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Development of instrumented soccer footwear for kicking analysis and training purposes

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Abstract

The kicking action in different ball sports is a prime skill that can decide the success of a team. The magnitude of the kick force and the movement of the centre of pressure (COP) during the impact phase between the soccer ball and the foot were determined by developing a novel low-cost pressure sensing system. This system was calibrated by a Kistler force plate and then validated for a range of forces (368-2146N). The COP was tested for two curve kicks at about 1100 N and the movement of the COP results showed similarity in the pattern (COPx = ±5 mm; COPy = ±10 mm). In addition, the COP data were displayed on a 4D colour-coded vector diagram model of a soccer boot. From the system calibration data, the coefficient of determination was found to be r^2_{max} = 0.9882, r^2_{min} =0.9333. For validating the system the measured and calculated forces were correlated (r^2 = 0.9125). The system is useful for counting the number of kicks, assessing the magnitude of the kick force, displaying the COP on the boot and correlating the COP and force to kicking accuracy.

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*Keywords:*centre of pressure (COP); soccer; kicking; curve kick; foot to ball impact phase; force; pressure; piezoresistive; 4D vector diagram.

1. Introduction

Soccer is the most popular sport in the world [1] and kicking is the most important action in the game [2]. The performance of the athlete strongly relies on a player's skill level which improves the chances to score a goal, accurately pass the ball to a teammate and ultimately win a match. The basic performance criteria when kicking a ball are the kicking velocity (KV) and kicking accuracy (KA) and the characteristics of the foot to ball impact phase

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is a source for team success [2].The attempt to improve the kicking skill through different patented instrumentations and footwear [3-6] started in the late 70's with a kicking shoe to improve the accuracy and distance of a kick [4] and is still continuing today [3]. At the same time, a number of studies [2,7,8,9] dealt with the quality of the kick from the KV and KA perspective. However, very few researchers have attempted to measure and quantify the foot to ball impact phase of different types of kick with respect to the quality of the kick. The reason for this is that the kick force is technically difficult to measure mostly due to short impact time of less than 10 milliseconds [2]. Studies that explore the overall kicking performance often use few different technologies such high speed video imaging technology [2], motion analysis systems [10] and Doppler radar guns [7]. Hennig [1] used a Pedar (Novel Inc.) force sensory system for mapping the force distribution during the impact phase of barefoot and shod kicking. Other technologies that aimed for KA performance used a plywood bull's eye target covered with carbon paper which can be used as a training tool for improving the skill of players [8], circular electronic targets that measure the ball contact location [1] and kicking accuracy measurement systems that included both, a high speed video camera and bull's eye target [11].While many studies frequently deal with the instep kick, there are other important types of kicks in soccer. Curve kicks for instance are becoming increasingly popular in recent years and require a high skill performance to spin and bend the trajectory of the ball [12]. To the author's knowledge, the curve kicks are not commonly studied in depth so far, in particular from the aspect of the foot to ball impact phase.

The purpose of this study was to develop a low cost instrumented system for soccer footwear using a novel sensing platform and to investigate the average force distribution and movement of the COP of curve kick tests, displayed by a 4D force vector diagram projected on a model of a soccer boot.

Fig.1. Test set-up of the instrumented soccer footwear; left: a 4x4 multi-node system placed on Kistler force plate; right: system placed on the instep part of the foot for kicking tests

