A METHOD OF MOTION ANALYSIS FOR SELF-PROPELLED AQUATIC CRAFTS

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Introduction

Design advancements in self-propelled aquatic crafts have a direct impact on performance outcomes. Although, the Hatchet oar design may reduce total race time by less than one percent , (Nolte, 1993), the selection of racing design may determine who finishes first and last in high performance competitions. In addition, design modifications in most self-propelled aquatic crafts have maintained a rapid pace over the past thirty years. However, assessment methods that provide accurate pictures of the kinematics and net forces acting on the system have not.

The purpose of this study is to describe a method of combined videography and computerized manipulation of acceleration data that facilitates motion analysis of self-propelled aquatic craft.

Methods

The following describes the motion analysis technique in operation at Dalhousie's Sport Science Lab.

Videography. A Pentax high-8 mm camcorder is used for all filming. The instrument's sampling rate is used to relate acceleration and video data along a time line. The precise rate of sampling must be determined for each instrument through experiment. Simply accepting the manufacturer's statement of average sampling rates for the specific model of equipment can lead to significant cumulative errors.

To calibrate the video camera (sampling rate) an object is dropped from a measured height. With the assumption that air resistance is negligible, the time required for the object to reach the surface of the earth is calculated. The sampling rate of the video camera is then calculated by counting the number of frames from release to impact and dividing by the elapsed time.

Excessive rotation of the freely falling object could result in a miscalculation of the time required for the free fall. This time would then lead to incorrect sampling rate values. In order to correct for this, a medium sized ball is used (racquet ball), with highly reflective tape evenly spaced over six locations on the ball. When the ball is dropped, one of the markers is perpendicular to the camera. If the marker rotates out of view and another marker rotates into view, the trial is discarded.

The number of frames are counted on different video cassette recorders. The Sony Hi-Fi VCR (model SLV-676UC) is used and the tape is advanced to the first field in which the ball was released. The fields are then stepped through, one by one, until the ball impacts the earth.

The number of frames is also counted on the Peak Performance 2D System. This video digitization system is capable of splitting a frame into two fields, thus doubling the sampling rate of the camera. In order to count the frames, the video tape is encoded. By doing this a set of sequential numbers are written on the tape to ensure that no frame is skipped during counting.

To count the frames using the Peak System, the field number is recorded of the first image of the release of the ball. The field number of the ball's impact with the earth is also recorded. The difference is taken in order to determine the number of frames from release to impact.

Accelerometer: The accelerometer used is the g.analyst (Valentine Research). It is a triaxial accelerometer with three piezoresistance sensors mounted in orthogonal planes. Piezoresistance accelerometer are mechanical devices that contain a seismic mass supported on flexural beams (Henry et al., 1990). The mass is reflected relative to these beams by inertial vectors while undergoing acceleration (Shaoqun et al., 1992). The piezoresistance design allows the device to be tested using electrostatic deflection of the seismic mass (Henry et al., 1989). This method assumes that the voltage and initial separation gap are constant, but the temperature and piezoresistance coefficients can be neglected (Henry et al., 1989). This design allows for accurate self-testing with minor calibration adjustments made in the field (Henry et al., 1989). Therefore the use of a traditional dynamic calibration technique such as a shaker table is not required)

Data collected during the sampling period is stored in the accelerometer's internal random access memory (RAM). This provides a capacity per 4800 bytes of information during a single sampling period, after which the information is downloaded into the computer using a serial port and software that is provided with the acceleration.

the g.analyst has an internal calibration system that requires the accelerometer to be placed on a level surface in all three planes. The g.analyst will then adjust its sensors so that they record the acceleration due to gravity. The method used to calibrate its sensors is given in the owner's manual.

To ensure that the internal calibration system is accurate, the accelerometer is placed on a horizontal surface. A level and shims are used to ensure that the surface is, in fact, horizontal. A small weight is attached to a two foot piece of string and is allowed to hang freely. This provides a reference point for the perpendicular axis from the horizontal surface and the surface of the earth. A line is then drawn on the g.analyst indicating the vertical direction.

Since the acceleration due to gravity si always directed vertically downward the g.analyst should record a value of 1.00 when its sensor is perpendicular to the horizontal. When the accelerometer is tilted in two dimensions, it should record the line of the angle formed between the horizontal surface and the line of tilt.

The accelerometer is randomly placed in one of five positions with a right horizontal angle formed between the line on the g.analyst and the horizontal surface. This angle is measured with a goniometer.

