A MODELLING METHOD FOR DISCRETE LOW SAMPLING FREQUENCY TEMPORAL SERIES ON THE EVALUATION OF INTRA- CYCLIC SWIMMING SPEED FLUCTUATIONS

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INTRODUCTION

Profiles of intra-cycle swimming speed fluctuations has been widely used as a highly informative parameter on swimming biomechanics. Methods described in literature include: (i) free swimming and (ii) linked swimming approaches.

In a previous study (Vilas-Boas. 1992), we described a photo-optical method for the assessment of free swimming intra-cyclic velocity fluctuations. This method was characterized by a low sampling frequency and by a least adequate mathematical modelling method, since conventional polynomial regressions do not fully respect the cyclicity of the phenomena itself: both extremes of the model curve don't fit with each other, imposing-sudden velocity descontinuities that could only be explained through infinite accelerations and forces.

The purpose of this paper is'to describe a modelling method for discrete intra cycle velocity fluctuation analysis with reduced sampling frequencies.

METHODOLOGY

Data acquisition: Intra-cyclic velocity (v) / time (t) pairs of values were obtained from a intermittent light-trace photographic method (Vilas-Boas, 1992). The method consists in the photographic registration. with prolonged exposure, of the trace produced by a pulse-light device attached to the waist of the swimmer, at a middle distance between the two hip joints. Photos (Canon T70, 35mm, Kodacolor 1000 ASA film) were digitized using a Calcamp digitizing table, the Sigma Scan software and a PC computer.

The modelling method: The first step consists in the superimposition of three consecutive breaststroke cycles, sampled with reduced frequency. This was performed subtracting, or adding, a estimated cycle period (T) to each t value of the extreme cycles sampled in each photograph. The initial T value was estimated from the time interval between two consecutive absolute v minimums. This first step was performed in order to: (i) increase the number of points to define the final model; and (ii) allow the individual model of the stroke cycle velocity / time curve to be calculated on more than one isolated stroke cycle. Once translation was accomplished, one first 8th degree polynomial regression was calculated:

$$v = a + \sum_{i=1}^{8} b_i \cdot t^i \qquad (1)$$

In order to allow the polynomial equation to respect the cyclical nature of the phenomena, two constrains were imposed to the regression, both on the initial (t = 0) and the final (t = T) instants of the stroke cycle model:

(i) $$v(0) = v(T) \qquad (2)$$

and

(ii) $$\left.\frac{dv}{dt}\right|_{t=0} = \left.\frac{dv}{dt}\right|_{t=T} \qquad (3)$$

This was accomplished as follows:
Taking into account the equation **(1),**

$$v(0) = a \tag{4}$$

and

$$v(T) = a + \sum_{i=1}^{I} b_i * T \tag{5}$$

Changing (4) and (5) into equation **(2),**

$$a = a + \sum_{i=1}^{I} b_i * T \tag{6}$$

then:

$$\sum_{i=1}^{I} b_i * T^i = \tag{7}$$

In the other hand, once:

$$\frac{dv}{dt} = \sum_{i=1}^{I} i * b_i * T^{i-1} = b_1 + 2b_2 t + 3b_3 t^2 + \ldots + I * b_I * t^{I-1} \,, \tag{8}$$

the first derivatives of the velocity in order of time for the first (t = 0) and last (t = T) points of the stroke cycle can **be** described as follows:

$$\left.\frac{dv}{dt}\right|_{t=0} = b_1 \tag{9}$$

and

$$\left.\frac{dv}{dt}\right|_{t=T} = b_1 + \sum_{i=2}^{I} i * b_i * T^{i-1} \tag{10}$$

Considering the second imposed constraint **(3),** is possible to note that:

$$b_1 = b_1 + \sum_{i=2}^{I} i * b_i * T^{i-1} \tag{11}$$

and then:

$$\sum_{i=2}^{I} i * b_i * T^{i-1} = \tag{12}$$

Starting from (12) is then possible to calculate the b_I coefficient of the regression equation, **taking** into account the optimized estimations of the coefficients b_2 to b_{I-1}, performed through the Marquardt (1963) algorithm.
If:

$$2b_2 T + 3b_3 T^2 + \ldots + Ib_I T^{I-1} = \,, \tag{13}$$

then:

$$2b_2 T + 3b_3 T^2 + \ldots + (I-1) * b_{I-1} T^{I-2} + I * \left(- \sum_{i=1}^{I-1} \frac{b_i}{T^{I-1}}\right) * T^{I-1} = \tag{14}$$

It means:

$$2b_2 T \quad 3b_3 T^2 \; \ldots \; (I-1) \; b_{I-1} T^{I-2} - 1 \left(\frac{b_1}{T^{I-1}} \; \frac{b_2}{T^{I-2}} \; \ldots \; \frac{b_{I-1}}{T}\right) T^{I-1} = \,, \tag{15}$$

or:

$$2b_2 T \quad 3b_3 T^2 \; \cdots \; (I-1) \; b_{I-1} T^{I-2} - (Ib_1 \; Ib_2 T \; \cdots \; Ib_{I-1} T^{I-2}) = \tag{16}$$

