during industrial vegetables sorting, *International Journal of Industrial Ergonomics*, **44** (2014), 601-605. http://dx.doi.org/10.1016/j.ergon.2014.03.005

[3] N. Egelund, Spectral analysis of heart rate variability as an indicator of driver fatigue. *Ergonomics*, **25** (1982), 663-672. http://dx.doi.org/10.1080/00140138208925026

[4] J. Evers, A. van der Krol, J. Vos, P. Struik, Understanding shoot branching by modelling form and function, *Trends in Plant Science*, **9** (2011), 464-473. http://dx.doi.org/10.1016/j.tplants.2011.05.004

[5] H. Gonzalez-Jorge, B. Riviero, E. Vazquez-Fernandez, J. Martinez-Sànchez, P. Arias, Metrological evaluation of Microsoft Kinect and Asus Xtion sensors, *Measurement*, **46** (2013), 1800-1806, http://dx.doi.org/10.1016/j.measurement.2013.01.011

[6] J.A. Healey, R.W. Picard, Detecting Stress During Real-World Driving Tasks Using Physiological Sensors, *IEEE Transactions on intelligent transportation systems*, **6** (2005), 156-166. http://dx.doi.org/10.1109/tits.2005.848368

[7] F. Marinello, A. Pezzuolo, F. Gasparini, J. Arvidsson, L. Sartori, Application of the Kinect sensor for dynamic soil surface characterization, *Precision agriculture*, **16** (2015), 1-12. http://dx.doi.org/ 10.1007/s11119-015-9398-5.

[8] F. Marinello, A. Pezzuolo, F. Gasparini, L. Sartori, Ergonomics analyses through motion capture in a vehicle cabin by means of Kinect sensor, *International Conference of Agricultural Engineering*, C0253 (2014), 1-5.

[9] K.N. Ogle, Some aspects of stereoscopic depth perception, *Journal of the optical society of America*, **9** (1967), 1073-1081. http://dx.doi.org/10.1364/josa.57.001073

[10] A. Pfister, A.M. West, S. Bronner, J.A. Noah, Comparative abilities of Microsoft Kinect and Vicon 3D motion capture for gait analysis, *Journal of Medical Engineering Technology*, **5** (2014), 274-280. http://dx.doi.org/10.3109/03091902.2014.909540

[11] C. Tran, M.M. Trivedi, Towards a Vision-based System Exploring 3D Driver Posture Dynamics for Driver Assistance: Issues and Possibilities, *Proceedings of the 2010 IEEE Intelligent Vehicles Symposium*, (2010), 179-184. http://dx.doi.org/10.1109/IVS.2010.5547957

[12] W. Wang, C. Li, Size estimation of sweet onions using consumer-grade RGB-depth sensor, *Journal of Food Engineering*, **142** (2014), 153-162. http://dx.doi.org/10.1016/j.jfoodeng.2014.06.019

[13] C.C. Yang, Y.L. Hsu, A review of accelerometry-based wearable motion detectors for physical activity monitoring, *Sensors*, **10** (2010), 7772-7788. http://dx.doi.org/10.3390/s100807772

[14] J.Y. Zhang, W.W. Qiu, H.J. Fu, M.T. Zhang, Q.G. Ma, Review of techniques for driver fatigue detection, *Applied Mechanics and Materials*, **433-435** (2013), 928-931. http://dx.doi.org/10.4028/www.scientific.net/amm.433-435.928

Received: March 30, 2015; Published: October 16, 2015