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Capturing complex human behaviors in representative sports contexts with a single camera

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Key words: *TACTO device; direct linear transformation; representative sports contexts; complex behavior.*

Summary. *Background and objective. In the last years, several motion analysis methods have been developed without considering representative contexts for sports performance. The purpose of this paper was to explain and underscore a straightforward method to measure human behavior in these contexts.*

Material and methods. Procedures combining manual video tracking (with TACTO device) and bidimensional reconstruction (through direct linear transformation) using a single camera were used in order to capture kinematic data required to compute collective variable(s) and control parameter(s). These procedures were applied to a 1vs1 association football task as an illustrative subphase of team sports and will be presented in a tutorial fashion.

Results. Preliminary analysis of distance and velocity data identified a collective variable (difference between the distance of the attacker and the defender to a target defensive area) and two nested control parameters (interpersonal distance and relative velocity).

Conclusions. Findings demonstrated that the complementary use of TACTO software and direct linear transformation permit to capture and reconstruct complex human actions in their context in a low dimensional space (information reduction).

Introduction

In the last years, theoretical and experimental evidence from sports performance literature have emphasized the need for a complex systems approach to sports behaviors (1–4). In fact, athletes perform in a complex environment within which they exchange energy, matter, and information (5). This mutuality between the performer and his/her surrounding is the basis for the study of behavioral dynamics in sports contexts (6, 7). Accordingly, the dynamics of the environment-athlete system should be captured by context-dependent variables (8). For example, Passos and colleagues (4) demonstrated how the angle formed between the defender-attacker vector and an imaginary horizontal line parallel to the try line captured the dynamics of attacker-defender interactions in youth rugby union. These types of variables that synthesize several degrees of freedom and describe the dynamics of the sport system subphase are called collective variables (or order parameters) (9, 10). The collective variables (i.e., the system state of order) may change qualitatively by the continuous scaling of other type of variables known as control parameters (9, 10) (for an example in sailing see (11)). At critical values, these parameters may abruptly change the state of the system (9, 10). For instance, Passos and colleagues (12) showed how specific values of interpersonal distance and relative velocity (i.e., the control parameters) influenced the dynamics of the attacker-defender interactions in rugby union near the try line, prompting qualitative changes in the previously mentioned angle (i.e., the order parameter).

One way to capture the collective dynamics of team sports at the level of individual-environment system is by means of players' kinematic data collection (13). In this sense, the selection of procedures to capture and reconstruct players' movement in their context of action comprises one of the most important issues for studying collective behavior in team sports. In the last years, several motion analysis methods have been developed, as well as different mathematical procedures used to reconstruct players' spatial coordinates (14). Moreover, when analyzing movement with video-system analysis, a critical issue is the transformation of the virtual world data (i.e., what is seen on the computer screen) into real world data (i.e., what occurs in the

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real frame of reference), minimizing the error (15). To adequately deal with this problem, the direct linear transformation (DLT) method has been one of the algorithms mostly used for camera calibration and reconstruction (16).

In this methodological paper, we will present procedures that joint manual video tracking and bidimensional reconstruction (2D–DLT), using a single camera. These procedures will allow the capturing of the kinematic data required to compute candidate order and control parameters to study complex behavior in team sports.

Material and methods

For illustrating the conceptual and motion analysis procedures used in this line of research, the 1vs1 football subphase was selected. This task was previously used by Duarte and colleagues (17) to investigate the interpersonal dynamics among youth football players. A detailed description of the representative task design, data collection, image treatment, camera calibration and 2D-reconstruction, signal filtering, reliability analysis, and data computation is presented.

Representative task design. With the purpose of generalizing performers' behavior from the research context (the experimental setting) to the performance context (the football game) (18, 19), we created an in situ experimental task. The designed task allowed performers to explore available informational variables and use them to achieve specific mutually exclusive goals (see Fig. 1).

