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Application of the AS-4 Software in Research on Players' Kinematics on a Large Area in 3D Coordinates As an Alternative to Commercial Programs

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Abstract

Background: In this work an original computer program for the video analysis of players on a large area by using a single camera is presented. Video analysis is one of the basic research techniques of human movement applied in sport. A set of cameras and special computer software is used for this purpose. Many companies provide hardware and software, but, unfortunately, their high cost and difficulty in usage are their major drawbacks. In order to simplify and reduce the costs of data analysis (obtained from a single camera), AS-4 program was developed. Material/Methods: The program includes an original algorithm which enables positioning of the camera in any place. Specifying dimensions of the playing field and an object, the program automatically calculates a scale and transfers the data to the 3D matrix. Then, using flat transformation, 3D coordinates can be determined. Results: The algorithm was tested in the field. The accuracy of determining coordinates was studied in 3 areas and errors of the method were within an acceptable range. Conclusions: With the present program, it was possible to determine the kinematic parameters at any time during the movement. The accuracy of the program was sufficient to determine the 3D position. It can be used to determine the movement path over a large area and then to calculate velocity and acceleration.

Keywords

photogrammetry, video analysis, 3D motion trajectory, optical geometry

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Authors' Contribution:
A – Study Design
B – Data Collection
C – Statistical Analysis
D – Data Interpretation
E – Manuscript Preparation
F – Literature Search
G – Funds Collection

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Introduction

Since the end of the 20th century video analysis has been one of the basic research techniques of human movement. With the help of this technique one can obtain geometric quantities: linear (length, breadth, height) and angular ones, and also derivative kinematic quantities such as velocity and acceleration. A set of cameras and special computer software is utilized for this purpose. The most developed companies providing hardware and software are: VICON, Ariel Dynamics, Peak Performance Technologies and Motionprosoftware from the USA, Bioengineering Technology & Systems (Elite) from Italy, SIMI Reality Motion Systems from Germany [1, 2, 3, 4, 5, 6]. These systems are especially made for movement's technique analyses. In the field of research on large areas, a set of various tools for the analysis of activities of football players is offered among others by Prozone® [7] and Amisco Pro [8]. Unfortunately, a disadvantage of these systems is their high cost and difficulty in handling. Thus the approximate cost of using the program Pro zone ranges from €140,000 per year (excluding support costs), for Amisco – it is about €50,000, plus €3,000 for each match analysis (giving a total of about €140,000). The exact cost of the purchase and use is difficult to determine, because it depends on individual confidential contracts between the club and the company.

The knowledge on the exact distance competitors cover in function of time within several sports disciplines can be utilized for an assessment of sport performance in individual and team sports. Computer programs, based on the reading of one or more cameras, e.g. elaborated in Poland [9, 10], Brazil [11, 12, 13, 14], Spain [17], Netherlands [16, 17], Japan [18, 19, 20] allow semi-automatic or automatic tracking of a player's position on the pitch.

While taking into account 2D coordinates, the above-mentioned special programs and some other ones are sufficient, but for 3D coordinates in large areas there are no simple and cheap methods. The existing systems [1, 5, 6] need recording with several cameras, utilization of markers and calibration of the scene. This is impossible to obtain during a match. For example, the Prozone® system [7], which was described, among others, by Di Salvo [21, 22], is an alternative to obtain exact 3D coordinates. However, the use of the system is associated with huge costs and it is available only to the largest research centers and rich football teams. The market lacks easy-to-use and low-cost programs allowing accurate reading of 3D coordinates over large areas with a single camera with a high resolution image.

In order to make recording and analysis of sport performance by one camera easier, a computer program AS-4 was written. This program enables defining a player's coordinates on the pitch both in 2D (e.g. to obtain the distance a player has covered during a match play) and in 3D (e.g. to define jump height by volleyball players during a match play).

Material and Method

Description of the program

Positioning of the camera. For simplicity of the test procedure the AS-4 program was developed. The AS-4 determines search values based on a video recording using a single camera. The program includes an original algorithm which enables positioning of the camera in any place at the spectators' stand. Only dimensions of the playing field are needed and the program would calculate the distance of the camera from the pitch and the angles of setting. Then an object of known height should be indicated (e.g. a net, a goal) and the program would automatically calculate the scale of an image transferring it into a three-dimensional matrix (see Fig. 1).

