VALIDATION OF A THREE-DIMENSIONAL FILM ANALYSIS TECHNIQUE

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INTRODUCTION

Biomechanical studies have moved into more flexible film analysis techniques with the onset of computer technology. A number of these techniques have allowed for the analysis of sport movements in three-dimensions instead of the more restricted two-dimensional setting (Anderson, 1970; Bergemann, 1974; Martin & Pongratz, 1974; Miller & Petak, 1973; and VanGheluwe, 1974). Methods have been developed that use three-dimensional film analysis but require special metric cameras (Ayoub, Ayoub, & Ramsey, 1970; Bullock, 1974; Bullock & Harley, 1972; Lippert, Hussain, & Veress, 1974).

A technique that utilizes nonmetric cameras was developed by Abdel-Aziz and Karara (1971) for still cameras, and later adapted for use with high speed cameras. This method is referred to as direct linear transformation (DLT). The DLT process allows for data collected from two different cameras to be merged into three-dimensional output (Shapiro, 1980).

A computer program written by Marzan and Karara (1975) performs the complicated mathematical equations associated with DLT. Verification of this program was necessary because of program changes made when adapting it from one computer system to another.

PURPOSE

The purpose of this study was to verify two different computer programs: DLT, which stands for direct linear transformation, producing three-dimensional output by merging two camera views; and LKP, which stands for linear kinematic program, kinematically analyzing the three-dimensional data.

METHODS

In order to verify the programs known displacements, velocities, and accelerations were needed. It was decided that the parabolic flight of a steel ball would provide this information. A ramp was built that projected the ball at a 45 angle, and known three-dimensional positions in space were provided by a control point system. Both ramp and control point system were specially designed and constructed for this study.

The ramp was constructed to send the ball into a parabolic curve. It was built at an angle of 45 to allow the ball to reach a peak in its flight before beginning a downward descent. The lip of the ramp was 46 in. above the ground allowing for adequate acceleration of the ball.

The control point system had a total of 18 points that could be seen by both cameras during the filming. Styrofoam balls were attached to dowel rods inserted into a hollow base of plywood. The rods were of varying lengths to allow the points to be in different positions in the three planes (x, y, and z). The origin of the control point system was positioned on the upper left corner of the base, on the side facing the cameras.

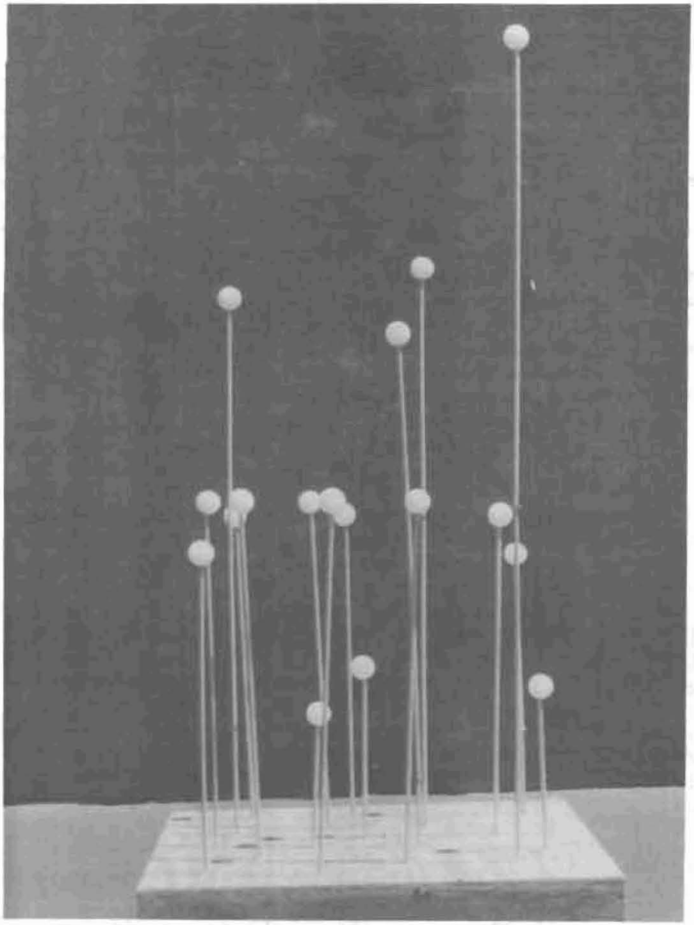

Figure 1. Control point system.

