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SMART GLOVE USAGE POSSIBILITY FOR BASKETBALL TRAINING: PROOF OF CONCEPT

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Abstract. *Nowadays, basketball is one of the most entertaining and popular sports. In the last years, the number of people that are dedicating themselves to basketball has grown rapidly. The increasing number of sportsmen defines the increasing demand to monitor and analyse their performance, hereby granting the possibility to review and evaluate mistakes made within different game phases, which, in turn, would be useful for future training. The present research is the first step to develop a wireless system (Smart Basketball Glove (SBG)) for basketball shot analysis and training. SBG system is based on knitted tension and pressure sensors that were already successfully used in Smart Socks and Smart Shirt applications. These sensors, while embedded into the proposed system's textile part, showed high tactile sensitivity and speed of response and, therefore, demonstrates potential abilities to analyse the wrist and fingers movement and estimate the forces with which fingers interact with the ball during basketball shot. Necessary requirements for data acquisition and transition device of SBG are formulated for further system's development as well.*
Keywords: *basketball, free shot, monitoring, Smart glove.*

Introduction

Nowadays, globally, more than 450 mil. people are playing basketball ("Many people play basketball worldwide", 2018). The increasing number of sportsmen defines the increasing demand in some ways to monitor and analyse their performance, therefore granting the possibility to review and evaluate mistakes made within different game phases, which, in turn, would be useful for future training. Historically there is a wide field of training techniques developed to help a player in gaining an upper hand over the opponent. The victory in basketball game depends on a number of factors, which could be purely physical – stamina, strength, agility or are based on skills – dribbling, shot accuracy, current

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situation analysis. Nevertheless, the result of the game is decided by the largest amount of points scored by either of teams. That implies, that shot is one of the most important parts of the game. Its accuracy depends on many factors based on biomechanics of the player during the shooting process which finalizes by wrist and fingers movements. Thus, wrist and fingers movements play key role to provide shot angle, ball speed and rotation and finally determine whether the ball will be in the basket (Zhen, Wang, & Hao, 2015).

Nowadays to increase the effectiveness of a training process systems to monitor biomechanics of basketball players are used.

Most of the systems, that are available in the market at present moment are either expensive/sophisticated or provide too small information to be considered as a reliable source of data to increase the quality of sportsmen performance.

Currently, most popular are time lapse and Motion Capture systems, similar to those used in cinematography (Verhoeven & Newell, 2016). Time lapse is only available in specially organized environment with at least one high FPS camera. Analysis is made after the shot and requires a lot of time due to thorough frame-by-frame review (Hoesl, Mörwald, Burgdorf, Dreßler, & Butz, 2017). Motion Capture systems may provide online movement registration, which allows to analyze the performance of a player at the very same moment, but players must use uncomfortable and complicated system of markers for the whole system to work. There are also non-marker Motion Capture systems, but they need special environment, similar to time lapse technology (Razavian, Greenberg, & McPhee, 2019).The only currently available system in the market that provides some of the features, like shot count, palm flexion angles and arm movement accelerations monitoring is SolidShot® sleeve (SolidShot, California, USA, 2018). This device is based on the functionality of three 3-axis accelerometers, that are positioned evenly on the elastic compressive sleeve, and a microcontroller that collects sensors information. Major flaw of this system is that it does not provide any information on finger movement, that is considered as important as palm flexion during the shot.

