Using Inertial Sensors in Driver Posture Tracking Systems

Silviu Butnariu(✉), Gheorghe Mogan, and Csaba Antonya

Transilvania University of Brasov, 500036 Brasov, Romania
`butnariu@unitbv.ro`

Abstract. Improving position of car drivers leads to superior driving performance. Ensuring an ideal position can be achieved by real-time tracking and evaluation of the driver's posture. Thus, this paper proposes a lower-body tracking system using inertial sensors. The developed equipment has the ability to compare the driver's posture at a given moment with an ideal posture, recorded in the calibration phase, with hardware equipment. In order to compare and evaluate the driver's postures during driving the car, a mathematical model of the human body has been developed, having as input data the measurements realized with the inertial sensors. This product contains great added value (software component) on a hardware structure (parts such as: smartphone, inertial sensors and controller) which already exists on the market.

Keywords: Tracking systems · Driver posture · Inertial sensors

1 Introduction

In the last decades, researchers had various approaches to research on systems used to track the movement of the human body, with the ability to record body trajectory data in various applications: sports, medicine [1–6], the position in certain day-to-day activities [7–9].

Several types of sensors used in body tracking have been identified: mechanical, optical, inertial, electromagnetic, and ultrasonic [10]. However, inertial sensors have a number of advantages: small dimensions, low energy consumption, high precision, the possibility of being part of portable equipment [11–13]. This type of sensors can be used in commercial equipment used in various activities: (1) sports (fitness, cycling, running) (http://www.bestfitnesstrackerreviews.com/comparison-chart.html); (2) medical (http://healthtechinsider.com/tag/exercise/, http://nextbigfuture.com/2015/07/exosuit-soft-exoskeleton-update.html, http://www.apdm.com/wearable-sensors/); (3) games (optical sensors - Kinect, LeapMotion, inertial - Wii) – (http://www.fitness-gaming.com/news/markets/home-fitness/perception-neuron-brings-motion-capture-technology-to-average-consumer.html); (4) medical recovery exercises: system Re.Flex, http://reflex.help/. The last mentioned system consists of a pair of sensors that are applied to the limbs of the human body either on hand (forearm and arm) or leg (thigh and pulp), with the possibility to measure the angle between the two sensors. The software runs on a smartphone and contains various preset exercises that can be done and tracked by the

N. Burnete and B. O. Varga (Eds.): AMMA 2018, PAE, pp. 17–24, 2019.
https://doi.org/10.1007/978-3-319-94409-8_2

patient. However, having only one recorded parameter - the angle between the two sensors, one can notice the simplicity of this system.

In [14] there is presented a system containing 2 inertial measurement unit (IMU) sensors mounted on the foot and recording the differences between the angles between the legs with the vertical axis.

2 Methodology

The main idea of the proposed equipment is represented by the data collection method: we want to use one set of sensors applied on body using a Velcro strips. Using the angular data collected by the sensors, we developed a mathematical model in order to reproduce the kinematic structure of the body through link, associated to bones, connected by kinematic joints. The recorded motion is an offset of the bones movement, and is captured by a system of sensors and transducers.

In Fig. 1 is presented a mannequin over which a skeleton is built, similar to that used in motion tracking systems with RGB-D sensor [15]. In the proposed application the segments of this skeleton will be identified and tracked, according to Fig. 1b, where the segments and joints between them are represented.

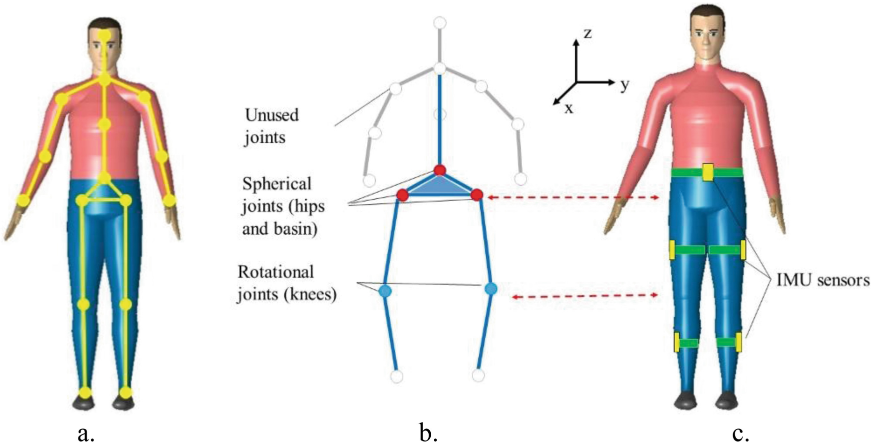

Fig. 1. (a) Mannequin with skeleton; (b) skeleton with joints; (c) mannequin with sensors

