Applied Computer Science,vol. 12, no. 1, pp. 17–26

Submitted: 2016-02-11
Revised: 2016-02-29
Accepted: 2016-03-14

biomechanical analysis of motorsports drivers,
modern 3D technologies in motorsports, balance analysis, long jump analysis

*Maria SKUBLEWSKA-PASZKOWSKA**, *Edyta ŁUKASIK***,
*Jakub SMOŁKA****, *MarcinKWIATKOWSKI*****

MODERN 3D TECHNOLOGY USED FOR THE EVALUATION OF MOTORSPORTS DRIVERS

Abstract

The article presents selected modern 3D technologies (a motion capture system, forceplates) that can be used to examine the biomechanics of motorsports drivers. The aim of this paper is to prove the following thesis:"modern 3D technologies allow for precise and objective biomechanical analysis of motorsports drivers as a complement to psychomotor tests" based on the preliminary research. Three motorsports drivers participated in this study.

1. INTRODUCTION

Today 3D technologies are exhibiting very fast growth and development. Modern systems offer new ways for analyzing biomechanical parameters. These systems often combine different types of equipment (both hardware and software)

* Lublin University of Technology, Electrical Engineering and Computer Science Faculty, Institute of Computer Science, 20-618 Lublin, Nadbystrzycka 38 D, +48 815384354, maria.paszkowska@pollub.pl
** Lublin University of Technology, Electrical Engineering and Computer Science Faculty, Institute of Computer Science, 20-618 Lublin, Nadbystrzycka 38 D, +48 815384354, e.lukasik@pollub.pl
*** Lublin University of Technology, Electrical Engineering and Computer Science Faculty, Institute of Computer Science, 20-618 Lublin, Nadbystrzycka 38 D, +48 815384354, jakub.smolka@pollub.pl
**** Gdansk University of Physical Education and Sport, Department of Psychology, 80-336 Gdańsk, Kazimierza Górskiego 1,+48 585547269, m.kwiatkowski@sportandminds.pl

for capturing motion and so-called “analogs” for further analysis. All data streams (motion and “analog”) are synchronized. This allows for the correlation analysis of data streams. An example of such a system is presented in this paper. It combines three components: an optical motion capture system for recording 3D movements, an electromyographysystem(EMG) for capturing electrical muscle activity and two force plates used for measuring ground reaction forces (GRF).The system is accurate and non-invasive. It is located at the Lublin University of Technology.

Modern 3D technologies enable many research projects concerning car driving ability and vehicle parameters. Due to the fact that optical motion capture systems are static (the cameras are in fixed positions on tri-pods or wall mounts),frequently a car simulator has to be used instead of a real car. The motion capture system can record human movement during various activities. The task of driving on a simulator is studied in several aspects. The hand grip force is examined in [1] and the pattern of hand positioning is analyzed in [2]. The electrical muscle activity and its relationship with forces applied on a steering wheel are described in [3], [4]. The analysis of the force wrench of individual hands is examined. A specific calibration process which compensates for the effects of both static weight and inertia is proposed. The instrumented steering wheel allows one to measure all the forces and torques. The research shows that the driver does not steer the wheel with symmetrical hand actions. The steering effort of each individual hand shows rapidly changing actions that are well coordinated to produce a smooth combined action on the steering wheel [5]. Another motion capture application concerns the measurements of the kinematic of the driver’s upper limbs and torso [6]. The research is conducted using a platform built out of a Peugeot 206 vehicle. Steering movements are analyzed.

Vehicle egress and ingress are analyzed in several papers [7, 8]. The first exampleis a study concerning cervical spine motion examined during extrication from the vehicle [7]. A motion capture system is used to record head movement relative to that of the torso. Various extrication techniques are examined. The second research is about the egress of the younger and older persons [8]. Collected data is used to simulate movement using a Digital Human Model. An occupant’s posture and its effect upon the overall risk of injury in frontal collisions are studied in [9, 10]. A motion capture system is used to determine the range of motion of the following parts of the body: neck, corpus, right hip and right knee.