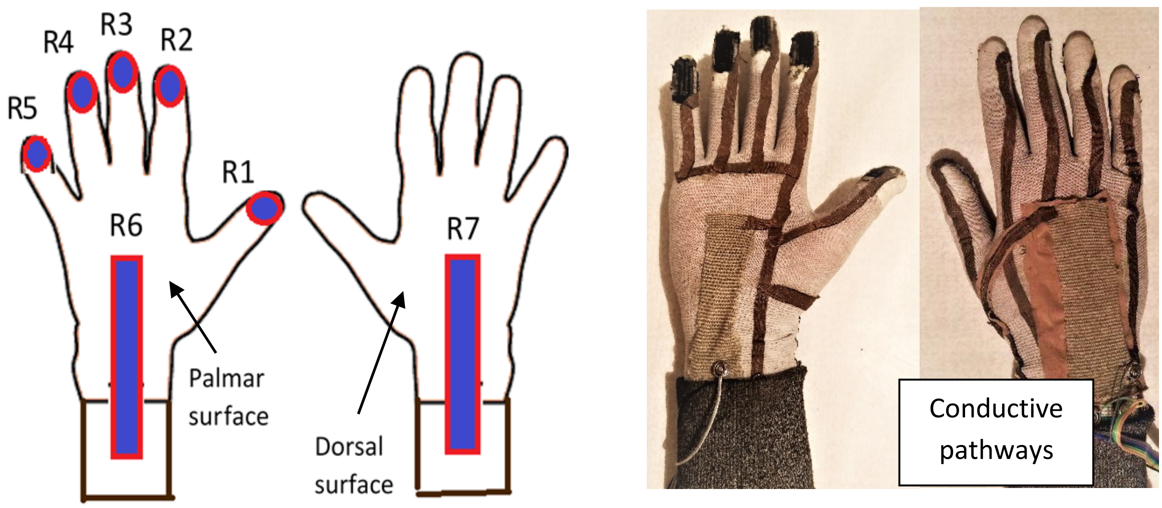
The attempts to monitor wrist motion and fingers-ball and palm-ball interaction during the shot were made in studies (Ohnishi, Ryu, Chung, Colbaugh, & Rowen, 1992) and (Hung, Chen, Lin, & Chung, 2017), correspondently. Wrist motion was analysed using custom made electrogoniometer. Fingers-ball and palm-ball interactions were studied using adopted TekScan Grip system. The studies confirmed that monitoring of wrist and fingers motions can essentially increase the efficacy of training process of shooting. Unfortunately, proposed devices are complicated and uncomfortable for broad application in basketball training.

The aim of present paper is to represent a newly developed system that could provide the potential ability of monitoring and analysing the palm and finger movement in real time and includes the finger load-unload sequence as well as flexion durations and angles, that are vital during the basketball training sessions, as well as review the training results later on.

System design

Before the start of the system design, an opinion poll of six professional basketball coaches was collected, where they implied, that there is a training type, which is used to improve the grip of a ball. Training includes both shooting and dribbling while wearing gloves. Therefore, it was decided to develop monitoring system in the form of a glove.

The first prototype of the designed Smart Basketball Glove (SBG) and position of its sensing array elements are presented at Figures 1a, b.



a) b)

Figure 1 ***Smart glove design***

Proposed system consists of a glove with knitted pressure sensors distributed over the five fingers' third phalanx surface (R1 - R5) and two knitted strain sensors R6 and R7, placed on both palmar and dorsal parts of wrist/palm (Fig. 1a). The sensors are connected by conductive pathways (Fig. 1b) and custom-designed connectors with an electronic device that can collect and transmit data, acquired from sensors, to the data processing device (smartphone or computer).

Sensors. Used pressure and strain sensors are an original RTU designed piezoresistive knitted structures (Oks, Katashev, & Litvak, 2014), that are thin, comfortable to use and make no impact on one's movement, when the sensors are sewn into a piece of clothing: both of them change their electrical resistance with fluctuation of applied load. Wherein electrical resistance of pressure sensors lowers with increasing of the applied load, while electrical resistance of strain sensors increases with the increase of the tension. Both sensor types were previously used in Smart Sock (Oks, Katashev, Zadinans, Rancans, & Litvak, 2016) and Smart Shirt (Semjonova, Vētra, Okss, & Kataševs, 2018) systems.