Division, standardization and discrete measures of acceleration data: A program has been written in C in order to convert the raw acceleration data from g's to m/s/s and parse the acceleration data into approximate cycles. It can also integrate and differentiate the acceleration cycle curves, standardize the cycle size, filter the data and determine discrete measures.

The raw acceleration data is inspected and it is noted how long (number of data points) it takes the craft before the acceleration of the craft becomes consistent. The program is directed to ignore the first selected data points, removing the effects of a net increase in acceleration during.

The software steps through the data looking for a minimal decrease from the highest value since the end of the previous cycle. Once this minimum value is located it continues to examine the data until a minimum increase in the data is found. Once these two conditions are met and a minimum number of points are examined, the location of the vertex is recorded. This point would be considered the ending point for the previous cycle.

These approximate start and stop locations for the cycle are passed to a cubic spline function. A series of third order polynomials are used to describe the cycle according to Gerald (1973). The cycle is then interpolated using a modified routine from Press et al. (1990a & 1990b), in order to produce a new set of data of a prescribed length of 100 points for comparison. The above procedure is repeated for the entire set of acceleration data until all cycles are detected.

The cycle acceleration curve is analyzed to detect the percentage time of the cycle to the vertex of the first CCU curve (first concave up curve) (%tap1m and %tap1h) and the value at the vertex (aplm and aplh). This procedure is repeated for the CCD curve (%tav1m, %tav1h, avlm and av2h) and the second CCU curve (%tap2m, %tap2h, ap2m and ap2h). (A complete list of abbreviations are presented in the previous Dalhousie paper dealing with this topic.)

Calculation, and discrete measures of velocitv data: The acceleration data for each wave is integrated using Simpson's Rule, because it has the smallest error bound for all known numerical integrations of this type (Stewart, 1991). Simpson's Rule requires a minimum of six points to integrate. This means that the initial six percent of the velocity data would be lost. The Trapezoidal Rule is used at the end points in order to approximate the value. The following formula was obtained for Simpson's Rule from Stewart (1991):

$$V_i = t/3 * (A_1 + 4*A_2 + 2*A_3 + 4*A_4 + \ldots + 2*A_{i-2} + 3*A_{i-1} + A_i)$$

It is desirable to be able to relate velocity and acceleration on a one-to-one basis, but Simpson's Rule only allows for summation of an even number of points. In order to maintain the one-to-one relationship, the velocity is passed through a cubic spline which is used to interpolate between each point and maintain the balance in the number of points and to normalize cycle length.

When the data is integrated, there is a cumulative error which caused a linear increase of the velocity data. After integrating eight minutes of data, the craft is shown to be travelling at velocities that far exceeded any realistic value. The vertex values of each CCD curve are manually extracted and a linear regression analysis is performed. The slope value (C) is then used to correct for the linear error by adding a constant C*i after each integration.

However, it was found that the velocity data was very irregular. This may have resulted from the large C value, and the fact that the data had been passed through a cubic spline twice. It was decided that the Trapezoidal Rule should be used for the integration even though this has a higher error bound than Simpson's Rule. Stewart's (1991) definition of the Trapezoidal Rule was used:

$$V_i = t/w * (A_1 + 2*A_2 + \ldots + 2*A_{i-1} + A_i)$$

This integration method produces the same linear increase error found when Simpson's Rule is used. The same procedure is used to rectify the problem, but the C value is substantially smaller in this case.

The velocity data are then filtered. Discrete measures of the time to and the value at the first vertex of the CCD curve, as well as the time to and value at the vertex of the CCU curve, are made.

Calculation and discrete measures of impulse data: A FORTRAN program is used to calculate the impulse. The formula used for impulse can be derived from Newton's fundamental equation of motion.

An initial velocity of zero is assumed for the beginning of each cycle. The velocity values are not correct as the initial conditions are set to zero even though the craft is in motion. Thus the value to the impulse data is incorrect, but is only erroneous by a constant, and does not have an effect on the one-way ANOVAs used for statistical analysis. The impulse is calculated from the initial phase until the treminiation phase.

The total negative impulse (tnih and tnim), total positive impulse (tpih and tpim) and the total impulse (tih and tim) for the interval from ten to ninety percent of the cycle are summed.

Conclusion

This procedure has been used successfully in flatwater kayaking, flatwater canoeing, and rowing (sweeping and sculling). Its usefulness in other activities such as; swimming, whitewater kayaking and canoeing, windsurfing, waterskiing and surfing should be explored. From a coaching standpoint, this equipment and method may be useful in crew selection, technique alterations and matching equipment with athlete.

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