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A New Objective Semi-Automatic Forensic Kinematic Human Motion Comparison

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Abstract: With the development of technology, new services in the field of forensics are also being developed. In practice, there is a great need for objective human comparison between different video recordings. For this reason, we have developed a new forensic kinematic motion comparison service. This is based on a relative 2D kinematic analysis of the perpetrator's motion, usually based on a surveillance camera recording, and an absolute 3D kinematic analysis of the suspect's motion, performed under laboratory conditions. These two analyzes are compared using an advanced algorithm (the absolute 3D coordinate system is superimposed on the relative 2D coordinate system). All anthropometric points are rotated along the vertical, horizontal and transverse axes around the selected anthropometric point of the body. In this procedure, the size of all images of the 3D kinematic model of the suspect is proportionally adjusted to the height of the corresponding images of the perpetrator. The described method can be used to compare individual body positions or a selected image sequence of motion regardless of the type of body position when walking or other movement.

Keywords: 2D kinematics, 3D kinematics, human motion, biomechanics, forensics, comparison

1. Introduction

To date, not much scientific research has been done in the field of forensic analysis of human motion. Gait as evidence should be treated with caution, as they should any other form of evidence originating from disciplines without fully established codes of practice, error rates, and demonstrable applications in forensic scenarios ([4]). Therefore, we decided to develop a new method. It is an advanced comparison of two kinematic analyses. First, we need to perform a relative 2D kinematic analysis of the perpetrator's motion from the surveillance camera footage, and then an absolute 3D kinematic analysis of the same movement of the suspect's in the laboratory. We then calculate the average percentage match between all anthropometric points of the body. According to the scientific rules of biomechanics and kinematics, we also calculate the agreement of the body center of gravity. For this purpose, we have been developing for several years a procedure and method that uses an advanced algorithm. Based on these values, we create a table with statistical data on average values, minimum values, maximum values and standard deviation. Of course, first we need to make sure that we are comparing the appropriate body position. This is achieved by defining the characteristic positions of the body during the movement. The advantage of our method is the objective (mathematical, physical and biomechanical) analysis, where the subjective influence on the result are almost completely excluded.

2. Materials and Methods

We compared the analysis of the perpetrator from surveillance camera footage with a suspect measured in the laboratory. In reviewing the literature, we found no scientific work that objectively compares the kinematics of human position or motion between a video from a surveillance camera and a laboratory video with an exact mathematical limit if the same person is compared. With our method, we also neutralize most of the problems of surveillance camera recordings, such as poor resolution, low light sensitivity, too long exposure time, low number of frames per second, inexpensive lenses, wrong shooting angle, and the mode of image compression. First, we review the video from the surveillance camera at all stages, assessing the suitability and adequacy to continue the forensic investigation. Then we select the part of the movement that forms the meaningful whole. This is usually one or two steps. Then the video is converted into a format that can be recognized by our kinematic analysis system. In the next phase, anthropometric points on the perpetrator's body are manually determined for each frame individually. Then a mathematical transformation is performed according to the rules of kinematic analysis. This is followed by an interpolation to the appropriate number of frames per second according to the 3D kinematic analysis. By choosing the filtering of the coordinates calculated in this way, any deviations in the individual axes of motion are smoothed out. The same procedure is repeated for the video recording of the suspect's laboratory movement. With the difference that the determination of the anthropometric points is now doubled, because in our case we have two camera angles. We used the same methods and procedures as in the analysis of running technique ([3]). There is also a difference in the space calibration because we have the width (depth) in addition to the height and length. Two exported data files are our basis for further investigation. We import these two numerical files into our human motion forensic investigation system. It is first necessary to determine the characteristic positions of the body on both analyses. Then we decide at which anthropometric point the comparison should be made. This is the pivot point for the 3D view. If there are special reasons, we can also exclude individual points from the comparison. Then we start a special mathematical algorithm that search for the degree of agreement between these input points. This method can be very time consuming. When the algorithm calculates the percentage by which the comparative analysis agrees by the degree-by-degree method, only the creation of a statistical table and the preparation of a written report follow. Using advanced kinematic analysis, we compared the degree of agreement between 2D motion of the perpetrator and 3D motion of the suspect under laboratory conditions. The Ariel Performance Analysis System (APAS) ([2]) was used to convert the two two-dimensional laboratory recordings into an absolute 3D coordinate system (Figure 3). The 2D surveillance video was converted to a relative 2D coordinate system using the same APAS procedure (Figure 2). To calibrate the space under laboratory conditions, we used two aluminum cubes with a side length of 1 m and a profile diameter of 3 cm at the corner points (Figure 3). The second position of the cube was 3 m further in the direction of motion. On the calibration cube, we determined 24 points on both images whose coordinates represent the absolute measures of the length, height, and width of the reference space (Figure 1). The images were acquired using two Panasonic FZ200 cameras with an acquisition frequency of 100 Hz, a resolution of 1280 x 720 pixels in progressive mode, and an aperture of one hundredth of a second. To ensure comparability with 2D camera re- cordings, we converted the 3D video to 50 Hz. The subject's body was defined using a 17-point anthropometric model (Table 1 and Figure 5) associated with 15 body segments.