A version of the DLT program originally written by Marzan and Karara (1975) for an IBM cardfed system was used in this study. Adaptation of the program was done on a DECsystem 2060 in FORTRAN 77 using TOPS-20 version 5.1 of the operating system. Adaptations made in the DLT program included: change in data formatting, arrangement of data, open and closing of sequential files, and the reading of data.

The LKP program was written by the investigator to kinematically analyze the three-dimensional output from DLT. This program was also written in FORTRAN 77 for the DECsystem 2060. As it executes, the program reads the data generated by DLT and calculates displacements, velocities, and accelerations for each point. These points are then stored in a file.

A Numonics Graphic Digitizer was used to create digitized numeric data points from film. The digitizer was interfaced directly with a DECsystem 2060 computer. One trial of the control points and ball in free flight was selected for analysis based on film clarity. The data from each camera view was digitized, stripped of the blank lines between digitized points and then smoothed with a least squares quadratic fit smoothing routine.

A data file was created, by the investigator, that contained the digitized control points, hand-measured control points, and digitized data from each of the cameras' views of the ball in free flight. This data file was automatically opened by DLT, with the contents being used to calculate the three-dimensional coordinates. Another data file was opened which stored the DLT output once the program finished its calculations.

An inner verification was performed by the DLT program. This was done by comparing the hand-measured control points to those calculated by the program. A matrix was included in the output that compared these sets of data points.

DLT output was once again smoothed using the same technique as before. These smoothed points were submitted to LKP where displacements, velocities, and accelerations were calculated.

Coordinates calculated by hand were correlated to those produced by LKP to test the accuracy of the program. Twenty random numbers were

TABLE I. COMPARISON OF HAND-MEASURED CONTROL POINTS TO PROGRAM COMPUTED POINTS

POINT	HAND-MEASURED			COMPUTED		
	X	Y	Z	X	Y	Z
1	15.438	23.917	22.500	15.129	23.465	22.831
2	17.042	15.146	23.125	17.142	15.254	23.674
3	20.354	23.875	17.042	20.884	23.032	17.929
4	34.271	35.000	7.583	34.737	35.040	7.440
5	30.917	8.875	18.042	30.851	8.887	18.271
6	25.917	10.313	18.875	25.731	10.901	18.207
7	27.708	7.458	19.833	27.124	7.332	19.268
8	28.271	1.125	20.313	28.598	1.570	20.228
9	19.813	40.500	16.814	19.499	40.077	16.736
10	18.104	30.729	22.208	17.950	30.720	22.860
11	18.667	26.042	23.021	18.944	26.129	23.271
12	17.063	23.667	26.167	17.828	23.295	26.042
14	20.479	14.542	26.146	20.029	14.749	26.322
15	22.313	8.438	25.167	22.587	8.438	25.149
16	19.396	29.375	19.917	19.374	29.449	19.649
17	17.396	31.068	20.917	17.971	30.972	20.766
18	15.625	27.083	23.542	15.901	27.867	23.937

AVERAGE MEAN SQUARE ERRORS FOR 17 points are
0.0820 0.0828 0.0534 0.0845

selected from the output of DLT to use in the formulas for producing results calculated by hand. These 20 numbers were then correlated to those produced by LKP. An r of .99 or better was considered acceptable for the program to be determined as accurate.

FINDINGS

The DLT program with its self verification had a low standard error, which demonstrated the accuracy of the program. The matrix of x, y, and z coordinates are shown in Table 1.
A high correlation (r = .99) was found between the hand calculations and the program-calculated points. The program LKP was deemed accurate in view of this high correlation. Both DLT and LKP were found accurate and acceptable for biomechanical analysis.

CONCLUSION

Even though DLT has been available for a number of years, verification of the program is necessary when adapting it to a different computer system. A small standard error is found within DLT, and a high correlation is found between LKP data and hand calculated points. This indicates that these three-dimensional kinematic computer programs are appropriate as a tool in sport biomechanics.

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