3 Equipment

There is a set of five IMU sensors (type Bosch BNO055), positioned on the subject as in Fig. 1c. IMU sensors are mounted in a plastic casing provided with eyelets for fastening using Velcro strips (Fig. 2a). The local coordinate system attached to the IMU sensor is shown in Fig. 2b oriented according to the technical data provided by the manufacturer [16]. During the tracking process we take into account the correspondence between the global coordinate system (shown in Fig. 1) and the local coordinate systems (shown in Fig. 2) of each sensor. The correspondence of these coordinate systems will be established in the calibration phase of the equipment.

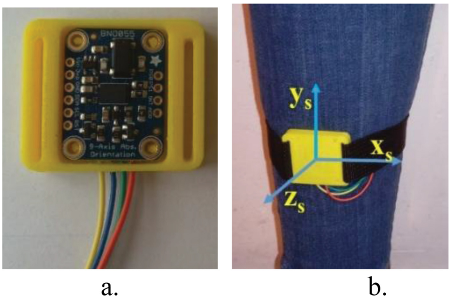

Fig. 2. (a) IMU sensor in plastic case; (b) sensor mounted on the leg and local coordinates system

According to [16], the BNO055 sensor returns absolute values of the Euler angles and quaternion. Each of the five sensors will measure its tilt angle in the three directions. So, as measured sensor inputs for the evaluation phase will be the five sets of angular values in three orthogonal planes. On the other hand, in the calibration phase, anthropometric measurements will be performed and certain dimensions of the subject will be calculated.

The sensors are placed on the external surface of the human body. The data collected by them must be transposed for the virtual reconstructed skeleton (Fig. 3). This has also been studied in the literature [17, 18]. In the driver posture determination phase, the subject will sit in the car and perform a few maneuvers without starting the engine. In addition to the five sensors on the body surface, there is also a sensor of the same type fitted in the car seat, in order to have a reference (Fig. 4a).

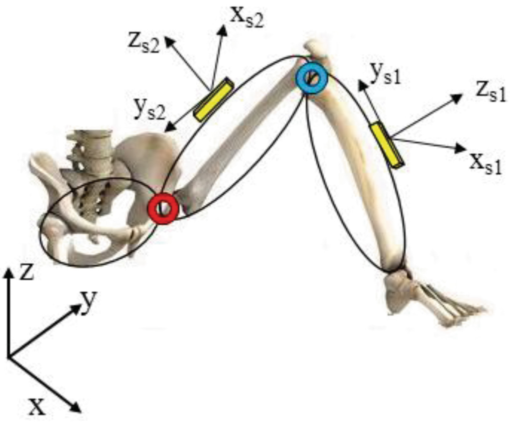

Fig. 3. Position between sensors, bones and geometrical joints and global coordinates system

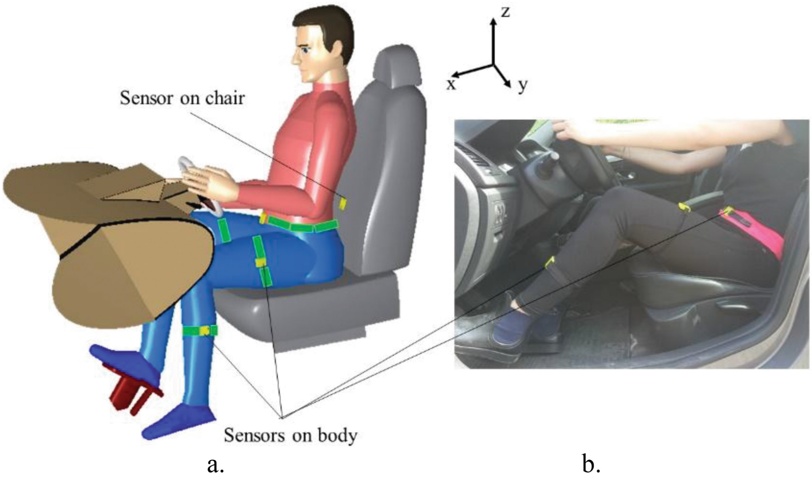

Fig. 4. (a) Model with mannequin and the positions of the sensors; (b) testing equipment - driver with sensors mounted in plastic cases.

In the first case study, the inertial sensors will be placed on the lower limbs (2 × 2) and other one on the subject's waist. They are connected to an Arduino controller via an I2C multiplexer. Sensor signals are collected and transmitted in data packets at very short intervals to a portable computer (smartphone), based on the Android operating system.