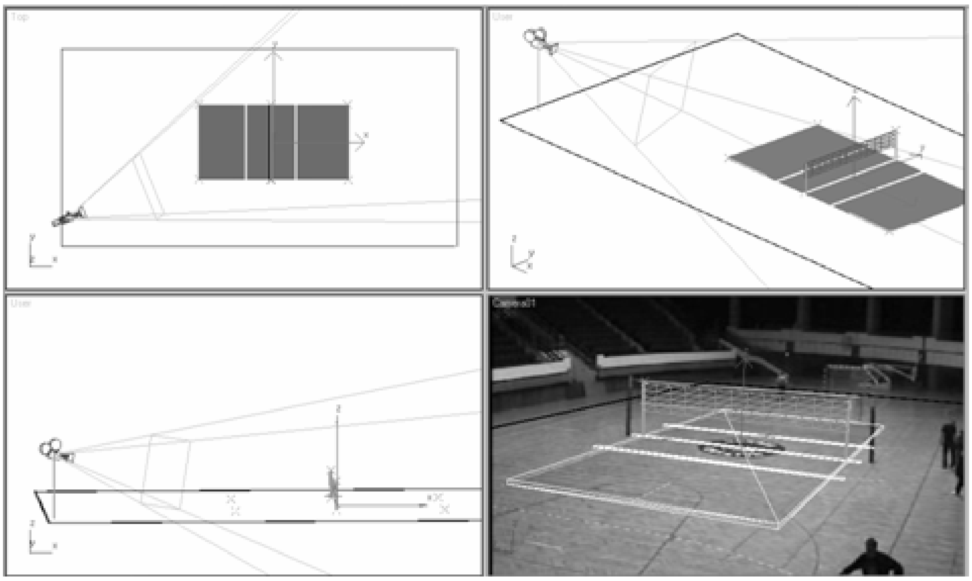

Fig. 1. Positioning of the camera for calibration of a volleyball pitch

Description of the algorithm

It is assumed that the recorded picture is a perspective (central) projection on a plane of light of a sensitive microprocessor (Fig. 2).

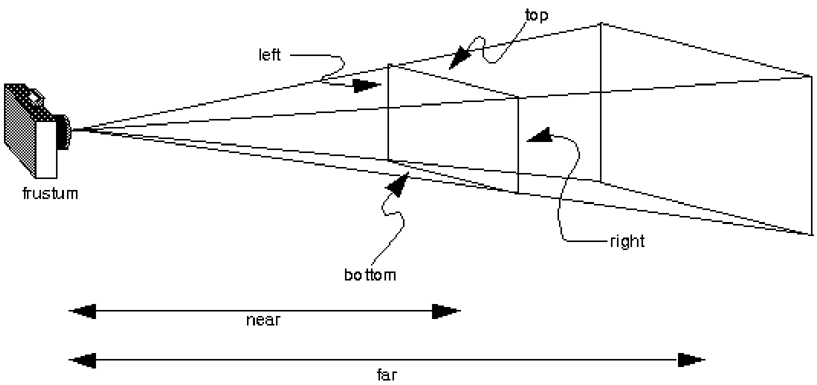

Fig. 2. Central projection (by Zydler) [23]

With the help of a transformation matrix in homogenous coordinates one can describe the perspective projection:

$$\begin{bmatrix} x' \\ y' \\ z' \\ W' \end{bmatrix} = M \cdot X = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & \frac{1}{d} & 0 \end{bmatrix} \cdot \begin{bmatrix} x \\ y \\ z \\ W \end{bmatrix} = \begin{bmatrix} x \\ y \\ z \\ \frac{z}{d} \end{bmatrix} \qquad (1)$$

The received image of a projected point is scaled according to parameters of objects on the field given earlier and transformed to obtain right angles. The flat transformation is a mapping which assigns points belonging to a single plane to points of the second plane. The first plane, called monitors, is identified with the image sensor of the camera or monitor. The second plane, called the local plane, is the corresponding plane in the space. In our case the local plane is made of e.g. field of play (turf).

The flat transformation *TP* can be written as:

$$TP(P_M) = P_R\ ,\quad P_M \in R^2\ ,\quad P_R \in R^2 \tag{2}$$

The exact relationship between the points belonging to both planes is described by the formula (3):

$$TP(P_M) = P_R = \begin{bmatrix} x_R \\ y_R \end{bmatrix} = \begin{bmatrix} \frac{a_1 \cdot x_M + b_1 \cdot y_M + c_1}{\alpha \cdot x_M + \beta \cdot y_M + 1} \\ \frac{a_2 \cdot x_M + b_2 \cdot y_M + c_2}{\alpha \cdot x_M + \beta \cdot y_M + 1} \end{bmatrix},\quad P_M = \begin{bmatrix} x_M \\ y_M \end{bmatrix} \tag{3}$$

Points with known positions on the field (for example, the end lines of the penalty area) are found in the camera image (monitor plane). Then, based on knowledge of the position of points on both planes, flat transformation is identified. A graphic interpretation of the situation is presented in Fig. 3.