Data collection. The first step for motion analysis procedures consisted in recording performers' behavior using a regular digital video camera. In the study of 1vs1 football subphase taken as a task vehicle, a fixed digital camera was set in an elevated plane (4 meters of height) using a tripod placed on the bleachers of a football stadium. In order to capture the movement of all players participating in each trial, the video camera formed approximately 45 degrees with the longitudinal dimension of the task (see Fig. 1). The (x, y) coordinates of several noncollinear control points' candidates were also taken for subsequent calibration procedures (see camera calibration and 2D-reconstruction subsection). Video recorded images of every trial were transferred to digital support, coded, and saved as *.avi format.

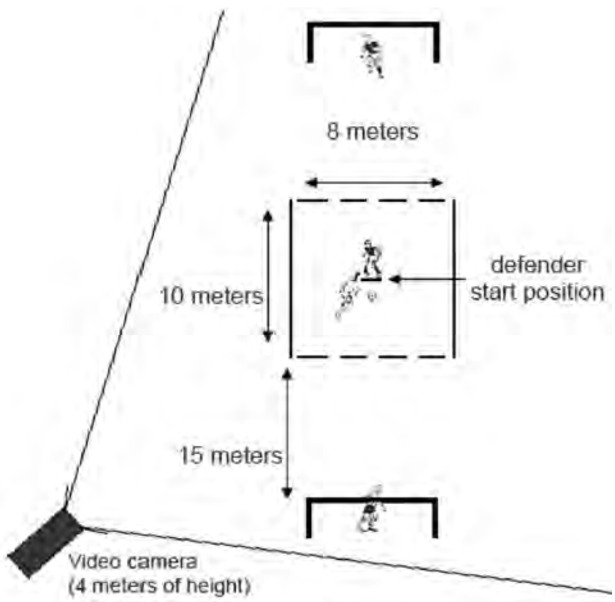

Fig. 1. Schematic representation of experimental task, with the video camera fixed at 4 meters of height and approximately 45 degrees

Image treatment. For image treatment, we used the TACTO 8.0 software (15) originally created by Fernandes in Microsoft Visual Basic 6.0 programming language. This device has been continuously improved since its original version. It was created to collect and analyze the physical performance of football players (20). TACTO has been adapted to different goals in several studies, ranging from the measurement of the physical performance (20, 21) to measuring players' behavioral patterns in many sports (6, 22) or to the codification of certain action categories (21).

TACTO screen is illustrated in Fig. 2. The procedures for digitization consisted in following the selected working point with a mouse cursor. For this study, the working point selected was the middle point between the feet of each player, as this point somehow represents the projection of the player's center of gravity on the ground. The film was played in slow motion (1/2 normal velocity), and virtual coordinates were obtained at 25 Hz. The desktop resolution was 1280×800 pixels, and the device window did not move during the procedures.

Camera calibration and 2D-reconstruction. In the study of Duarte and colleagues (17), the authors utilized a planar analysis using the 2D-DLT method (16, 23) for calibration and object-plane reconstruction. This two-dimensional method uses the same DLT algorithms employed in tri-dimensional analysis, but considers the z-coordinates always equal to zero. The DLT method directly relates an object point located in the object space/plane and the corresponding image point on the image plane (see Fig. 3).

Object O is mapped directly to the projected image I. The projection plane is called image plane, while point N is the new node or projection center. Hence, the object point (O), the image point (I), and the projection center (N) are collinear. This is the so-called collinearity condition, the basis of the DLT method. Two reference frames are defined in Fig. 3: object-space reference frame (the XYZ-system) and