In the next phase, the data is processed based on the mathematical model and the results can be sent via WiFi to a server or can be used for visual or audible alert of the user. In another case study, the sensors could be mounted on the arms, in order to control posture of the superior half of the human body.

4 Results

The aim of this research is to create a mathematical model able to use the sensor outputs (anglular values), calibrated according to the anthropological characteristics of the user and then able to generate a geometric model of the driver posture.

We are interested in the position of the knee and hips joints. According to the literature [19], the hip joint is considered as a spherical coupler and the knee joint as a simple rotation coupler. But, by eliminating the rotation movement of the femur in the hip joint around its own longitudinal axis, it can also simplify this joint, reducing it to two rotation joints, one on the X-axis and the other on the Y-axis (Fig. 5).

In the calibration phase, several driver measurements will be performed to complete some of its geometric features. Thus, the following data will be saved: the basin's half-width (b), the height of the basin (h), the basin angle from the vertical (r), body length (l_0), femur length (l_u), tibia length (l_l).

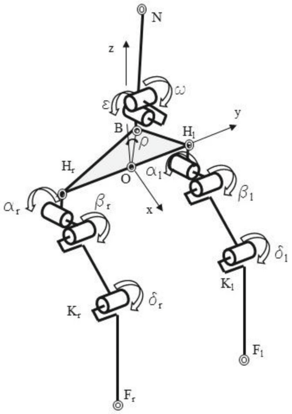

Fig. 5. Kinematic scheme

The used letters symbolize the following points: *H* – hip, *N* – neck, *B* - basin; *K* – knee, *F* – foot, *S* - sensor and the used indices at points *H*, *K* and *F* and at angles *a* and *β* symbolize the followings: *r* – right leg, *l* – left leg, *u* – upper part, *l* – lower part.

Next, the calculation of the points coordinates will be presented only for the right side of the kinematic scheme, with the observation that in the left side the calculation is identical.

The following assumptions have been made: in the point H_r there are two simple rotation couplings. The first rotation is performed around the *X* axis with the angular value *a* and the second around the *Y* axis with value *β*. At the same time, the point H_r is at a distance *b* from the point *O* on the *Y* axis and the point K_r is at a distance l_u from the point H_r on the *X* axis.

The calculation of the coordinates of K_r point in global coordinates system involves the use of the following transformation matrices (see Fig. 5): *Trans* (*y*, −*b*) – translation in the *Y* direction of the point H_r against the center of the global coordinate system *O*; *Rot* (x, a_r) - rotation around the *X* axis in the point H_r; *Rot* (y, β_r) - rotation around the *Y* axis in the point H_r; *Trans* (x, l_u) - translation in the *X* direction of the point H_r in the point K_r (Eq. 1).

$$K = Trans(y, -b) + Rot(x, \alpha_r) \cdot Rot(y, \beta_r) \cdot Trans(x, l_u)$$

$$\begin{bmatrix} x_{Kr} \\ y_{Kr} \\ z_{Kr} \\ 1 \end{bmatrix} = \begin{bmatrix} 0 \\ -b \\ 0 \\ 1 \end{bmatrix} + \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & cos\alpha_r & -sin\alpha_r & 0 \\ 0 & sin\alpha_r & cos\alpha_r & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} cos\beta_r & 0 & sin\beta_r & 0 \\ 0 & 1 & 0 & 0 \\ -sin\beta_r & 0 & cos\beta_r & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} l_u \\ 0 \\ 0 \\ 1 \end{bmatrix} \tag{1}$$

In order to calculate the coordinates of the point F_r, it will start from the coordinates of the point K_r, where there is a simple rotation couple around the *Y* axis, which take into account the distance on the *X* axis between F_r and K_r (Eq. 2).

$$F = K + Rot\left(y, \delta_r\right) \cdot Trans\left(x, l_l\right)$$

$$\begin{bmatrix} x_{Fr} \\ y_{Fr} \\ z_{Fr} \\ 1 \end{bmatrix} = \begin{bmatrix} x_{Kr} \\ y_{Kr} \\ z_{Kr} \\ 1 \end{bmatrix} + \begin{bmatrix} cos\delta_r & 0 & sin\delta_r & 0 \\ 0 & 1 & 0 & 0 \\ -sin\delta_r & 0 & cos\delta_r & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} l_l \\ 0 \\ 0 \\ 1 \end{bmatrix} \tag{2}$$