Smart glove. Pressure sensors are sewn onto the glove’s fingers on the third phalanx surfaces regions (main pressure points when holding a ball, marked blue - see Fig. 1a), whereas the strain sensors are attached to the glove on palmar and dorsal surfaces of the wrist/palm. Such sensor distribution ensures the coverage of most informative regions of hand, allows to monitor wrist flexion and extension as well as the pressure of fingers, applied to the ball during the shot. The conductive pathways are made by cutting highly conductive stretchable silver coated fabric (Shieldex®) into stripes and attaching the stripes to the glove with dielectric glue. The technology ensured that there is no contact between the conductive pathways or pathways and wearer’s skin. Conductive lines ended with the metal male buttons snap connectors, while female connectors were soldered to the lead wires of the data acquisition system.

Data acquisition system. The acquisition system used in present research, was similar to the same, applied earlier in “Smart Socks” project (Oks et al., 2016). It included several voltage dividers (one for each sensor) and acquisition device. Dividers had converted resistivity of textile sensors into voltage which was recorded using PC-connected telemetry data acquisition device BioRadio® 150 (Clevemed Inc., Ohio, USA), capable to capture differential voltage signal in the range ± 2V over eight channels at sampling frequency up to 800 Hz per channel. Data processing and visualisation software were developed using LabView® platform.

Methods

Validity and the operation of the designed system was checked first by calibration of sensors. Then tests were conducted by shooting a ball into the basket at different paces to check system’s ability to distinguish one shot from another. Some attempts on harvesting data while dribbling have been made as well, demonstrating perspectives for future research.

Sensor calibration was made using weights and goniometer for pressure sensors and strain sensors accordingly. Harvested data were analysed and calibration curves were obtained.

Penalty-type shots were made by a 23 y.o. male, wearing SBG with data acquisition system attached to the throwing arm. Apart from ordinary shots, subject tried to simulate intentionally incorrect shot techniques (wrong palm position, finger movement, etc.) to distinguish finger and wrist movement tracking capabilities of the system.

Data from sensors R1 – R7 (Fig.1a) were recorded in a form of output voltages from voltage dividers. Then the harvested data time series were compared with visually assessed parameters of a basketball free shot.

Basketball shots data were harvested with 800Hz data gathering frequency.

Results and discussion

Calibration. During the process of calibration, the data were gathered from 3 experiments for each sensor and then averaged. Averaged data were used to create calibration / approximation curves. All of curves have approximation coefficients above 0.97, which can be assessed as a reliable result.

Resulting calibration curves are shown on Figures 2 and 3.

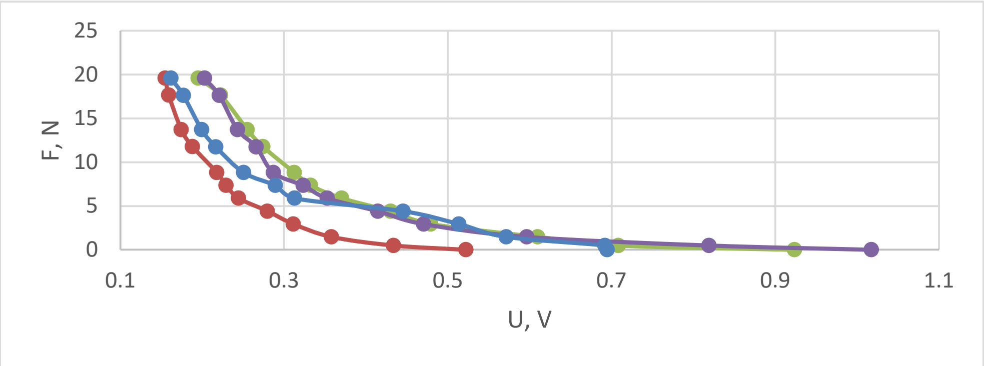


Figure 2 ***Pressure sensor calibration curves. Red – index finger, blue – thumb, purple – ring finger, green – middle finger***