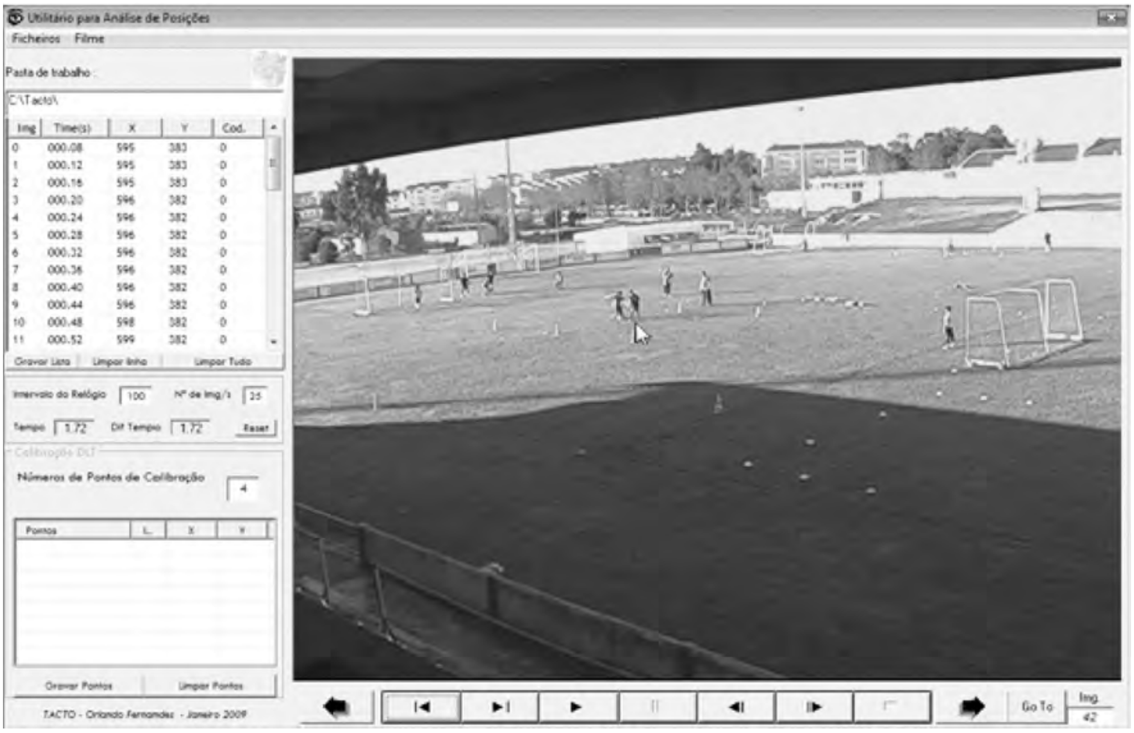

Fig. 2. The TACTO 8.0 device window

By following a selected working point with the mouse cursor, the software computes over time the virtual coordinates for the tracked object (see up left side of the window).

image-plane reference frame (the *UV*-system). The (*x, y, z*) is the object-space coordinates of point *O*, while (*u, v*) is the image-plane coordinates of the image point *I*. There is a direct relationship between the object space coordinates, (*x y, z*), and the image plane coordinates, (*u, v*) (16, 23), as it is shown in equations (1) and (2) :

$$u_i - u_o - \Delta u_i = -\lambda_u w_o \cdot \frac{t_{21}(x_i - x_o) + t_{22}(y_i - y_o) + t_{23}(z_i - z_o)}{t_{11}(x_i - x_o) + t_{12}(y_i - y_o) + t_{13}(z_i - z_o)} \quad (1)$$

$$v_i - v_o - \Delta v_i = -\lambda_v w_o \cdot \frac{t_{31}(x_i - x_o) + t_{32}(y_i - y_o) + t_{33}(z_i - z_o)}{t_{11}(x_i - x_o) + t_{12}(y_i - y_o) + t_{13}(z_i - z_o)} \quad (2)$$

where *i* is the control point number, $(0, u_i, v_i)$ and (w_o, u_o, v_o) are the image plane coordinates of the image point (*I*) and the projection center (*N*), respectively, (x_i, y_i, z_i), and (x_o, y_o, z_o) are the object space/plane coordinates of the object point (*O*) and the projection center (*N*), respectively, $(\Delta u_i, \Delta v_i)$ are the optical errors (optical distortion and decentering distortion (24)) involved in the image coordinates, and (λ_u, λ_v) are the scaling factors for the unit conversion from the real-life unit to the digitizer unit (DU). The t_{11}–t_{33} in equations (1) and (2) are the elements of a 3×3 transformation matrix from the object-space/plane reference frame to the image-plane reference frame.