There is a lot of psychomotor research conducted on motorsports drivers without investigating their movements. Reaction time to sound and light stimuli, hand-eye coordination, depth perception and results of the Poppelreuter test are studied [11]. The studies use monitoring tools for measuring the above-mentioned parameters. The tools include: reaction time meter, hand-eye coordination testing device, tremometer, computer software for the assessment of concentration and divided attention. The studies also use normalized diagnostic tests such as: Automated Neuropsychological Assessment Metrics-4 (ANAM-4), the Cambridge Neuropsychological Test Automated Battery (Cantab) and the Vienna Test System (VTS). The tests are carried out using purposely built devices; however, their disadvantage is low precision and measurement accuracy [12].

The drivers' abilities, both cognitive and psychomotor together with driving performance, are examined in [13]. The research is performed with the participation of professional (licensed) drivers (over and under 40 years old). The study is performed using simulated driving.

This paper presents the idea of combining a motion capture system together with psychomotor tests for the purpose of a motorsports drivers' examination. This kind of interdisciplinary research may bring many benefits for improving drivers' performance. The results, both obtained from motion capture system and psychomotor tests, may create a precise and objective tool for drivers' examinations.

2. MODERN 3D TECHNOLOGIES

Modern technologies are more and more available, thus making possible interdisciplinary research. This paper describes the use of a motion capture laboratory for motorsports drivers' examination. It is part of the Laboratory of Motion Analysis and Interface Ergonomics located at Lublin University of Technology in Poland.

The motion capture laboratory consists of three connected systems which provide time-synchronized data streams. The three systems are: an optical motion capture system, an EMG system and two force plates. They are often used together during recordings: in this this way the recorded material can be analyzed in many aspects.

2.1. The motion capture system

The motion capture system used for the research presented below consists of 8 T40S infrared cameras, two Bonita reference video cameras, a Giganet hub, a PC with 8 GB of RAM and other accessories (e.g. markers, double-sided tape, a calibration wand). The T40S cameras are mounted using wall-mounts, two cameras on each wall. Their positions determine the visible area where the motion may be recorded. All the relevant movement should fit into this area.Infrared cameras allow framerates up to 512 per second at full frame resolution (4 Megapixels). These cameras record the position of each marker in 2D. If a marker is seen by at least two cameras,the PC software is able to reconstruct its position in the 3D space of the laboratory (this is possible because of a calibration step performed prior to the motion capture session).

The Giganet hub ensures that the data received from the cameras is synchronized and transferred to a PC. Two Bonita reference cameras record video. This is frequently useful during the post-processing step (for indicating the right marker) and for creating a video with an overlay (video combined with the biomechanical model outputs).

The system tracks retro-reflective markers attached to the recorded object. When recording human motion, the markers may be placed directly on the skin or on a special motion capture suit. The markers are placed on the body according to a selected schema called a biomechanical model. The type of model should be adapted to the particular sport being investigated.

2.2. Force plates

Two AMTI force plates are often used for the motorsports drivers' examination. They are built into the laboratory floor and are at the same level as the floor, thus ensuring that the patient's movement is not disturbed (there is no step up or down of any kind). Two platforms are installed next to one another, in one line as shown in fig.3. There can be no contact between the platforms and the floor tiles. The force platforms measure ground reaction forces (three orthogonal force vectors and moment components along X, Y and Z axes). They are highly sensitive, hence they are often used in interdisciplinary research, such as for motorsports drivers' evaluations. The platforms are presented in fig. 1.