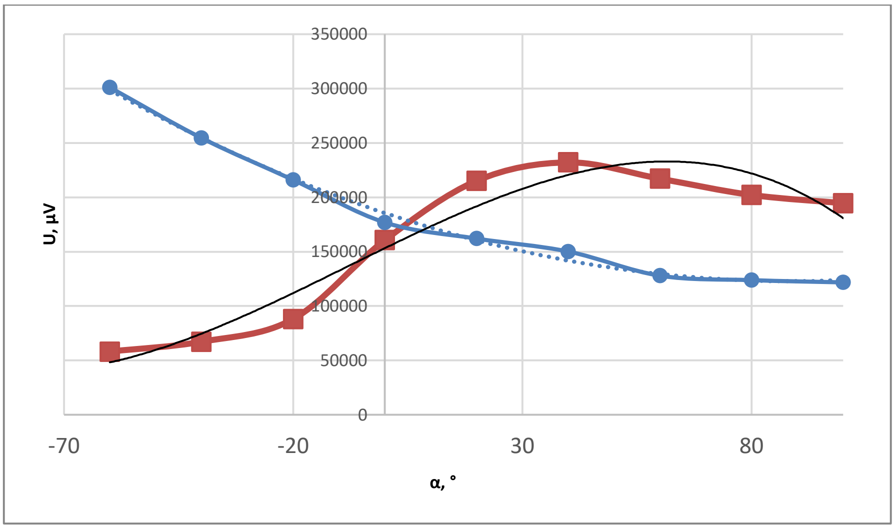


Figure 3 ***Strain sensors calibration curves. Red – dorsal sensor; blue – palm sensor***

Shot analysis. The example of data gathered using BioRadio® during single shot is presented at Figure 5. It can be seen, from the figure that the shot is accompanied by decreasing of fingers pressure sensors and increasing of dorsal strain sensor output signals accordingly. That means increasing of finger pressure load and wrist flexion (see Fig. 2). So, SBG qualitatively correctly reflects the biomechanics of lower hand during the shot. Moreover, SBG also provides a clear view on fingers' load sequence, after which the extension-flexion of a wrist occurs. From these data the basketball shot could be divided into 4 phases (A, B, C and D, Fig. 4). Phase A – wrist is in extension, start position for shot to be made; B – thumb pressure sensor signal starts to decrease, which occurs due to increasing of the load that thumb is applying to the ball; C – all the fingers consequently breakaway from the ball; D – wrist flexion after the shot.