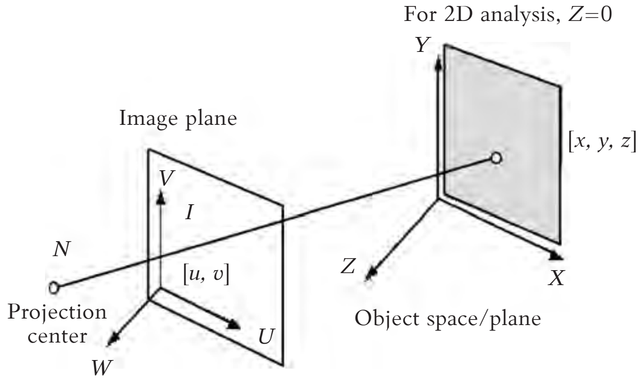

Fig. 3. Mapping in imaging and reconstruction: object-space/plane and image-plane reference frames

Successive rearrangements of equations (1) and (2) resulted in 11 DLT parameters that reflect the relationships between the object-space/plane reference frame and the image-plane reference frame. In the current study, due to the utilization of planar analysis, DLT parameters were reduced to 8 (for mathematical details see (25)).

To study the 1vs1 football subphase, several non-collinear control points were tested. The use of 6 points was sufficient for accurate camera calibration and 2D-reconstruction procedures. Fig. 4 shows control point location, as well as the bidimensional reference frame for this task. In order to ensure the proper calculation of kinematic variables, zero-zero

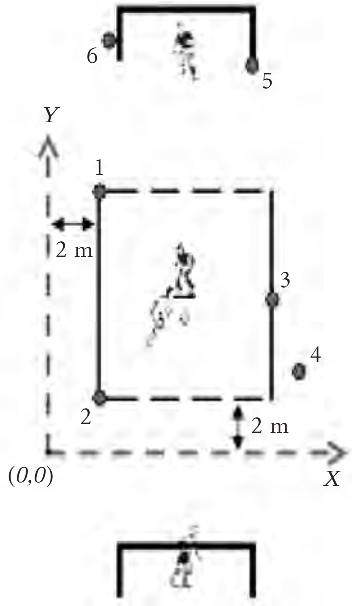

Fig. 4. Control points and zero-zero coordinates identification

coordinates *(0, 0)* were assigned with 2 m of safety margin (see Fig. 4).

Table displays the real coordinates (x, y) measured in the field and the virtual coordinates obtained from TACTO software.

These coordinates (i.e., the virtual and the real coordinates) were the starting point to calculate the DLT parameters used in calibration and reconstruction procedures. MATLAB files were then created with 2D-DLT algorithms to create the DLT parameters. These parameters were firstly used for camera calibration and afterward for image reconstruction.

Filtering. Some data fluctuations may be due to lack of accuracy in digitization and calibration processes. Failure to treat these errors properly results in amplified and noisy velocity and acceleration data (16). However, due to the inherent variability of human movement data, it is difficult to distinguish it from instrumentation noise. In order to deal adequately with instrumentation error, a Butterworth low-pass filter was used (26). The original data set was compared with different cut-off frequencies. Fig. 5 concerns an illustration of this comparison made between a 3-Hz and 6-Hz filtering cut-off frequency on the x coordinates of an attacker displacement, in the 1vs1 football subphase. The per-

