

# PROBLEMS IN DATA REDUCTION: TRACKING A ROUND OBJECT

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In many biomechanical studies it is desirable to know the position or velocity of a round object. When only the product element of velocity is of interest, it is appropriate to use photoelectric devices (Nelson, Larson, Crawford, & Erose, 1966; Roberts, 1972). However, when process elements (e.g., segmental kinematics) as well as product elements are being investigated, the predominant research tools are cinematography and videography.

The biomechanics literature contains many studies in which a cine/video analysis was performed to obtain the position or velocity of a sports implement. Examples of round objects which have been filmed include: baseball (McIntyre & Pfautsch, 1982), basketball (Hudson, 1982), bowling ball (Bouse & Owen, 1984), golf ball (Cooper, Bates, Bedi, & Scheuchenzuber, 1974), hammer body (Dapena, 1985), handball (Bolt, 1969), lacrosse ball (Stevenson, 1981), netball (Elliott & Smith, 1983), racquetball (Kent & Barlow, 1982), shot put (Dessureault, 1974), soccer ball (Toc & Hoshizaki, 1984), softball (Zollinger, 1973), tennis ball (Putnam, 1984), volleyball (Brue & Shapiro, 1981), water polo ball (Davis & Blanksby, 1977), and weight plate of a barbell (Burdett, 1982).

In general, the typical procedure for cine/video data reduction is to: (a) project the film onto a computerized graphic tablet (Owen & Adrian, 1974) or television monitor (e.g., Peax Performance Technologies, 1983), (b) use an attached stylus or cursor to digitize displacement data from previously marked locations, (c) remove random digitizing error in the raw data points by fitting the points with a digital filter (Winter, Sidwell, & Hobson, 1974), and (d) obtain derivatives by employing direct differentiation of the spline functions or by using finite difference methods (Miller & Nelson, 1973) with the filtered data (Pezack, Norman, & Winter, 1977). Unfortunately, many conventional aspects of cine/video data reduction are inappropriate when analyzing the behavior of a ball.

First, problems arise at the stage of digitizing because no previously marked location remains at the center of a ball in flight. Although it may be possible to treat a small ball (e.g., golf ball) as a point and estimate its center (Shapiro, 1978), it is doubtful that a large ball (e.g., basketball) could be treated accurately as a point (Disch & Hudson, 1981). Rather than estimating the center of a ball, an alternate procedure is to digitize the top, front, bottom, or back edge of the ball. Given the precision of modern digitizing systems, there are many points which appear to be the topmost, frontmost, etc.. In the best case, the error associated with this method may not be much greater than that associated with digitizing small, round joint markers. However, in the worst case, accuracy of data reduction is diminished if the selected edge is blurred, deformed, obscured, indistinguishable from the background, or leaves the film image.

Second, errors introduced in digitizing are difficult to eliminate. For splines and filters to work properly with round object data, several frames of data are required. Wold (1974) has advised that if there are fewer than 25 data points (frames), the spline method should be used with caution. Although there is no established minimum number of frames to use with a digital filter, the inclusion of additional frames, which bracket the region of interest and are subsequently deleted, is considered necessary (Patrick, Widule, & Hillberry, 1981). If there are too few frames to use splines and filters, it is still possible to fit the data with a polynomial equation, but this method is considered to be less satisfactory than splines (Zernicke, et al., 1976) and filters (Pezack, et al., 1977). Typically, a biomechanical film of a ball skill might include only 5-10 frames after impact or release. Of course, a larger focal length lens could be used to keep the object in view in more frames, but the compromise is that the subject becomes smaller and more difficult to digitize accurately.

Third, if the digitizing errors are not removed, the inaccuracies are magnified in each subsequent derivative. Although derivatives can be obtained by using finite difference procedures, even when there are a small number of frames with the ball in view, this technique tends to amplify error if the data have not been filtered (Pezack, et al., 1977).

Because it is imperative for the digitized displacement data of the ball to be accurate so that derived velocity data are valid, a procedure has been developed for estimating the center of a round object from cine/video records. Suggestions for using this procedure to establish reliability and validity in tracking a round object are included also.

## PROCEDURES

### Triangulation Method

Using principles of analytic geometry (Murdock, 1966) the location of the ball center can be computed from three sets of coordinates on the periphery of the ball. As seen in Fig. 1, the center of the ball (X,Y) is at the junction of the perpendicular bisectors of the legs of the triangle formed by the peripheral points. The only restriction in terms of the choice of location of the peripheral coordinates is that for any given frame the x coordinates must be nonidentical and the y coordinates must be nonidentical. Given the resolution of digitizing systems, it is rare for randomly chosen points to have coordinates in common. The practical solution is to perform a check for identity during the computational routine and, if two values are found to be identical, add one unit of resolution to one of the values.