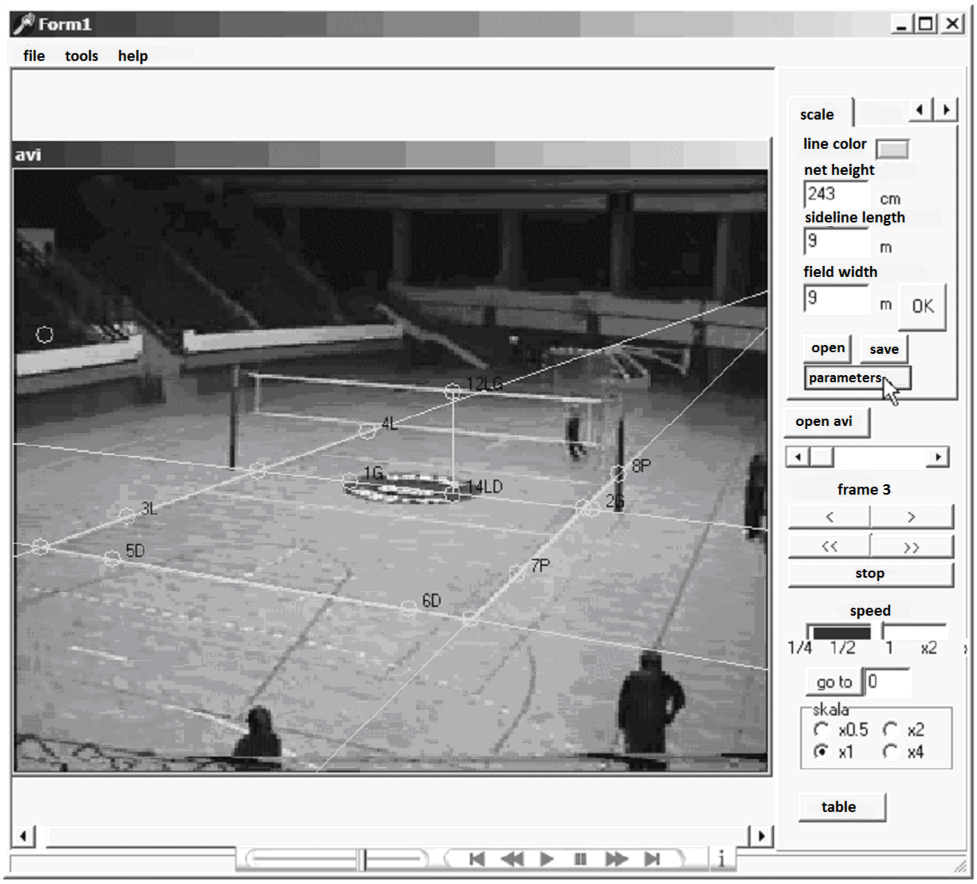

Fig. 3. The monitoring plane with marked points for identification of flat transformation in the AS-4 program

After specifying the coordinates the plane, Z coordinate (height) can be determined on the basis of knowledge of the camera focal length and the distance from the viewport (Fig. 4). The focal length of the camera is calculated beforehand by the algorithm of the program knowing the height of a previously selected object.

