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# *Ergonomics analyses through motion capture in a vehicle cabin by means of Kinect sensor*

*Francesco Marinello, Andrea Pezzuolo, Franco Gasparini, Luigi Sartori, University of Padova - Department TESAF, Viale dell'Università 16, I-35020 Legnaro (Padova)*

## Abstract

Ergonomics studies encompass a lot of researches aimed to the evaluation of the discomfort and of the suitability of a tractor cabin at different working conditions.
In the present study for driver movements analysis we propose implementation of the Kinect sensor, a low-cost infrared depth camera allowing markerless skeletal tracking, both in standing or seating position. Such sensor allows generation of a stick skeleton mode, extracting and tracking skeletal joint locations (two for each hand, two for the head, four for shoulders and arms, etc.) at a sampling rate of 10 positions per second.
The tracking system was developed by means of the Microsoft software development kit (SDK), and allowed tracking of body movements of a tractor driving person for several minutes.
In order to test the applicability of the sensor, it was applied for monitoring two different drivers (an expert and a beginner) on two different paths taking advantage of a 81 kW tractor allowing assisted steering. Tests highlights how the sensor can be successfully implemented for quantification of drivers body movements.

**Keywords: ergonomics, tractor, real time, sensor, Kinect**

## 1. Introduction

Agricultural operations are typically characterized by an inherent variability, consequently causing a lot of physical and mental stress upon operators. In particular when driving tractors, the body undergoes to severe physiological demands due to frequent movements needed by steering (arms and shoulders), looking forward, backward and sideways to control implements and monitor operations (head, neck, shoulders and back), operating clutch, brake and other control levers (arms), etc. Furthermore driver fatigue is extremely influenced by the specific cabin layout, being minimized in those vehicles featuring an optimal dimensioning and ergonomic disposition of seat and commands and implementing driving aids. As a consequence, stress cannot be merely quantified in terms of working time, and more accurate systems have to be implemented in order to evaluate or compare driving quality of different machines.
Excluding qualitative self-reporting (very much influenced by driver assessing attitude), two different approaches are typically proposed as a solution for fatigue monitoring.
The first approach deals with implementation of sensors which allow real time analysis of physiological parameters. Physiological signals have the advantage of providing a quantitative feedback on driver's state with almost no interference with the driver's task performance.
Among these, electrocardiogram (for heart activity monitoring), electromyogram (to measure the electrical activity of muscles), chest cavity expansion (for respiration) or skin conductivity

(to estimate sweat activity) are certainly the most common and interesting (Egelund 1982; Healey and Picard 2005; Zhang et al. 2013). The main limitations connected with implementation of such instruments lie in the need for high competence (for physiological data interpretation) and in the low sensibility to long term phenomena (sensors are responsive to short time variations).
The second approach deals with integration of sensors which allow real time analysis of driver movements. Motion analysis is very interesting due to the fact that both short and long term effects can be observed. Indeed not only instantaneous movements can be quantified, but also the average motion rate and the cumulative angle or distance run by different body parts and joints can be monitored. Different approaches have been proposed in the past, mainly dealing with implementation of gyroscopes and accelerometers (Young and Hsu, 2010) or with image processing (Tran and Trivedi, 2010). Rotational and linear accelerometers have the merit to allow accurate monitoring in real time, however often multiple sensors are needed for three-dimensional analysis of different body parts. On the other hand, motion capture cameras allow real time acquisition of positions of given markers on a body but are expensive and, requiring multiple point of view, are difficultly installed inside vehicle cabins.
Motion capture devices costs can be significantly reduced taking advantage of hardware devices from videogame industry. The present study exploits motion sensing input devices developed by Microsoft for Xbox videogame console, for ergonomics analyses in vehicle interiors.

## 2. Materials and methods

### 2.1 The Kinect depth sensing camera technology

The present work takes advantage of depth sensing cameras technologies. Such technology is not new, but in the last years has raised a great interest and widespread diffusion mainly thanks to recent applications to the videogames industries. As a consequence, technology has rapidly reached a mature level, and at present depth cameras costing as low as 100 € or less are available on the market. Some examples are the PlayStation 4 Eye distributed by Sony, Kinect developed by Microsoft, or Asus Xtion PRO LIVE distributed by Asus.
For the present study a Microsoft Kinect™ RGB-depth camera was implemented (Zhang, 2012), which is already raising significant interest and growing attention in agriculture applications for its high quality and low cost (Chéné et al., 2012; Tanke et al., 2012; Marinello et al., 2013).
This sensor includes an infrared laser emitter, an infrared camera and an RGB camera. Reconstruction of depth information is achieved by means of a triangulation process: a diffraction grating split the infrared laser into a grid which is projected onto the scene. Such projected pattern is then collected by the infrared camera: detected shifts generate a disparity map, where larger shifts values correspond to farer positions and, conversely, lower values correspond to positions closer to the sensor.
A schematic view of the sensor is reported in Figure 1.