From the point of view of the upper body position (thorax), we assume that the driver's body will follow the seat profile and the sensor mounted on the basin area (S_B) will only sense the rotations around the *Y* and *X* axes rotations. Thus, the coordinates of the point *N*, corresponding to the neck, will be calculated using the following matrices of rotations and translations: *Rot* (*x, ε*) - rotation around the *X* axis in the point *B*; *Rot* (*y, w*) - rotation around the *Y* axis in the point B; *Trans* (*z,* l_0) - translation in the *Z* direction of the point *B* in the point *N* (Eq. 3).

$$N = Rot(y, \rho) \cdot Trans(z, h) + Rot(x, \varepsilon) \cdot Rot(y, \omega) Trans\left(z, l_0\right)$$

$$\begin{bmatrix} x_N \\ y_N \\ z_N \\ 1 \end{bmatrix} = \begin{bmatrix} cos\rho & 0 & sin\rho & 0 \\ 0 & 1 & 0 & 0 \\ -sin\rho & 0 & cos\rho & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} 0 \\ 0 \\ h \\ 1 \end{bmatrix} + \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & cos\varepsilon & -sin\varepsilon & 0 \\ 0 & sin\varepsilon & cos\varepsilon & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} cos\omega & 0 & sin\omega & 0 \\ 0 & 1 & 0 & 0 \\ -sin\omega & 0 & cos\omega & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} 0 \\ 0 \\ l_0 \\ 1 \end{bmatrix} \tag{3}$$

On the other hand, for the calculation of the coordinates of the point *B*, we will take into account the angle r (rotation around *Y* axis in the point *O*) and the dimension *h* of the basin (*OB* distance), geometric characteristics measured by each driver in the calibration step. In the table below (Table 1) are presented the coordinates of all the points (Fig. 6) corresponding to the posture of the driver's legs, depending on the position of the basin.

Table 1. Coordinates of the points

	x	y	z
H_r	0	$-b$	0
H_l	0	b	0
B	h sinr	0	h cosr
N	h sinr + l_0 sin$w$	$-l_0$ sinε cos$w$	h cosr + l_0 si cos^2w
K_r	l_u cosβ_r	$-b + l_u$ sina_r sinβ_r	$-l_u$ cosa_r sinβ_r
K_l	l_u cosβ_l	$b + l_u$ sina_l sinβ_l	$-l_u$ cosa_l sinβ_l
F_r	l_u cos$\beta_r + l_l$ cosd_r	$-b + l_u$ sina_r sinβ_r	$-l_u$ cosa_r sin$\beta_r - l_l$ sind_r
F_l	l_u cos$\beta_l + l_l$ cosd_l	$b + l_u$ sina_l sinβ_l	$-l_u$ cosa_l sin$\beta_l - l_l$ sind_l

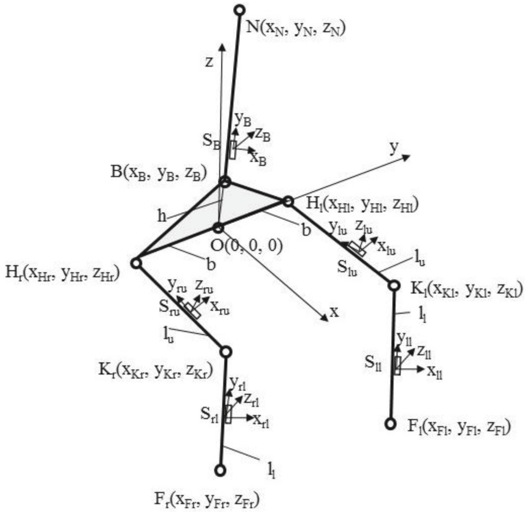

Fig. 6. Calculated geometrical points

5 Conclusions

This paper presents the design and functionality of a driver's posture monitoring system, which is a mechatronic device that will permit the driver to maintain a correct posture during his activities.

As a result, an IMU sensor, controller and data transmission and storage system was built to monitor the driver's posture for the lower body. Also, a mathematical model was developed to geometrically reconstruct the posture of the lower limbs, having as input only the angular values measured by the sensors and the anthropometric data of the subject.

Acknowledgments. The publishing of this paper was supported by the project no. 1804/2018, entitled "SIM-TACK/Real-time motion tracking system for physiotherapy exercises for people with special educational needs" financed by Transilvania University of Brasov, programme "Grants for interdisciplinary teams", competition 2018.