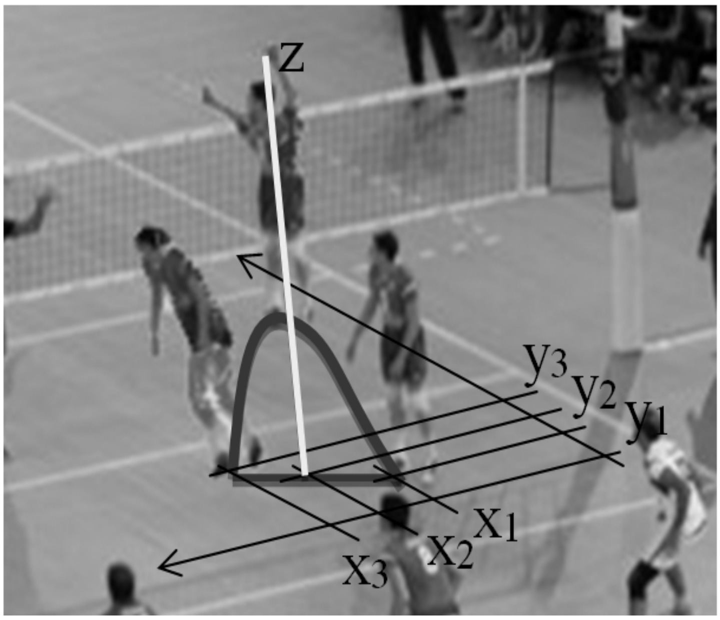

Fig 4. Determination of the height of jumping in a volleyball match in the AS-4 program

Errors of the method. Using an optical method with a video camera and a computer system for the analysis of movement, the following measurement errors should be considered: determining the time, determining the linear and angular distance, determining the velocity.
Error of determining the time. At a sampling frequency of 50 Hz frame rate a specific event is described in time with an accuracy of 0.02 seconds in time. With interpolation, an accuracy of 0.01 seconds was obtained. An absolute error (e) is then 0.01 s. Accordingly, the relative error for the interval of 1 second is:

$$\varepsilon.t = e.t/\Delta t$$

$$\varepsilon.t = 0.01 / 1 \bullet 100\% = 1\%$$

Error of determining the linear and angular path. Assuming an image resolution in the PAL standard at 720 x 576 pixels, the error of marking a point on the image is 1 pixel, which gives the error dependent on the scale for the current distance of the camera. The angular size does not depend on the scale of the image, but on the accuracy of the selected points. It is assumed that the e error of reading distance is 0.1 to 0.25 millimetres multiplied by the scale and depends primarily on the experience of the person operating the computer set and on the resolution and the screen size.
Error of determining velocity. The absolute error of velocity is calculated by multiplying velocity and the sum of relative errors of time and distance.

The real cameras are subjected to systematic errors, such as lens distortion and random effects, such as noise sensor. Some systematic errors may be included in the model by adding correction phrases (dx, dy) on a bilinear transformation (Fig. 5).

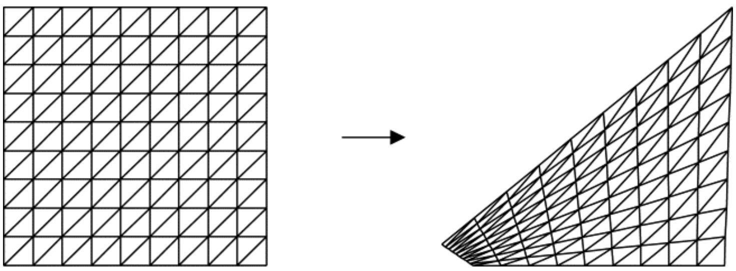

Fig. 5. A schematic illustration of the bilinear transformation (according to Ryan et al.) [24]

Results

The algorithm was tested in the field. A professional video camera (Canon XL H1S) was used for recording [25]. The accuracy of determining the coordinates was studied in 3 areas: a football pitch with dimensions of 105 m x 68 m, a volleyball court (18 m x 9 m) and a tennis court (23.8 m x 10.9 m). The camera was placed in five points, in a distance about 10m from the lateral or final line. A pole with a height of 2 m was set on the pitch surface, at intervals of length and width, at 5 m on the football pitch, and at 2 m on other fields. Values of absolute and relative errors (in percentage) are shown in Tab.1 and Tab. 2 and in Fig.6. Deviation in percentage was calculated as a percentage of the absolute difference between the real dimension and the dimension calculated as a real one. The distance (2D) between adjacent pole positions (an average of four distances) and their height (3D) were taken into account.

Tab. 1. An absolute error of determining the coordinates on the field, depending on the distance and the angle of the camera [%]

		Distance [m]											
		5	10	15	20	25	30	35	40	45	50	55	60
Angle [°]	0	3.4	2.9	3.1	4.2	5.5	9.1	5.6	9.1	13.3	13.4	13.9	17.8
	15	3.5	3.0	3.2	4.3	5.6	9.7	5.6	9.7	13.5	14.1	14.7	18.4
	30	3.5	3.0	3.2	4.6	5.8	10.1	6.0	10.2	13.6	14.2	15.1	19.2
	45	3.7	3.1	3.4	4.6	6.1	10.4	6.5	10.5	13.7	15.3	15.9	20.9