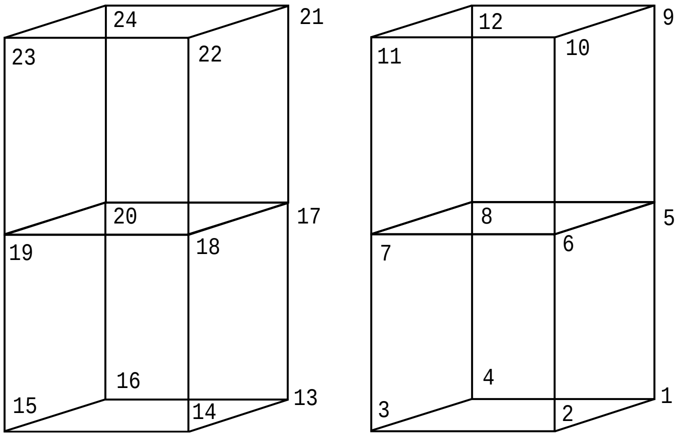

Figure 1. 24 points (x,y,z) 3D space calibration scheme.

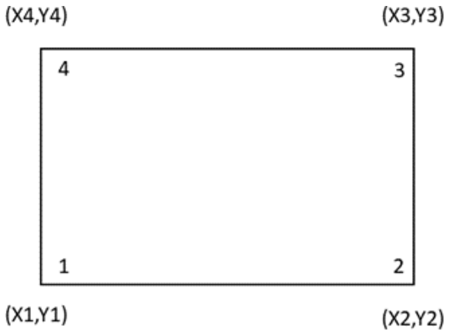

Figure 2. 4 points (x,y) 2D space calibration scheme.

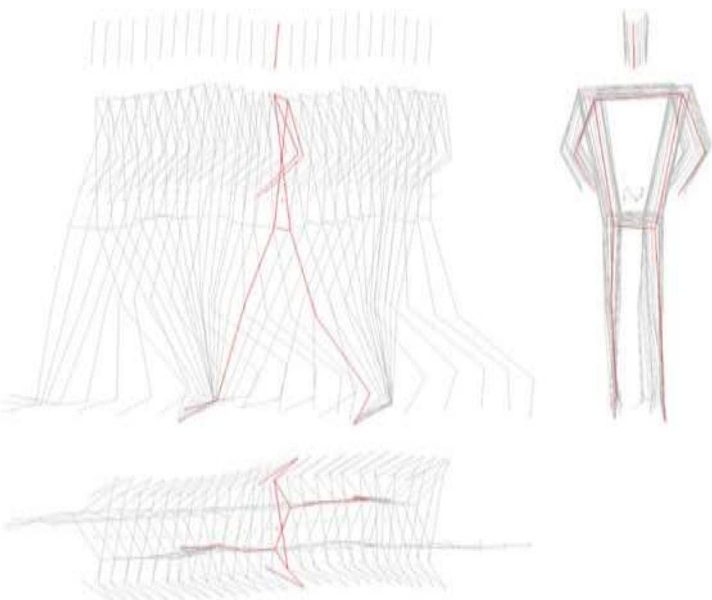

Figure 3. 3D absolute human body kinograms from side (upper left), from front (upper right) and from above (bottom left).

Figure 4. 2D relative human body kinogram from surveillance camera view angle.