Fig. 1. Arrangements of two force plates [source: own study]

3. THE EXAMPLE ANALYSIS OF BIOMECHANICS MOTORSPORTS DRIVERS

Body balance is essential in most sport disciplines. Operation of the body control system is something which can be improved through sports training [14]. Measurement of balance is conducted by a technique that belongs to one of two groups: tests of balance and instrumental techniques. The former is a simple and good tool for a coach. The tests include: Eurofit, rotary test and Starosta test. They all are very inaccurate [15]. The solution using 3D technology proposed in this article is a technique of the latter type. The analysis of three motorsports drivers is presented in this paper. They are among the top Polish professional racing drivers. Their ages are between 12 and 17 years. The values, presented in this analysis, were computed by a custom piece of software written by the authors in C++ language.

4.1. The long jump test

The long jump is analyzed in two aspects: its length and ground reaction forces (GRF). The examined person makes a jump from the two force plates (with one leg on each force plate). The 39 retro-reflective markers are attached directly to the skin. 3D motion is captured using a motion capture system while AMTI platforms record GRF vectors (in 3D) and the center of pressure (CP). The "analog data" (from the force plates) is recorded together with motion data using one piece of software (Vicon Nexus).

The length of the jump is computed using 3D marker position data. At the beginning of the jump one marker (the toe marker from the either right or left foot) is used to find the start position of the farthest marker. At the end of the jump the final position of the closest (to the initial position) heel marker is taken. These two positions are used to compute the jump length along one axis (X).

The maximum GRF is computed in two steps. First, the GRF for the right (F^r)leg is computed using formula 1. The GRF for the left leg (F^l) is calculated analogously.

$$F^r(t) = \sqrt{\left(F_x^r(t)\right)^2 + \left(F_y^r(t)\right)^2 + \left(F_z^r(t)\right)^2} \qquad (1)$$

Second, force (F) is defined as the maximum GRF average for both legs as specified by formula 2.

$$F = \max \frac{F^r(t) + F^l(t)}{2} \qquad (2)$$

The values of jump length and GRF computed for three drivers are presented in table 1. Additionally, jump length was compared with the International Physical Fitness Test (IPFT). The results were obtained with the norms included in IPFT.

Tab. 1. Analysis of jump length based on 3D data and force F [source: own study]

No.	*Jump length [mm]*	*F [N]*	*IPFT/maxIPFT(age) [point]*
1.	2275	716,2	53/100 (17)
2.	1638	461,6	49/100 (12)
3.	2009	637,8	45/100 (16)

Three graphs of GRF vector components obtained from Polygon software for one of the drivers are presented in figures 2 to 4.

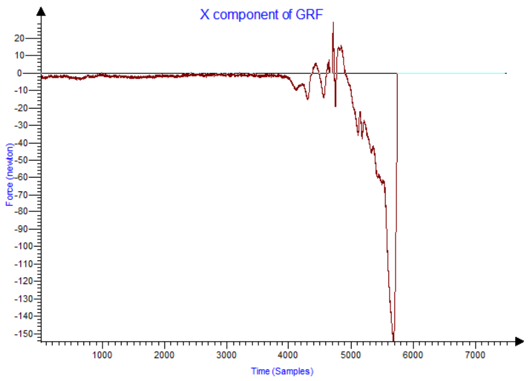

Fig. 2.The X-axis GRF component [source: own study]

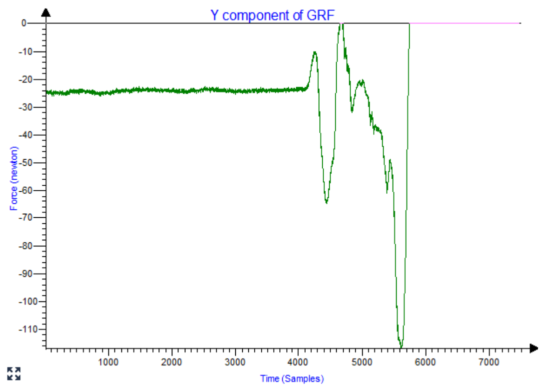

Fig. 3. The Y-axis GRF component [source: own study]