Tab. 2. A relative error of determining the coordinates on the field, depending on the distance [%]

		Distance [m]											
		5	10	15	20	25	30	35	40	45	50	55	60
Angle [°]	0	1.3	1.0	1.1	1.8	2.0	3.2	2.2	3.1	5.1	4.6	6.0	7.1

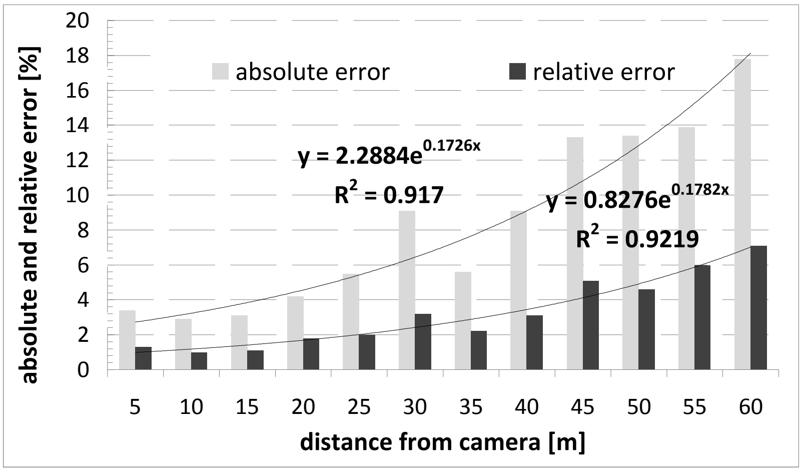

Fig 6. Errors of the method

Discussion

In modern sport, it is necessary to control loads, both the training and competitive ones. During the competition, only non-invasive techniques can be used, those not disturbing competitors, judges and spectators. Available video analysis systems are based on video recording or use GPS and radio transmitters for this purpose. For example, Henning et al. [22] showed that the accuracy of the GPS system is too small for the kinematic analysis in studies on the playing field, and in subsequent studies [23] they used a satellite navigation system with a higher accuracy, the so-called Differential GPS (DGPS), to determine the players' positions.

This system was associated with a necessity to carry receivers, which interfered with the players' natural locomotion and was impossible to use during a sports competition. Holzer et al. [26] used radio transmitters to designate a player's position on the pitch. The accuracy of this method is outstanding, but the registration of players, burdened with additional equipment, is possible only during training. Vandenbroucke et al. [16, 17] used algorithms based on extracting a color from the image segments to analyze players' movement on a football pitch, based on a video recording. That method allowed obtaining automatic tracking of a player, but the system proved to be unreliable in the case of a grouping of players in a small area. Iwase et al. [18] observed all players at the same time by determining their positions from multiple cameras. An analysis of that kind of data was extremely time-consuming due to the number of cameras used. Di Salvo et al. [21, 22] used the Prozone® system for motion analysis by means of an audiovisual recording. According to the authors, the accuracy of velocity measurement deviation was below 5%, which does not significantly differ from the error of the presented method. It is worth mentioning that the use of the Prozone® system requires considerable input cost and multiple cameras, which limits its application. Barros et al. [14] used four cameras and authoring software to analyze the distance covered by players and automatically tracked them on the field. The results obtained by the authors corresponded with the results of other researchers [18, 21, 22, 25]. However, using a set of four cameras makes it a very time-consuming method. Shiokawa et al. [19] and Toki et al. [20] applied the method of linear transformation (DLT) for video image analysis.

The proposed AS-4 program uses a similar concept. This is confirmed by the obtained results of research. Throughout testing of the presented system it was easy to determine the position of the monitored object. Designation of the position was possible at any place in the area marked by reference points. By means of video analysis, using appropriate mathematical formulas based on geometry, a distance which the object covers on the field was calculated, the time in which the distance was covered and the velocity based on the distance and the time. Designation of the position in a large space was also possible with only one camera. During tests and as a result of calculations, it turned out that the accuracy of measurement decreases with increasing the distance between the monitored object and the camera. Nevertheless, by using the presented program, it was possible to determine kinematic parameters at any time during the movement and accuracy was sufficient to define the 3D position.

Conclusions

The presented system has many advantages: it is non-invasive, low-cost (requires only one camera with high resolution), easy to use (transfer and analysis of data is simple and does not require special preparation). Furthermore, apart from the analysis of movement techniques, it can be used to determine a movement path over a large area and then to calculate the velocity and acceleration.

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