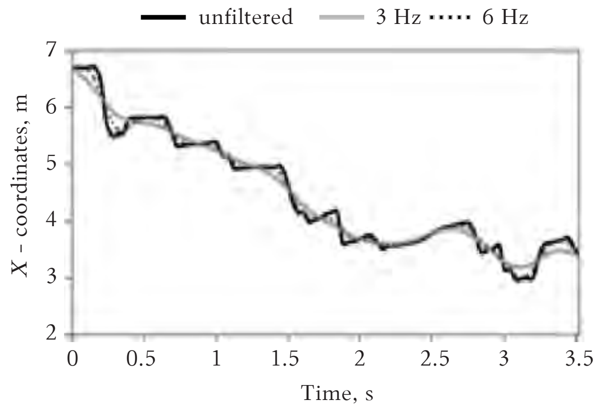

Fig. 5. Effect of filtering on the x coordinates of player displacements

centage of variance accounted for VAF, computed as the normalized error between the original and filtered signal, was used to assess the adequate cut-off frequency (27). Results demonstrated less variation using a 6-Hz than 3-Hz cut-off frequency. This similarity between unfiltered and filtered data was taken as a criterion to use the cut-off frequency of 6 Hz for all trials (26).

Reliability analysis. To obtain data with minimal error, we developed a digitization training program during 7 consecutive days. On the first day, the tracking operator (i.e., the observer) completed 5 trials for two times as a pretest. In the next five days, the operator made 30 trials per day (15 trials $\times$ 2 times). On the seventh day, he completed the same pretest protocol as posttest measures.

For the reliability measurements between trials in pretest and posttest, we used Pearson correlation coefficients and variation accounted for VAF (27). Results showed high R values for both pretest and posttest (pretest, R=0.997±0.004 for x component and R=0.875±0.173 for y component; posttest, R=0.996±0.003 for x component and R=0.894±0.178 for y component). VAF results also demonstrated high percentage of reliability for x and y component of the two players both in pretest and posttest (VAF always >99.99%).

Data computation. After the correct implementation of the aforementioned procedures, the kinematic variables that capture the collective behavior of the system under analysis were calculated. The running distance of any moving object in a t (time) interval was calculated as the sum of partial displacements

Table. Real (m) and virtual (pixels) coordinates of the control points measured

Control point	1	2	3	4	5	6
Real X-coordinate	2	2	10	11	9	2.9
Real Y-coordinate	12	2	7	3	27	28.2
Virtual X-coordinate	461	597	642	726	420	325
Virtual Y-coordinate	339	327	356	362	366	354

between each frame. By computing the derivative of the positions in each frame, instantaneous velocity data along time were obtained. Specifically created MATLAB files (MATLAB 2008a, MathWorks™) were used to compute these time series of kinematic variables. At a dyadic system level, as the one studied, the literature suggests the calculated kinematic variables as potential order and control parameters (for details see (4, 6, 12)).

Results and discussion

A graphical example of kinematic variables such as the distance to the defensive line and the velocity data of both players, in a random selected trial, are presented in Fig. 6.

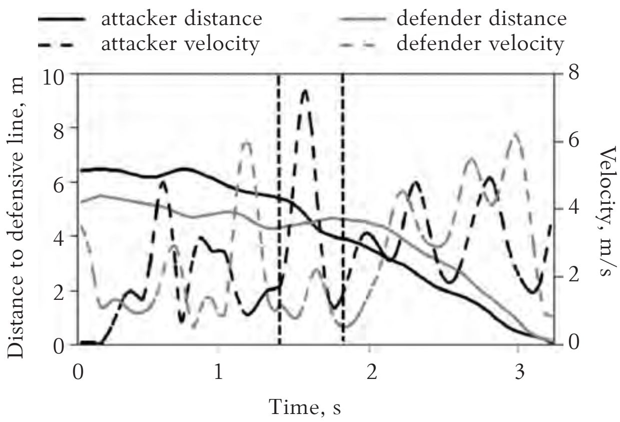

Fig. 6. Distance to defensive line and velocity data for each player

Fig. 6 displays the time series of the player's distance to defensive line, as well as player's velocity. Vertical dashed lines highlighted the moment where the attacker crossed the defender (i.e., when the projection of attacker's center of gravity on the ground was closer to the defensive line than the defender). At this point, it can be observed the differential velocity between the two players, in favor of the attacker. These preliminary observations help to identify a relevant collective variable that synthesizes the relational quantities between system components (see Fig. 7).