Working on, we obtain:

$$-Ib_1 \quad (2-1)b_2 T \quad (3-I) b_3 T^2 \; \cdots \; (-1) b_{I-1} T^{I-2} = \tag{17}$$

and:

$$Ib_1 \quad (I-2)b_2 T \quad (I-3) b_3 T^2 \; \ldots \; b_{I-1} T^{I-2} = \tag{18}$$

Developing in order to b1 we have:

$$b_1 = \frac{1}{I}[(I-2)b_2T + (I-3)b_3T^2 + \dots + b_{I-1}T^{I-2} \quad , \tag{19}$$

or:

$$b_1 = \frac{1}{I}\sum_{i=2}^{I-1}(I-1)\, b_i T^{i-1} \tag{20}$$

Starting from (11) it is also possible to calculate the last coefficient of the regression equation (b_I).

If:

$$b_1 T + b_2 T^2 + \dots + b_{I-1} T^I = \tag{21}$$

then:

$$b_I = -\frac{1}{T^I}(b_1 T + b_2 T^2 + \dots + b_{I-1} T^{I-1}) \tag{22}$$

and:

$$b_I = -\left(\frac{b_1}{T^{I-1}} + \frac{b_2}{T^{I-2}} + \dots + \frac{b}{T}\right) = \sum_{i=1}^{I-1}\frac{b_i}{T^{I-i}} \tag{23}$$

RESULTS AND DISCUSSION

Figure 1 presents velocity / time curves for three breaststroke techniques performed by 6 Portuguese male swimmers at 200 m race pace. It is possible to note the general coherence of the models.

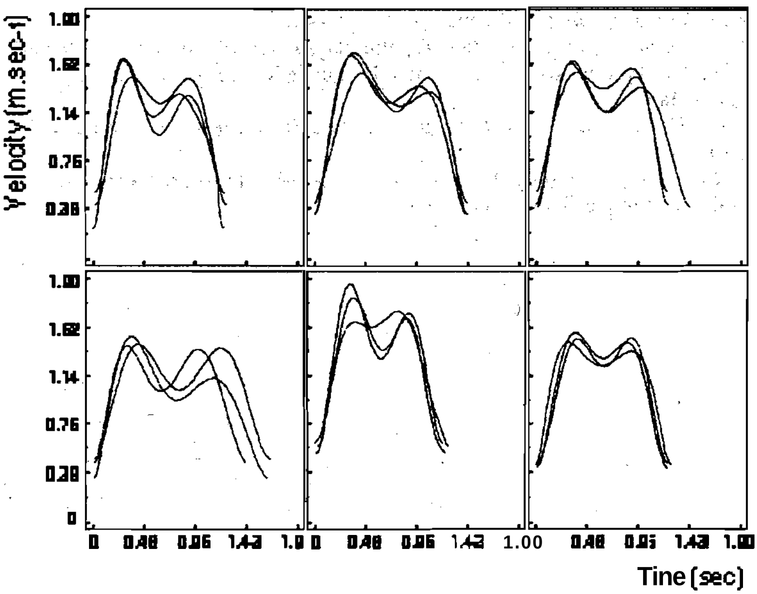

Figure 1. Individual velocity / time curves obtained for 6 swimmers, each one performing three breaststroke techniques at 200 m race pace.

Using PC-Matlab (3.13) for integration and derivation of the special **polynomial** equations, it is possible to assess acceleration curves, and per phase resultant impulses (Vilas-Boas, **1994),** as well as duration and horizontal distance covered per phase.

Results were highly compatible with previous reports (Vilas-Boas, 1993) and pointed out that: (i) mean minimum velocity **associated** with the recovery of the legs (vl) was .40 (SD = **.035) m.sec^{-1};** (ii) mean maximal **velocity** associated with the leg kick **(v2)** was 1.43 (SD = .039) m.sec^{-1}; (iii) mean minimum intermediate velocity associated with the transition phase between leg and arm strokes (v3) was 1.07 (SD = .027) m.sec^{-1}; (iii) mean peak velocity associated with the armstroke (v4) was 1.26 (SD = .038) m.sec^{-1}; (iv) mean acceleration and resultant impulse between v1 and v2 were 3.03 (SD = .314) m.sec^{-2} and 61.40 (SD = 3.726) Ns; (v) between v2 and v3 were -1.08 m.sec^{-2} and -21.43 (SD = 3.478) Ns; (vi) between v3 and v4 were .69 (SD = .084) m.sec^{-2} and 11.32 (SD = 1.853) Ns and (vii) between v4 and v1' were -2.24 (SD = .026) m.sec^{-2} and -51.13 (SD = .962) Ns.

CONCLUSIONS

Results of this study showed that the described mathematical method is feasible for modelling discrete low sampling frequency velocity / time curves of breaststroke swimmers. Nevertheless, further research on procedure fidelity should be conducted in the future.

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