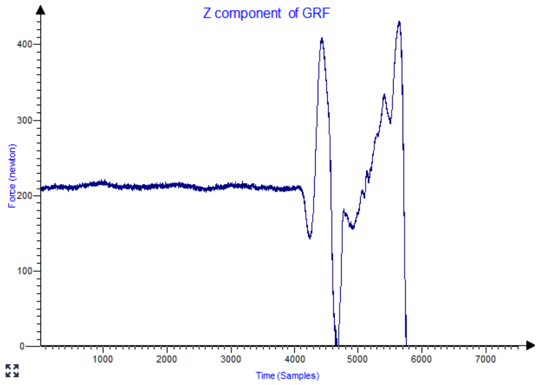

Fig. 4. The Z-axis GRF component [source: own study]

4.2. Balance analysis

The balance test is performed using two force plates. The driver stands with one leg on a single platform. The test consists of four exercises: 1) standing on the left leg with eyes open, 2) standing on the right leg with eyes open, 3) standing on the left leg with eyes closed, 4) standing on the right leg with eyes closed. The driver has to raise and bend one leg so that the angle between the thigh and calf is about 90° degrees. He/she has to keep the one position for at least 10 seconds. During the test arms should be kept along the body.

The balance coefficient (B_c) was computed based on the GRF obtained from force plates using formula 3.

$$B_c = \left(F^x_{\max} - F^x_{\min}\right) + \left(F^y_{\max} - F^y_{\min}\right) \tag{3}$$

The maximum and minimum X and Y components of forces from two platforms are computed. Then the difference between the maximum and minimum values for each component is calculated. The balance coefficient is the sum of those differences.

A screenshot of the post-processed subject during balance test is shown in fig. 5.

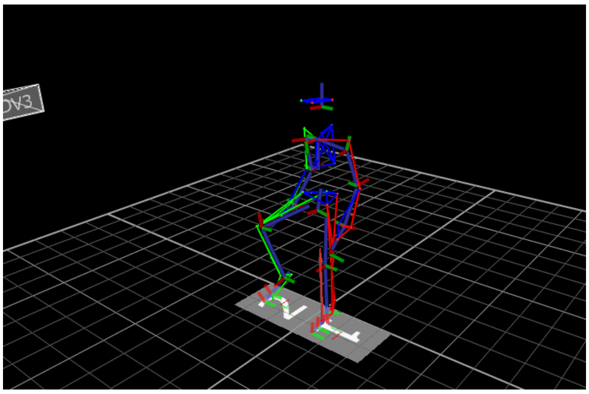

Fig. 5. The balance test on the left leg with eyes open [source: own study]

The results of the balance test analysis are presented in tables 2 and 3. The first table contains the balance coefficients computed for the left and right legs in the open and closed eyes tests. Additionally, the differences between the coefficient values from the open and closed eyes tests are shown. The differences between values computed for the right and the left leg are shown in table 3.

Tab. 2. Analysis of the balance test based on GRF data [source: own study]

No.	***GRF for left leg [N]***			***GRF for right leg [N]***		
	open eyes	***closed eyes***	***difference***	***open eyes***	***closed eyes***	***difference***
1.	37,0	164,6	127,6	84,4	66,1	18,4
2.	58,9	157,8	99,0	44,4	174,5	130,1
3.	19,9	40,3	20,4	31,6	63,7	32,2

Tab. 3. Analysis of balance test – the difference between legs [source: own study]

No.	***Difference between legs [N]***	
	open eyes	***closed eyes***
1.	47,4	98,6
2.	14,5	16,7
3.	11,6	23,4

Differences in the results with open and closed eyes were obtained for each person. Two of them are very significant. This indicates that general training should pay attention to training on both sides in order to minimize the difference between the left and right sides of the body. In improving the ability to maintain body balance, the following group exercises can be used: exercises isometric, exercises perfecting balance in place and in motion, central stabilization exercises, exercises using unusual starting positions, exercises shaping the ability to perform high-speed rotations and others.