The left panel of Fig. 7 shows how the difference between the distance of the attacker and the defender to defensive line synthesized and described the dynamics of this dyadic system. Near 1.5 seconds, when the attacker over passed the defender player, the collective variable changed qualitatively from positive to negative values. In the right panel, it is observed an increase in the rate of change (maximum absolute peak value) of the collective variable, near 1.5 seconds, associated to a phase transition. The negative rate of change at this moment indicated that attacker's distance to the defensive line decreased faster than the defender's distance.

The moment of phase transition (Fig. 6, dashed vertical lines) was related to the difference between the velocities of each player. Thus, the relative velocity (i.e., the difference between the velocity of the attacker and the velocity of the defender) was tested as a potential control parameter of this dyadic system. Left panel of Fig. 8 displays the relative velocity time series. This variable seems to be related to the phase transitions. This may indicate that the qualitative change of the collective variable was influenced by the increase in the velocity difference between both players. As demonstrated previously (17), a closed examination showed that high relative velocity values promoted phase transitions only when interpersonal distance displayed low values (right panel of Fig. 8). In fact, the organizational state of the 1vs1 association football subphase only jumped to another order state due to the nested influence of the two control parameters (i.e., relative velocity and interpersonal distance).

Conclusions

The presented time-motion analysis procedures revealed consistency to reconstruct the players' movement in the performance context, with intraobserver reliability. As demonstrated in this paper, the combination between TACTO device and DLT method provides real kinematic data with minimal error, allowing identifying relevant order and control parameters. Conceptualized as complex systems, the internal and external constraints on players' behaviors can be studied by analyzing the qualitative changes of the order parameter along time (10). As suggested by Passos and colleagues, the rate of change of the order parameter (i.e., its first derivative) seems to be a relevant way to understand this phenomenon.

The presented method captured and contributed to the understanding of the inherent complexity of team ball sport behaviors. The used time-motion analysis procedures can be carried out using a single camera. As a major limitation, manual tracking of each object, one by one, is very time consuming. However, the ongoing improvement of the TACTO device toward more automatic tracking procedures will overcome this limitation. It is worth outlining that these procedures captured the complexity of human movement systems, as the example provided at a team sports dyadic level. Using the concepts of order and control parameters applied to kinematic data, it is possible to study the collective behavior of the teams at different levels of analysis (3).

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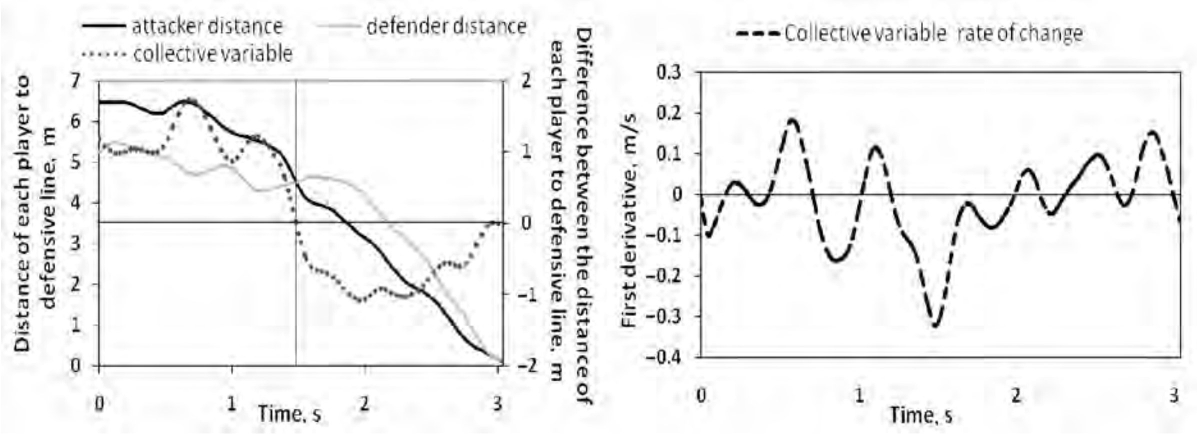