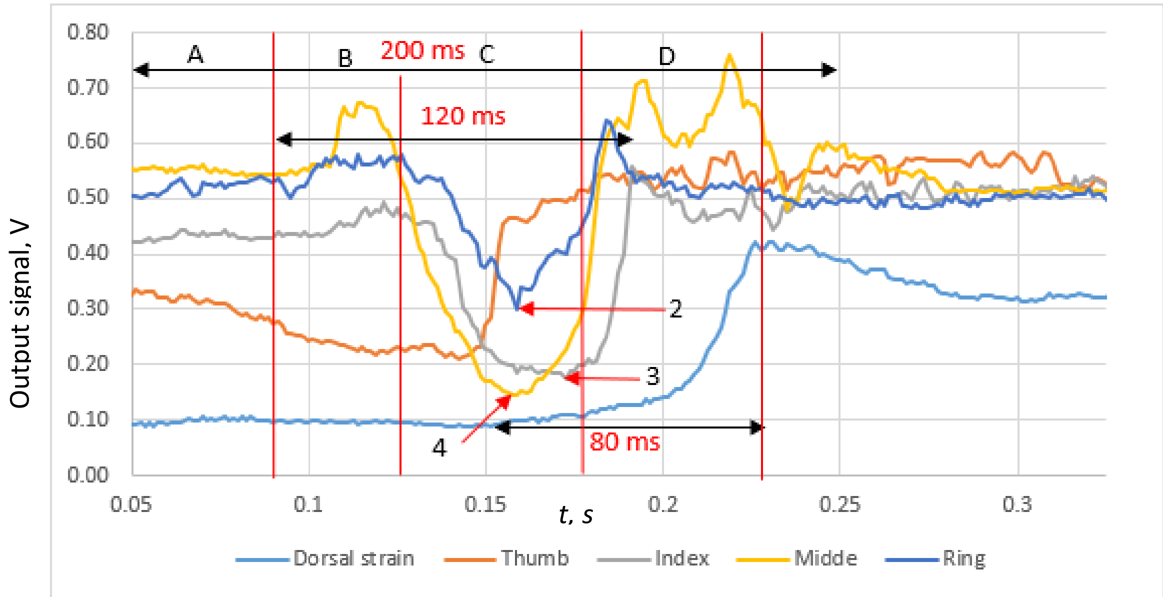


Figure 4 ***Basketball shot data***

The finger sensor load-unload sequence analysis shows that thumb and ring fingers have sharp extremum corresponding to maximal load from these fingers to the ball (points 1 and 2) with following fast unloading period. On the contrary, plots corresponded to index finger and middle finger have "plateaus" in the zones of maximal loading (the middle points of these zones are marked as points 3 and 4). These "plateaus" reflect the most essential contribution of index and middle fingers into the shot process when the ball is rolling over the fingers, which results in spin momentum, that is necessary for accurate trajectory of the shot. Index finger is the last finger, contacted with the ball before the moment of ball's breakaway from a hand. Obtained results are in accordance to the same received earlier (Hung et al., 2017).

Temporal parameters of wrist extension-flexion fazes obtains using data from palm/dorsal strain sensors (see Fig. 5) Application of corresponding calibration curves (Fig. 4) gives the possibility to determine absolute values of wrist angular positions too.

Thus, data analysis confirmed that applied knitted sensors are sensitive and fast enough to monitor finger loading and wrist motion during the shot.

Analysis of gathered data also provided a possibility to distinguish the time length of each of the shot phases: total fingers loading is about 120ms, the "shortest" single finger loading is about 60ms, palm extension-flexion is about 80ms.

Based on received temporal parameters of the shot, the lowest value of data acquisition frequency, necessary for correct monitoring of a shot process, was defined. Using Nyquist-Shennon theorem it was calculated that data harvesting frequency for correct records of basketball shot must be higher than 160 Hz.

The attempt to use SBG prototype device to estimate forces of fingers -ball interaction and velocity of a ball in the moment of breakaway from a hand was made, too.

According to momentum conservation law the following equation can be written:

$$mv_1 - mv_0 = \int_0^t F\,dt = \mathrm{P}, \tag{1}$$

where m – ball mass ;
v_0 – ball initial velocity;
v_1 – ball velocity in the moment of breakaway from a hand;
F – total force applied to the ball from the fingers;
t – time of interaction between fingers and the ball during the shot;
P – impulse of the force F.

Taking into consideration, that initial velocity of the ball is $v_0 = 0$, one can get from eq. (1):

$$v_1 = \frac{\int_0^t F\,dt}{m} \tag{2}$$

Force F is equal to the sum of partial forces of all five fingers.

$$F = \sum_i^5 F_\mathrm{i}$$

The partial forces F_i can be obtained from data recorded during the shot using calibration curves (Fig. 2).

Figure 5 represents example of total force F dependence from time t during the shot, obtained by summation of partial forces from all the fingers.