Assessment of the ability to maintain body balance is useful for athletes. Research carried out periodically in the long term will help to determine individual progress in a range of functions and in training methods' effectiveness. It will allow for the development of classification standards in this field.

4. CONCLUSIONS

3D modern technologies offer new ways for the biomechanical analysis of motorsports drivers. Comprehensive training planning is one of the basic conditions determining success in sports. Selected motion parameters obtained using 3D technology provide a coach with valuable information that he/she can use in planning appropriate training. Accuracy of the measurements is an advantage of the tests utilizing 3D technology. They complement the psychomotor tests already used on a large scale. Properly selected tests, at all training levels, are a source of information about the athlete. They can be excellent indicators of the effectiveness of training methods.

REFERENCES

[1] EKSIOGLU M., KIZILASLAN K.: *Steering-wheel grip force charcteristics of drivers as a function of gender, speed, and road conditio*. Int J and Ergonom, 38, 2008, p. 354–361.

[2] WALTON D., THOMAS J.: *Naturalistic observations of drivers hand positions*. Transport Res Part F: Traffic Psychol Behav, 8, 2005, p. 229–238.

[3] PICK A. COLE D.: *Measurement of driver steering torque using electromyography*. ASME J DynamSyst, Measue Control, 128 (4), 2006, p. 960–968.

[4] HOULT W., COLE D.: *A neuromuscular model featuring co-activation for driver simulation*. In: Proc. 20th IAVSD symposium on the dynamics of vehicles on roads and tracks, Berkley, USA, 2007.

[5] GABRIELLI F., PUDLO P., DJEMAN M.: *Instrumented steering wheel for biomechanical measurements*. Mechatronics 22, 2012, p. 639–650.

[6] GABRIELLI F., PAGANELLI S., SCHIRO J., PUDLO P., DJEMAI M.: *Driving simulation protocol to determine steering strategies*. International Journal of Industrial Ergonomics, 42, 2012, p. 469–477.

[7] ENGSBERG J. R., STANDEVEN J. W., SHURTLEFF T. L., EGGARS J. L.: *Cervical spine motion during extrication*. The Journal of Emergency Medicine, 44 (1), 2013, p. 122–127.

[8] CHATEAUROUX E., WANG X.: *Car egress analysis of younger and older drivers for motion simulation*. Applied Ergonomics 42, 2010, p. 169–177.

[9] BEHR M., POUMARAT G., SERRE T., ARNOUX P.J., THOLLON L., BRUNET C.: *Posture and muscular behaviour in emergency braking: an experimental approach*. Accident Analysis and Prevention 42, 2010, p. 797–801.

[10] BOSE D., CRANDALL J.R., UNTAROIU C.D., MASLEN E.H.: *Influence of precollision occupant parameters on injury outcome in a frontal collision*, Accident Analysis and Prevention 42, 2010, p. 1398–1407.

[11] ANDO S., KIDA N., ODA S.: *Proctide effects on reaction time for peripheral and central visual fields*. Perceptual and Motor Skills 95(3), 2002, pp. 747–752.

[12] KWIATKOWSKI M.: *The relationships of select psychological and psychomotoric variables to skill level*. Medycyna Sportowa. Medsportpress, 235(6), 2007, p. 271–278.
[13] SHANMUGARATNAM S., KASS S. J., ARRUDA J. E.: *Age differences in cognitive and psychomotor abilities and simulated driving*. Accident Analysis and Prevention 42, 2010, p. 802–808.
[14] KALINA M.R.: Sporty walki w edukacji dzieci i młodzieży – perspektywa metodyczna, Wydawnictwo Naukowe Novum, Płock, 2002.
[15] PYSKIR M., PUJSZO R., BOSEK M., GRZEGORZEWSKI B., BŁACH W.: *Influence of chosen physical exercises of human posture control system*, Medycyna Sportowa, 20(5), 2004, p. 247–253.