References

1. Ciuti, G., Ricotti, L., Menciassi, A., Dario, P.: MEMS sensor technologies for human centred applications in healthcare, physical activities, safety and environmental sensing: a review on research activities in Italy. Sensors (Basel) **15**, 6441–6468 (2015)
2. Kim, J.-N., Ryu, M.-H., Choi, H.-R., Yang, Y.-S., Kim, T.-K.: Development and functional evaluation of an upper extremity rehabilitation system based on inertial sensors and virtual reality. Int. J. Distrib. Sens. Netw. **2013**, 1–7 (2013)

3. Leardini, A., Lullini, G., Giannini, S., Berti, L., Ortolani, M., Caravaggi, P.: Validation of the angular measurements of a new inertial-measurement-unit based rehabilitation system: comparison with state-of-the-art gait analysis. J. NeuroEng. Rehabil. **11**, 2–7 (2014)
4. Li, H.T., Huang, J.J., Pan, C.W., Chi, H.I., Pan, M.C.: Inertial sensing based assessment methods to quantify the effectiveness of post-stroke rehabilitation. Sensors (Basel) **15**, 196–209 (2015)
5. Baba, M.J., Beyea, J., Landry, J., Sexton, A., McGibbon, C.A.: Comparison of strain-gage and fiber-optic goniometry for measuring knee kinematics during activities of daily living and exercise. J. Biomech. Eng. **134**, 084502 (2012)
6. Nerino, R., Contin, L., Tirri, A., Massazza, G., Chimienti, A., Pettiti, G., et al.: An improved solution for knee rehabilitation at home. In: 9th International Conference on Body Area Networks, London, UK, pp. 62–68 (2014)
7. Moncada-Torres, A., Leuenberger, K., Gonzenbach, R., Luft, A., Gassert, R.: Activity classification based on inertial and barometric pressure sensors at different anatomical locations. Physiol. Meas. **35**, 1245–1263 (2014)
8. Antonya, C., Butnariu, S., Pozna, C.: Real-time representation of the human spine with absolute orientation sensors. In: 2016 14th International Conference on Control, Automation, Robotics and Vision, ICARCV 2016 (2017)
9. Voinea, G.-D., Butnariu, S., Mogan, G.: Measurement and geometric modelling of human spine posture for medical rehabilitation purposes using a wearable monitoring system based on inertial sensors. Sensors (Switzerland) **17**(1), 3 (2017)
10. Qi, Y., Soh, C.B., Gunawan, E.K., Low, S., Thomas, R.: Lower extremity joint angle tracking with wireless ultrasonic sensors during a squat exercise. Sensors (Basel) **15**, 9610–9627 (2015)
11. Attal, F., Mohammed, S., Dedabrishvili, M., Chamroukhi, F., Oukhellou, L., Amirat, Y.: Physical human activity recognition using wearable sensors. Sensors (Basel) **15**, 31314–31338 (2015)
12. Papi, E., Osei-Kuffour, D., Chen, Y.M., McGregor, A.H.: Use of wearable technology for performance assessment: a validation study. Med. Eng. Phys. **37**, 698–704 (2015)
13. Patel, S., Park, H., Bonato, P., Chan, L., Rodgers, M.: Review of wearable sensors and systems with application in rehabilitation. J. NeuroEng. Rehabil. **9**, 2–17 (2012)
14. Bakhshi, S., Mahoor, M.H., Davidson, B.S.: Development of a body joint angle measurement system using IMU sensors. In: Engineering in Medicine and Biology Society, EMBC, 2011 Annual International Conference of the IEEE, 30 August–3 September (2011). https://doi.org/10.1109/iembs.2011.6091743
15. Kinect Sensor. https://msdn.microsoft.com/en-us/library/hh438998.aspx. Accessed 26 Apr 2018
16. Bosch Sensortec. BNO055, Data Sheets. https://www.bosch-sensortec.com/bst/products/all_products/bno055. Accessed 26 Apr 2018
17. Roetenberg, D., Luinge, H., Slycke, P.: Xsens MVN: full 6DOF human motion tracking using miniature inertial sensors, XSENS TECHNOLOGIES – ver. April 3 (2013)
18. Yuan, Q., Chen, I.-M.: Localization and velocity tracking of human via 3 IMU sensors. Sens. Actuators A **212**, 25–33 (2014)
19. Otani, T., Hashimoto, K., Miyamae, S., Ueta, H., Natsuhara, A., Sakaguchi, M., Kawakami, Y., Lim, H.-O., Takanishi, A.: Upper-body control and mechanism of humanoids to compensate for angular momentum in the yaw direction based on human running. Appl. Sci. **8**, 44 (2018). https://doi.org/10.3390/app8010044