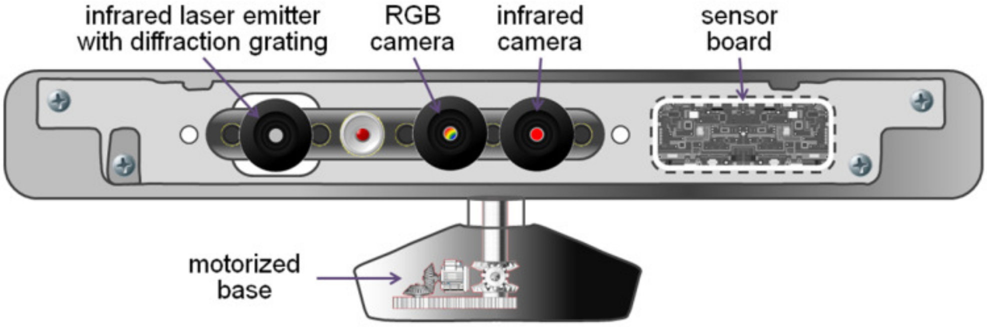


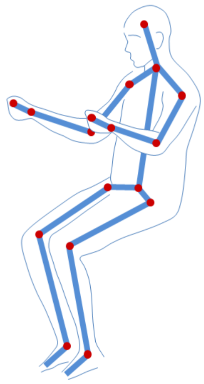
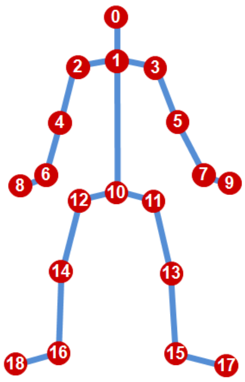

*Figure 1: Schematic view of the Microsoft Kinect™ RGB-depth camera implemented for ergonomics analyses.*

Using a projected and reflected image, the Kinect sensor suffers of all the problems typical of optical sensors. In particular the sensor has a limited view angle (about 57 degrees) and does not allow tracking of hidden parts: therefore parts which exit from the field of view or which are laying behind some obstacle (as is the case of legs which typically lie below the steering wheel) are not monitored. However an interpolation algorithm can be used for hidden joints comprised between to visible joints or for those joints which occasionally exit the field of view. A second limit of the sensor is the high sensitivity to excessive sun light exposition: however it is worth noting that typical shadowing in any vehicle cabin is fully adequate for satisfactory motion capture. A third limit is connected to the occurrence of vibrations and uncontrolled displacements between the sensor and the monitored body: in fact uncontrolled relative shifts are read as body motions, which can distort and abnormally increase detected movements.

## 2.2 Software analysis

Beside Kinect, Microsoft also released a Software Development Kit (SDK) which included a set of robust algorithms for real time extraction of three-dimensional surfaces and silhouettes. For the present work we took advantage of Kinect's SDK to develop and code a software tool for three-dimensional extraction and tracking of skeletal joint locations.
Joints positions and names are summarized in Table 1.

*Table 1: Modelling of a driver's body implemented into monitoring software.*

| Driver | Body model | Human body joints | |
|---|---|---|---|
|  |  |   | 0) Head<br>1) Shoulder center<br>2-3) Right and left shoulders<br>4-5) Right and left elbows<br>6-7) Right and left wrists<br>8-9) Right and left hands<br>10) Hip center<br>11-12) Left and right hips<br>15-16) Left and right ankles<br>13-14) Left and right knees<br>17-18) Left and right feet |

Each joint position is described by three coordinates *x*, *y*, *z*: two of them lie on a plane parallel to the Kinect sensor, while the third one is perpendicular to it. Positions can be monitored with a sampling interval $\Delta t$ which can be arbitrarily set between 0.1 s and 10 s (i.e. with a frequency in the range 0.1-10 Hz). For a given joint *j*, movements $d_j(t)$ and speed $v_j(t)$ at a given time *t* are therefore extracted according to the following equations (1) and (2):