Fig. 7. Left panel: collective variable of the 1vs1 association football sub-phase and the phase transition between the two different qualitative states of order. Right panel: collective variable rate of change (first derivative)

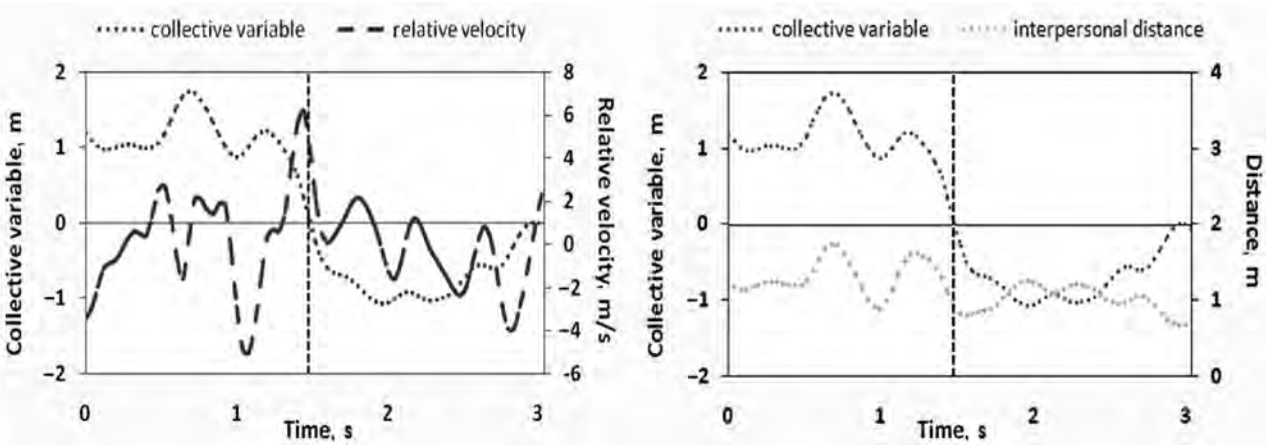

Fig. 8. Example of the complementarities of relative velocity (left panel) and interpersonal distance (right panel) acting as control parameters of the 1vs1 football subphase

Kompleksinės žmogaus elgsenos stebėsena su viena kamera reprezentatyviuose sporto kontekstuose

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Raktažodžiai: TACTO įrenginys, tiesinė transformacija, reprezentatyvus sportinis kontekstas, kompleksinė elgsena.

Santrauka. Paskutiniais metais sukurta keletas judesio analizės metodų neatsižvelgus į reprezentatyvų sportinį kontekstą. Šio darbo tikslas – paaiškinti ir pabrėžti tiesioginį metodą matuojant žmogaus elgseną šiame kontekste.

Tirtųjų kontingentas ir tyrimo metodai. Rankinio vaizdo stebėjimo (su TACTO įrenginiu), dvimatė rekonstrukcija (naudojant tiesinę transformaciją) ir viena kamera buvo naudojama siekiant fiksuoti kinematinius duomenis bei apskaičiuoti kolektyvinius kintamuosius ir kontrolinius parametrus. Šios procedūros taikytos 1:1 futbolo uždavinyje kaip grupinio sporto subfazės iliustracija ir autorių bus pateikiama kaip mokomoji priemonė.

Rezultatai. Pirminė nuotolių ir greičių duomenų analizė parodė kolektyvinius kintamuosius (nuotolis tarp atakuojančio asmens ir gynėjo gynybos zonoje) ir du susiję kontroliniai parametrai (tarpasmeninis nuotolis bei santykinis greitis).

Išvados. Tyrimas parodė, jog papildomas TACTO programinės įrangos ir tiesioginės transformacijos panaudojimas sudaro sąlygas fiksuoti ir atstatyti kompleksinius žmogaus veiksmus supančioje jį aplinkoje žemesnės dimensijos erdvėje (informacijos redukcija).

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