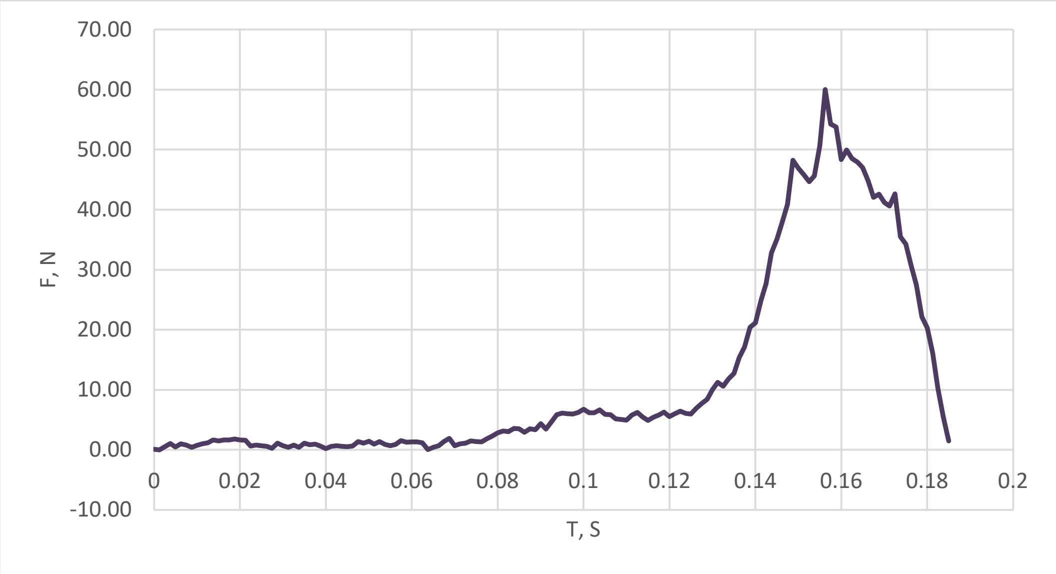


Figure 5 ***Total force applied to the ball from the fingers during the shot***

The value of $\int_0^t F\,dt$ was computed by trapezium method. It was obtained: $\int_0^t F\,dt = 2.19\,Ns$. Taking into consideration that the ball mass is m=0.5kg, according to eq. (2), the ball velocity at take-off v_1 is equal to

$$v_1 = 4.39\frac{m}{s}$$

To compare received value of shot velocity with theoretical one the projective motion theory (Changjan & Mueanploy, 2015) was used. The velocity of the ball for the similar to experimental tests shooting conditions have been calculated. The calculated theoretical value of the ball velocity at take-off was equal to 5.01 *m/s*. So, designed SBG prototype gave underestimated result for forces applied to the ball and correspondently, for the ball velocity.

The possible reason of such underestimation can be explained by follows. Applied finger sensors belong to piezoresistive type of soft pressure sensors. To harvest the correct output signals from such sensors it is necessary to provide uniform load distribution over the whole sensors surfaces. Such type of load exactly was provided within calibration process. During the experimental shot tests the ball had additional rotational movement (due to sequential contact between fingers and the ball to provide the ball spin). Thus, equivalent load of sensors surfaces wasn't uniform which lead to the different conditions of sensors loading during calibration and shot tests and, therefore, to quantitative error in force and ball velocity estimation. Possible solution of this problem can be using of several sensors with small squares with parallel electrical connection instead of big one which will be tested during future system development.

Conclusions

1. Developed Smart Basketball Glove prototype gives possibility to control simultaneously the fingers movement sequence and angles of a wrist extension/flexion during the basketball shot.
2. Data analysis showed that total duration of the shot is about 200ms, the time length of the shortest finger loading is about 60ms, the time length of a wrist extension-flexion is about 80ms. To provide successful functionality of SBG its data harvesting frequency must be higher than 160 Hz per channel. It is also vital that SBG's acquisition device must have at least 7 data channels to be able to collect data from 5 finger sensors and 2 strain sensors simultaneously.
3. Present SBG prototype gave underestimated absolute values of fingers-ball interaction forces and shot velocity. New pressure sensor design and/or interaction force correction algorithm must be developed and applied in future SBG version to compensate the error of force estimation.

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