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

$$\mathrm{v_j(t)} = \frac{\mathrm{d_j(t)}}{\Delta \mathrm{t}} \quad (2)$$

where $v_j(t)$ clearly represents the first derivative of the movements $d_j(t)$.
Relative positions of joints can be also monitored. In particular for a given joint *j* comprised between two adjacent joints *i* and *k*, the relative angle can be quantified as follows (3):

$$\alpha_j(t) = arccos\left(\frac{\left(x_i(t)-x_j(t)\right)\cdot\left(x_k(t)-x_j(t)\right)+\left(y(t)_i-y_j(t)\right)\cdot\left(y_k(t)-y_j(t)\right)+\left(z_i(t)-z_j(t)\right)\cdot\left(z_{k(t)}-z_j(t)\right)}{\sqrt{\left(x_i(t)-x_j(t)\right)^2+\left(y_i(t)-y_j(t)\right)^2+\left(z_i(t)-z_j(t)\right)^2}\cdot\sqrt{\left(x_k(t)-x_j(t)\right)^2+\left(y_k(t)-y_j(t)\right)^2+\left(z_k(t)-z_j(t)\right)^2}}\right) \quad (3)$$

Monitoring such parameters is very interesting in order to define not only instantaneous but also cumulative stress. Indeed, while accelerometers can difficultly provide quantitative information on total displacements or relative movements (such as angles between arms and body), by means of a motion capture sensor cumulative stress in a total time $T$ for a given joint can be estimated through the total distance $D_j$ or the total angle $A_j$, according respectively to equation (4) and (5):

$$D_j = \int_0^T d_j(t)dt \quad (4)$$

$$A_j = \int_0^T \alpha_j(t)dt \quad (5)$$

## 2.3 Measuring procedures

The Kinect sensor together with the developed software tool can be implemented for simultaneous tracking of different body joints during some typical driving operations.
In order to allow extrapolation of quantitative data, the Kinect sensor has to be installed in front of the driver, preferably in the vehicle cabin on the top of the front windshield. The position has to be chosen to give the sensor the widest optical access to the driver movements and to avoid reduction of visibility to the driver himself. The Kinect sensor has to be tightly fixed, in order to enhance stability and minimize vibrations.
A specific software was developed to collect data from the sensor and in particular to extract $x$, $y$ and $z$ coordinates of different joints (Table 1) with a frequency of up to 10 Hz. In particular during tractor driving positions of joints numbered from 0 to 10 could be revealed and monitored. Conversely, joints numbered from 11 to 18 were not revealed by the sensor, because of the presence of the steering wheel and of the dashboard hiding the corresponding body parts.

## 3. Results and discussion

The Kinect sensor was applied for monitoring two different drivers: an expert and a beginner driver. They were monitored in two different steering conditions:
- field straight driving, where the driver had the task of keeping the tractor wheels over a straight reference line
- road driving, where the driver had the task of steering the tractor along a path with curves

Tests were repeated on a Fendt 211v tractor equipped with continuously variable transmission (nominal power 81 kW), considering both manual and assisted steering system (EZ-Steer by Trimble). In all conditions, a standard speed condition of 3 km/h was defined.
For the sake of brevity, here results are reported only for the right and left wrists (positions 6 and 7) and for the head (position 0). It is interesting no note how implementation of the sensor, allow estimation of quantitative data (Table 2).

*Table 2: Monitored movements for wrists and head.*

| Driver | Path | Steering | Left wrist [cm/s] | Right wrist [cm/s] | Head [cm/s] |
|---|---|---|---|---|---|
| Expert | Straight | Manual | 13.7 | 9.5 | 3.2 |
| | | Assisted | 0.9 | 1.1 | 2.3 |
| | Road | Manual | 8.5 | 7.4 | 3.7 |
| | | Assisted | 1.0 | 1.2 | 3.0 |
| Beginner | Straight | Manual | 5.4 | 5.8 | 2.2 |
| | | Assisted | 1.0 | 1.2 | 2.9 |
| | Road | Manual | 9.1 | 9.2 | 4.2 |
| | | Assisted | 0.8 | 0.7 | 3.1 |

For our tests, the beginner tractor driver exhibits a more rigid behavior with movements which are in general almost the 20% lower than the expert driver, which, on the other hand moves arms and head frequently to put the tractor in the "perfect" position. Quantitative data also allow measuring average arms and head movements, which are about 1.6 cm/s in the case of assisted steering system and quadruplicates in the case of manual steering (with an average of 6.8 cm/s).
Such preliminary tests demonstrate how the sensor can be efficiently implemented for quantifying the impact of driving operations on drivers body and to understand how new technology (such as assisted steering, continuously variable transmission, etc.) and adequate cab design can help reducing body fatigue.

## 4. Conclusions

In the present study we propose implementation of the Kinect sensor for driver movements analysis. Such low-cost infrared depth camera allows markerless skeletal tracking, both in standing or seating position: as a results, average movements, relative positions, speeds and angles of different joints can be monitored at a relatively high sampling rate (up to 10 Hz) providing relevant feedbacks for optimization of tractor drivers working conditions.

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