2. Experimental procedure

2.1. Manufacturing and instrumentation

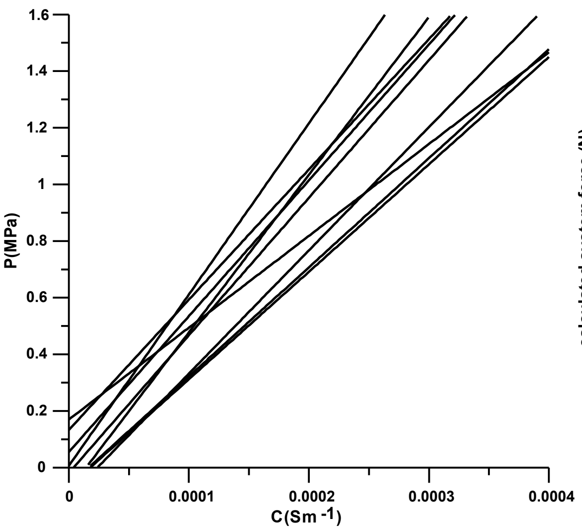
For the first part of the research, a feasibility prototype was designed with a visual feedback mechanism to display the location and magnitude of pressure applied to a multi-node cells area, made of 16 pressure sensors [16]. The system included a programmable micro-controller chip (ATmega328P, Atmel, San Jose, CA, USA, 16 MHz CPU) that was connected to 4x4 cells sensors grid made of piezoresistive material (Rmat1, RMIT material code), vertical and horizontal copper electrodes at the front and back of the pressure surface area and a basic character LCD screen. The Arduino platform (Arduino v1.0.6 IDE) was used for programming the microcontroller (via C language) and all measured drop voltages data from 16 cells were processed through the microcontroller to display only pressure magnitudes above a certain level (0-1023/10bits ADC). The general technical principle behind the development was such the programmable microcontroller generates 5/0 volts electrical signals by the top digital electrodes and reads the drop voltage from bottom analogue electrodes. The pressure data from each node are sampled from a reference resistor connected in series with each individual cell of the array. The following version of the multi-node sensor (Figure 1 left) was designed especially for the instrumented soccer footwear and had to follow specific dimensions and portability conditions to be inserted into a soccer boot for testing the kicking action. Consequently, a 4x4 multi-node (20x20 mm per cell size; 83x83 mm overall size) piezoresistive material (Rmat1, RMIT material code), flexible aluminium electrodes and a relatively small-sized and lightweight (~ 35 x 18 mm; ~ 5 g) powerful low cost microcontroller board (TEENSY 3.1, 32 bit ARM Cortex-M4 72 MHz CPU, PJRC, Oregon, USA) were selected for this innovative development.

2.2. Sensor calibration

In order to measure the peak pressure-conductivity correlation, the instrumentation was tested using a Kistler force plate (type 9260AA6, Kistler, Winterthur, Switzerland) at 10 kHz sampling frequency to record the vertical forces. A programmable micro controller (Teensyduino 1.22) with 2-2.5kHz sampling frequency rate recorded the drop voltages of all 16 cells during impact tests. The experiment included four different force slamming levels (500-2000N) with 85mm diameter stiff ball (Figure 1 left) at all possible quarters of the system. Each set included 10 force peaks in a relatively similar force level, resulting in a total of 40 peaks applied onto each possible quarter of the system (180 data points overall). The pressure was then calculated based on the recorded force and area (40x40 mm) and plotted against the conductivity which was calculated from the measured drop voltage and cells (20x20x1.3 mm).

2.3. System validation

To test the method in terms of the location of the COP, the system was slammed with a hard ball at each possible quarter (nine locations) 10 times each. To validate the calculated forces, which were converted to pressure subsequently, the system was placed on the same Kistler force plate and six sets of impacts (368-2146N) were imparted to the surface of the sensing system. Five sets included ten increasing forces onto diagonal and centre quarters, and sixth set on random locations of the multi sensor area. The measured and calculated peak forces were then compared to determine the standard deviation on average and the coefficient of determination.



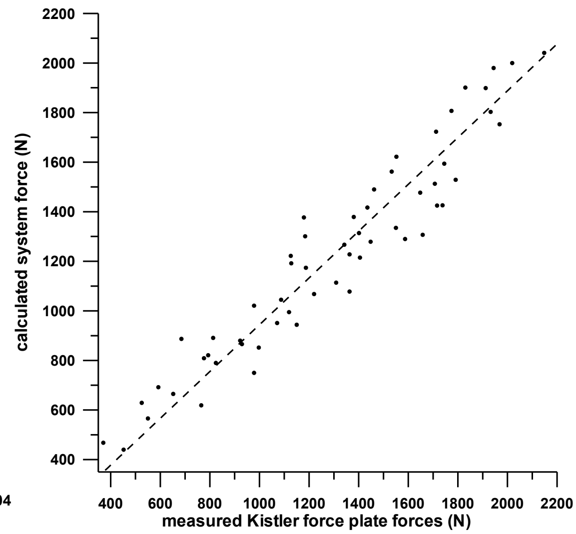


Fig.2.Pressure against conductivity calibration tests: all 9 possible quarters of the array (r^2_{max} = 0.9882,r^2_{min} =0.9333); Fig. 3: calculated system forces against measured Kistler force plate forces (r^2 = 0.9125; gradient: 0.944).