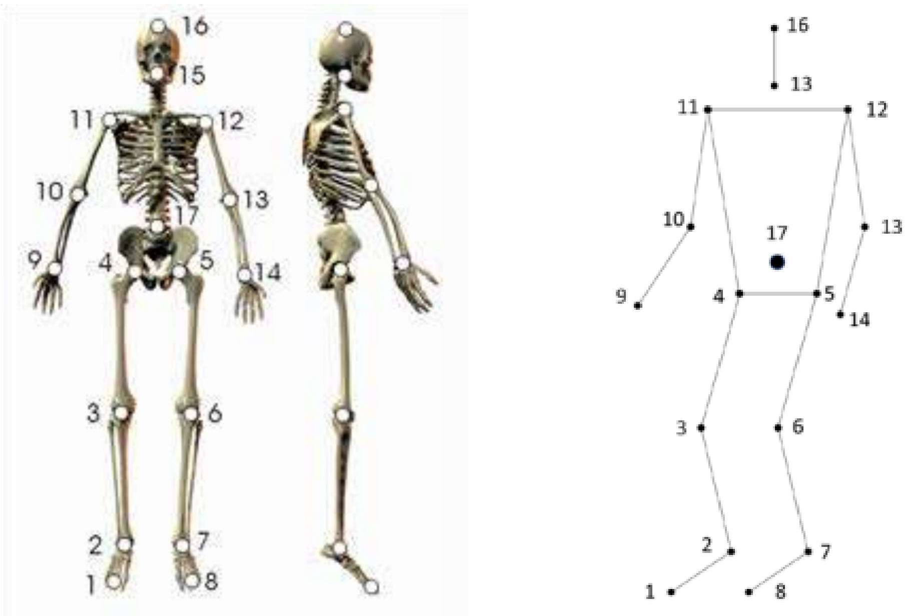

Figure 5. Human body model used for 2D and 3D kinematic analysis.

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Table 1. 17 body points (left) and 15 body segments (right) used for 2D and 3D kinematic analysis.

point number	point name
1.	right top of the foot
2.	right ankle
3.	right knee
4.	right hip
5.	left hip
6.	left knee
7.	left ankle
8.	left top of the foot
9.	right wrist
10.	right elbow
11.	right shoulder
12.	left shoulder
13.	left elbow
14.	left wrist
15.	atlas
16.	vertex
17.	body center of gravity

segment number	point A -point B	segment name
1.	1-2	right foot
2.	2-3	right shin
3.	3-4	right thigh
4.	4-5	hip axis
5.	5-6	left thigh
6.	6-7	left shin
7.	7-8	left foot
8.	9-10	right forearm
9.	10-11	right upper arm
10.	11-12	shoulder axis
11.	12-13	left upper arm
12.	13-14	left forearm
13.	11-4	torso right
14.	12-5	torso left
15.	15-16	head

To determine the anthropometric points and body segments and to calculate the body center of gravity, the model according to (Winter, D. A.) ([1]) was used. To filter the calculated coordinates of the points of both analyzes, a tenth-degree digital filter was used. Transformation (rotation, translation, projection, sizing, and best fit determination) of a 3D space into a 2D plane using descriptive geometry.

The 3D anthropometric points of a suspect and a perpetrator can be described by three coordinates representing length, height, and width (x, y, z). To calculate the degree of agreement between the two individuals, we need to project the 3D spatial coordinate system onto a 2D planar coordinate system defined by two coordinates for length and height (x, y). In this way, we can compare the similarities and differences in the location of each anthropometric point. This is done with the help of descriptive geometry ((x, y, z) to (x', y')), using the projection coefficients (p1, p2, q1, q2, r1, r2) (formula 1).

$$x' = (p1*x)+(q1*y)+(r1*z)$$
$$y' = (p2*x)+(q2*y)+(r2*z)$$

Formula 1: Transformation formula and projection coefficients.

Next, we define rotations around the vertical axis labeled α (alpha) around the horizontal axis labeled β (beta) and around the transverse axis labeled γ (gamma). Then we derive the formula for rotation along each axis (formula 2).

$$p1 = (\cos\beta)*(\cos\gamma)$$
$$p2 = (\cos\gamma)*(-\sin\beta)*(-\sin\alpha)+(\sin\gamma)*(\cos\alpha)$$
$$q1 = (-\sin\gamma)*(\cos\beta)$$
$$q2 = (-\sin\gamma)*(-\sin\beta)*(-\sin\alpha)+(\cos\gamma)*(\cos\alpha)$$
$$r1 = (\sin\beta)$$
$$r2 = (\cos\beta)*(-\sin\alpha)$$

Formula 2: Rotation along a single axis

3. Results

The forensic comparison is performed as a scientific model according to which we can compare the same body points of the perpetrator and the suspect. So, the body points must be determined manually for both comparison analyses, but in the following, the whole comparison is based on mathematics and is therefore an objective method.