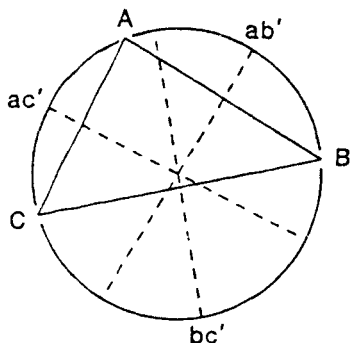


Figure 1: Triangulation method for locating the center of a round object. The peripheral coordinates  $(A_x, A_y)$ ,  $(B_x, B_y)$ , and  $(C_x, C_y)$  are used to determine the center  $(X, Y)$ .

One procedure of triangulation for finding the center of a round object is to:

a/ use the coordinates  $(A_x, A_y)$  and  $(B_x, B_y)$  to find the midpoint of line  $\underline{AB}$ , (b) use the same coordinates to calculate the slope of the line  $\underline{AB}$ , (c) determine the slope of line  $\underline{ab'}$  by taking the negative reciprocal of the slope of line  $\underline{AB}$ , (d) calculate the equation of line  $\underline{ab'}$  from its slope and midpoint, (e) repeat the process in steps (a) to (d) using coordinates  $(A_x, A_y)$  and  $(C_x, C_y)$  to obtain the equation for line  $\underline{ac'}$ , (f) compute the coordinates  $(X, Y)$  of the point of intersection of lines  $\underline{ab'}$  and  $\underline{ac'}$ .

By defining commonly used expressions and simplifying where possible, the following set of equations can be used to perform the triangulation procedure described above:

$$ABX = 0.5 \times (AX + BX)$$

$$ABY = 0.5 \times (AY + BY)$$

$$ACX = 0.5 \times (AX + CX)$$

$$ACY = 0.5 \times (AY + CY)$$

$$ABP = ABX + (BY - AY)$$

$$ACP = ACX + (CY - AY)$$

$$ABQ = ABY - (BX - AX)$$

$$ACQ = ACY - (CX - AX)$$

$$ABR = ABY - [ABX \times (ABY - ABQ) / (ABX - ABP)]$$

$$ACR = ACY - [ACX \times (ACY - ACQ) / (ACX - ACP)]$$

$$X = - \{ [(ACP - ACX) \times (ABR - ACR) \times (ABP - ABX)] / \{ [(ACP - ACX) \times (ABQ - ABY)] - [(ABP - ABX) \times (ACQ - ACY)] \} \}$$

$$Y = \{ [(ABQ - ABY) / (ABP - ABX)] \times X \} + ABR$$

### Reliability

It is recommended that reliability determinations be made for each cine/video analysis. If the data are reduced in more than one session or more than one person performs the digitizing, the stability paradigm with one- or two-way analysis of variance statistics is appropriate. However, if the research design involves testing a methodology (e.g., triangulation) and/or if all the data are reduced in one session, the internal consistency paradigm should be used.

To estimate the reliability of tracking the center of a round object with an internal consistency paradigm, compute the intraclass correlation coefficient (R) (Baumgartner & Jackson, 1982) for both the x and y coordinates of the first and second digitizing trials. Also, the average amount of measurement error in locating the center of the object should be estimated by calculating the standard error of measurement (Baumgartner & Jackson).

Considering that random errors in digitizing the peripheral points are averaged out to some extent in the triangulation process, using three points instead of one should be beneficial to reliability (Barrow & McGee, 1964). Because the internal consistency paradigm does not include error due to day-to-day changes in the performance of the instrumentation or the person who digitizes, it is possible that the reliability coefficient will be lower if a stability paradigm is employed.

### Validity

The validity of the triangulation method for estimating the center of a round object in cine/video analysis can be verified in two ways. Content validity can be assessed by using the McLaughlin, Dillman, and Lardner (1977) procedure of calculating the absolute difference between lengths which are known and measured from film. For example, the known radius of the round object can be compared to the radius computed by the difference between the peripheral points and the estimated center of the object. Measurement error is considered to be the standard deviation of the absolute differences in length.

Concurrent validity for a projected ball can be estimated by comparing the position array of the ball in flight to a criterion array. For large balls which are not moving rapidly, the development of the criterion array may be based on the assumption that the ball is not altered by fluid forces (Brancazio, 1984) and the suggestion that the coordinates of an object in flight can be modelled accurately by a second-order polynomial (Witule & Gossard, 1971). Thus, the x and y coordinates of the criterion array can be generated through regression procedures. Then, validity can be computed with a Pearson product-moment correlation.

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