2.4. Kicking experiment and 4D visualisation of the vector diagram

The sensory system was then placed on the instep of the foot between the foot and ball impact area (Figure 1 right) and connected via an extension USB cable to a laptop for recording the data collected at 2000-2500 Hz. Two inner curve kicks were conducted by an active experienced participant and were analyzed and processed for 4D visualization.

From the raw data and the calibration curve, the kick forces and COP were calculated. As the calculated kick force corresponds to the normal force at the boot, the friction forces required for a 3D vector diagram were estimated in the following way: 1) a force vector diagram displays the forces acting on system 2 (e.g. on the hand in climbing [13]; on the foot in gait analysis; on the ball in kicking), applied by system 1 (e.g. climbing hold; force plate; soccer boot, respectively), directly on system 1 (in contrast to a standard free-body diagram where forces acting on system 2 are displayed on system 2); this convention allows displaying the force vectors outside system 1 instead of penetrating its surface and thereby becoming invisible; 2) the direction of the kinetic friction force on system 1 is the same as the direction of velocity vector of the moving COP on system 1 (i.e. if the boot [system 1] moves forward with respect to the ball [system 2], then the COP moves backward on the boot, the friction force on the boot points backwards, and the friction force on the ball points forwards [to be displayed on the boot]); 3) the kinetic friction coefficient COF of polymers and leather undergoes force- and velocity-weakening at high forces and velocities [14]; 4) the COF at zero velocity (static) and small forces was set to a) 100%, b) at peak velocities and small forces to 50%, c) at peak forces and small velocities to 50%, decreasing linearly with the decadic logarithm of velocity and force, and d) to the product of the equivalent percentages at any force and velocity (e.g. 25% at peak velocity and force); 5) the average static friction coefficient at small forces between leather and a range of FIFA Soccer World Cup and UEFA Euro-Cup balls since 1960 is 0.54 [15]; 6) if the direction of the COP reverses (and so does the direction of the friction force), then the COF is not necessarily static, but can very well be sub-static (COF smaller than the static COF, and even instantaneously zero when reversing the direction of the COP).

The data sets of normal force, displacement and velocity of the COP against time were fit with a 5^{th}–order polynomial function. The 4D force vector diagram, with the time colour-coded as 4^{th} dimension, was imported into AutoCAD with a script file and visualised directly on the boot, using the vector diagram method of Fuss and Niegl [13].

3. Results

The results of the pressure-conductivity calibration analysis are shown in Figure 2 of all possible quarters of the multi-node area. The two best r^2 values were node1 r^2= 0.988235; node2 r^2= 0.976236. Figure 3 shows the calculated system forces against the Kistler force plate data (F_K; n = 58) with residual standard deviation σ_R= 125.6 N (r^2 = 0.91252). σ_R is force dependent (σ_R= 0.0437 F_K + 70.4), i.e. between 7.5% and 9% of F_K at the range of 1-2 kN.

The time series data of the curve kicks are shown in Figure 4. As expected in a typical inner curve kick, the COP is located on the inner side of the instep contact area (Figure 4 right). The movement pattern and the location of the COP (COPx and COPy) exhibited a similar curve for both kicks, starting with moving backward first, and reversing its direction at the peak forces of about 1100 N (Figure 4 left).

4. Discussion

The purpose of this study was to develop a novel multi-node, low-cost sensing platform to test different kicking action parameters. The experimental results show that, in spite of the inexpensiveness of the sensing material, the smart soccer footwear instrumentation delivers highly accurate and repeatable data. The coefficients of determination (r^2) of all calibration curves (Figure 2) were higher than 0.9. The residual standard deviation of 7.5-9% of the actual force is considered unexpectedly accurate given the low costs of the material. Consequently, the system is useful for counting the number of kicks, assessing the magnitude of the kick force, displaying the COP on the boot and correlating the COP and force to kicking accuracy. The kicking results presented in this study are based on curve kicks that were used to investigate the actual average force distribution and the movement of the COP. The results were displayed by a 4D force vector diagram on the model of a soccer boot. At this stage, the curve kick has only been repeated twice by the same participant. It was not possible to validate the COP against the force plate, as the Kistler force plate could not be benchmarked against the pressure sensing platform. The reason for this is that the force plate was not able to measure the COP accurately, and about half of all COPs were located outside the cells of the sensing platform, which were hit by the ball. From this view point, the sensing platform greatly exceeded the accuracy of the force plate. Interestingly, the results show that the COP moves in y-direction only within 10 mm as can be seen in Figure 4 and the colour-coded force vector diagrams (Figure 5). Although the investigators acknowledge that more kicks need to be investigated, the kicks analysed showed a clear repeatability of some parameters which may indicate a high level of the skill of the subject. Further experiments to study different types of kicks and accuracy are underway to establish better understanding of the foot to ball impact phase using this fairly inexpensive approach and subsequently to improve the kicking skill in different level soccer athletes.