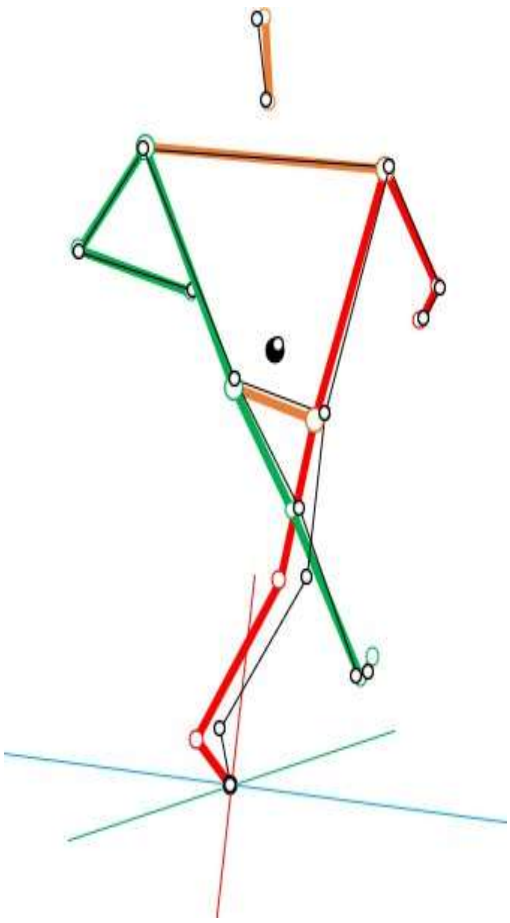

Figure 6. Example of overlaying two compared images (3D over 2D).

Table 2. Overall percent agreement (general %) with the added variables of minimum, maximum, and standard deviation values of each body point compared.

	general %	**99,05**	
	min %	96,25	96,89
	max %	99,90	99,77
	SD	1,07	0,84
	X and Y average %	99,07	99,04
	body point / axis	X	Y
2	right ankle	96,76	97,50
3	right knee	96,25	98,86
4	right hip	98,62	98,67
5	left hip	99,76	98,14
6	left knee	98,94	99,27
7	left ankle	99,52	99,50
8	left top of the foot	99,35	96,89
9	right wrist	99,67	99,48
10	right elbow	99,59	99,74
11	right shoulder	99,34	99,36
12	left shoulder	99,78	99,41
13	left elbow	99,90	99,67
14	left wrist	99,87	99,46
15	atlas	99,61	99,77
16	vertex	98,90	99,60
17	body center of gravity	99,26	99,26

Since we performed the overlay at the point of the right top of the foot, we did not use this point into the calculation.

4. Discussion

With this method, we provide a tool for comparing the similarity of human position or movements between a suspect and a perpetrator in forensic investigations that eliminates almost any subjective influence and provides scientific evidence. The choice of significance level, or alpha (α), is typically based on the specific research question, the type of statistical analysis being used, and the desired balance between Type I and Type II errors. A significance level of 5 % (or 0.05) is commonly used in many fields as a default threshold for statistical significance. However, some studies may require a more stringent level of significance to minimize the risk of false positives or to ensure that any true effects are not overlooked. We decided to use a 2.5 % cut-off percentage based on established statistical principles, which suggest that this level of significance provides a balance between Type I and Type II errors while still maintaining a sufficient level of statistical power to ensure the reliability and validity of the results.

5. Conclusions

The proposed new advanced semi-automatic objective forensic kinematic method for human motion comparison is as an independent evidence tool in courtrooms, where scientific accuracy is very important to determine the degree of agreement between two video recordings of movements. That is why we also decided to use a stricter measure of 2,5 % agreement instead of the generally accepted 5 % alpha error. In the future, we want to determine the validity, reliability, and measurement error we are dealing with when using this forensic comparison method between a suspect and a perpetrator.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Conflicts of Interest: The author declare no conflict of interest.

References

1. Winter, D. A. (2010). Biomechanics and motor control of human movement. John Wiley & Sons, Inc.
2. Ariel Dynamics (2001). Description - Ariel Performance Analysis System, Ariel Dynamics Inc. Retrieved from http://www.sportsci.com/adi2001/adi/products/apas/system/description.asp#destHeader275, on November 25, 2005.
3. Škof, B., & Stuhec, S. (2004). Kinematic analysis of Jolanda Ceplak's running technique.
4. Macoveciuc, I., Rando, C.J. and Borrion, H. (2019), Forensic Gait Analysis and Recognition: Standards of Evidence Admissibility. J Forensic Sci, 64: 1294-1303. https://doi.org/10.1111/1556-4029.14036