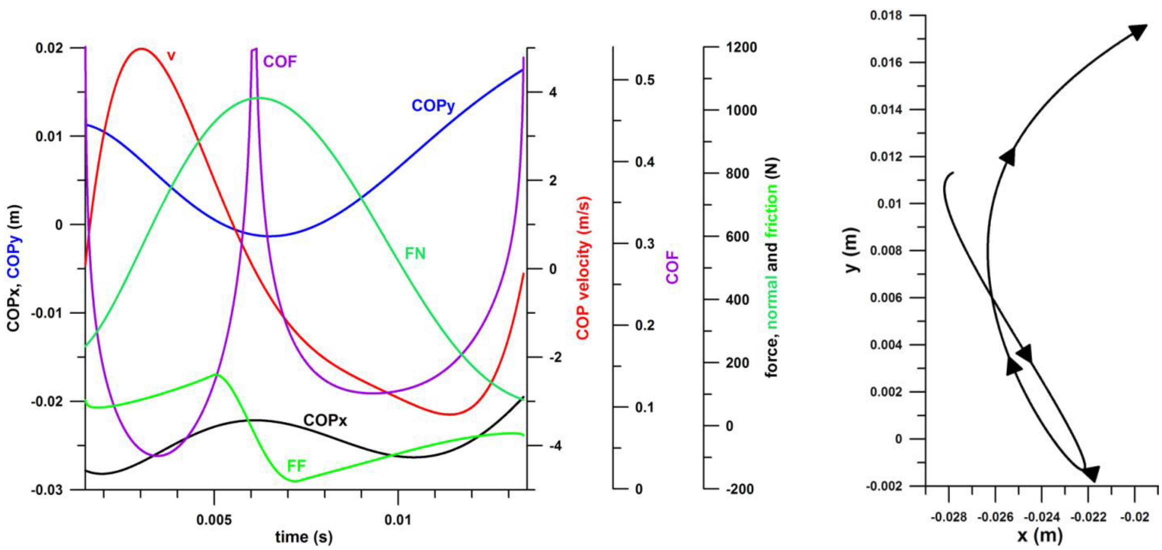


Fig.4.Curve kicks results; **left**: centre of pressure (COPx, COPy), COP velocity (v), coefficient of friction (COF), normal force (FN) and friction force (FF) against time; **right**: movement of the centre of pressure in x (rightwards) and y (forwards) direction.

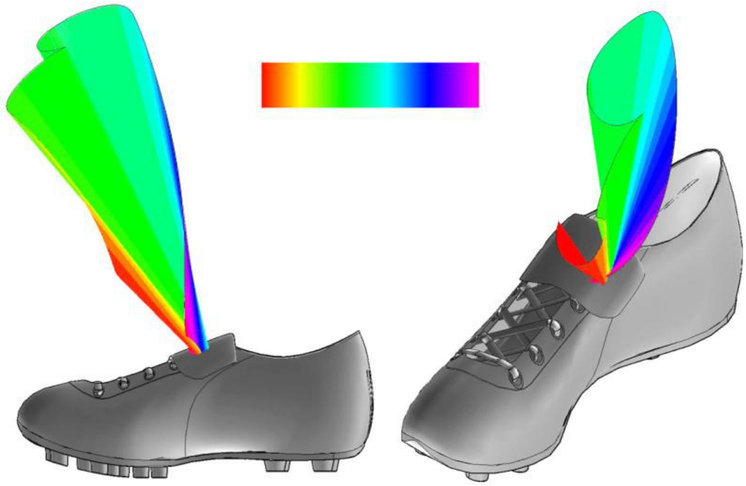


Fig.5.4D vector diagram of the kick force projected on a soccer boot model (the rainbow-coloured insert refers to the time scale).

5. Conclusions

Both visualisation and experimental data collected with the instrumented soccer footwear in this study prove that a novel multi-node low-cost sensory system can be used for measuring and visualising the foot to ball impact phase of kicking performance in soccer.

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