Jump Height Determination with Force Plate for Continuous Jumps

C. Calame[1], M. S. Kuster[2]
[1] Kistler Instrumente AG Winterthur, CH-8408 Winterthur, Switzerland
[2] Klinik fuer Orthopaedische Chirurgie, Kantonsspital, CH 9007 St. Gallen, Switzerland

Introduction

Using a force plate for jump performance analysis is a well accepted and proven method (1). One of the most often used parameters is the jump height s which is calculated using a "traditional" double integration of the vertical force F:

acceleration	$a(t) = F(t) / m$
velocity	$v(t) = \int (a(t) - a0)\, dt$
jump height	$s(t) = \int (v(t) - v0)\, dt$

The initial conditions for acceleration (a0) and velocity (v0) have to be determined carefully to prevent the integrations from "drifting".

A common method for single jumps is that the subject has to stand still and in the same position at the beginning and at the end of the jump. The initial conditions a0 and v0 are then adjusted so that velocity (v) and jump height (s) are zero at the beginning and at the end of the trial.

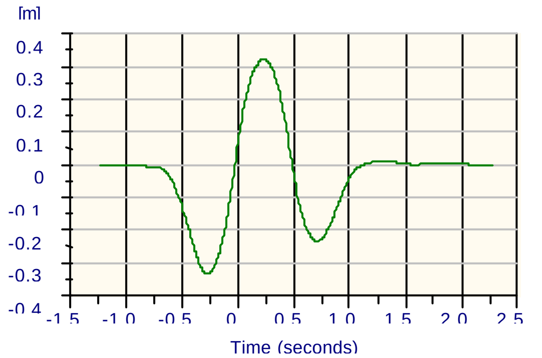

Figure 1 – Jump height s of one counter-movement jump using the "traditional" integration

This "traditional" method works well for double integration over a short period of time (few seconds) such as single jumps (countermovement jump, squat jump).

However it does not produce satisfactory results for continuous jump (rebound jump) over a longer period of time. The reason is that small measurement and A/D errors add up sample by sample creating drift and fluctuations of the double integrations.

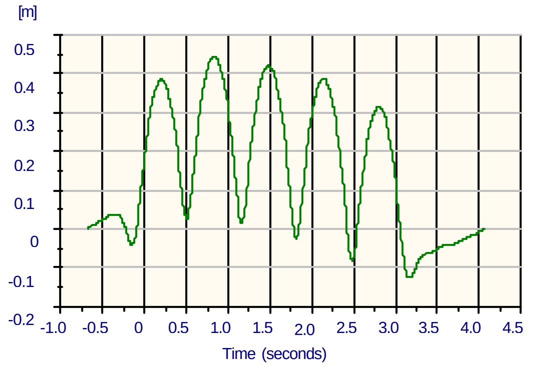

Figure 2 – Jump height s of the five jumps using the "traditional" integration method. The results obviously do not represent the reality.

This paper describes a new jump-to-jump method to determine velocity, jump height and related parameters even for long duration continuous jumping. The method is implemented with good results in the software of Quattro Jump, a force plate system for routine jump performance analysis.

Materials and Methods

Subjects

For all jump tests the same healthy male subject was used (age: 32; weight: 62 kg; height: 1.72m). The subject was well instructed and trained to perform the jumps correctly.

Experimental Setup and Procedure

Several different Kistler force plates (types: 9281CA, 9286AA and Quattro Jump) have been used which were all calibrated in a certified calibration laboratory less than 12 months ago. The data acquisition was performed through a 16 bit A/D board (Computerboards Inc., DAS1602/16) at 500Hz per channel into the Kistler

BioWare software. The continuous jumps were acquired (500Hz; 14bit) and analyzed with the Kistler Quattro Jump software.

Great care was taken that the subject stood still on the force plate at the beginning and at the end of the measurement.

Data Analysis

The integrations were performed within the BioWare and the Quattro Jump software using the Simpson's method (2).

The initial conditions for a0 and v0 were determined

1. in BioWare: automatically (using the "traditional" integration method).
2. in Quattro Jump:
   a) single jumps: automatically using the "traditional" integration method.
   b) continuous jump: using the described jump-to-jump algorithm.

Jump-to-Jump Integration of Continuous Jumps

Continuous jumps were integrated one by one, using the following assumptions to determine the initial conditions for a0 and v0 (see figure 5):

A. Velocity at mid-flight time is zero
   v(mid-flight) = 0.
B. Jump height at take-off is always the same value: an "anthropometric" constant ha (ankle height)
   s(take-off) = ha

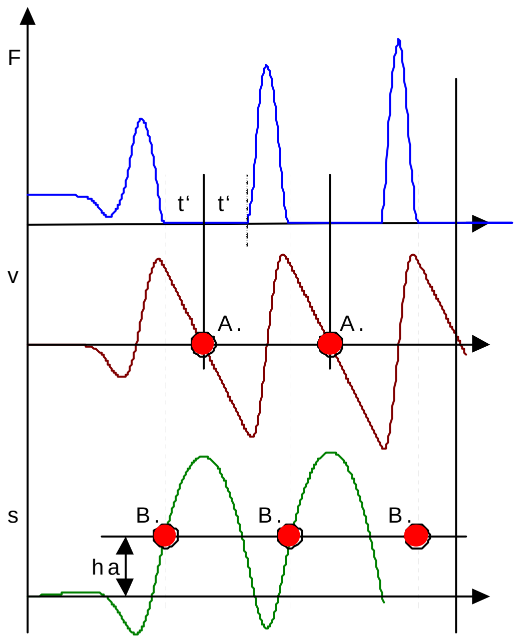

Figure 3 – Assumptions A. and B. used to determine initial conditions for jump-to-jump integration with continuous jumps

Jump-to-jump double integration

For the velocity v the following formula was used:

interval	mid-flight to mid-flight
acceleration	a(t) = F(t) / m
velocity	v(t) = ∫ (a(t) – a0) dt
	a0 = avg(a(t))

For the jump height s the following formula was used:

interval	take-off to take-off
jump height	s(t) = ∫ (v(t) - v0) dt + ha
	v0 = avg(v(t))

For the first and the last jump the algorithm was slightly modified because there is a standing-still condition before the first and sometimes after the last jump.

Ankle height ha

For reasons of simplicity the parameter ha was implemented as a function of body height.

Body Height	**ha (Ankle Height)**
< 1.60 m	0.09 m
1.60...< 1.70 m	0.10 m
1.70...<1.80 m	0.12 m
≥1.80 m	0.14 m

Table 1 – Parameter ha (ankle height) used as a function of body height.

Results

The results are demonstrated with 20 s continuous jumps:

- Figure 4 shows the jump height calculated with the "traditional" double integration method. The fluctuations due to the effects explained in the introduction are obvious.
- Figure 5 shows the jump height (all jumps overlaid) calculated with the described jump-to-jump method.

Validation

The described method was validated against a different method for jump height measurement with a rubber band goniometer attached to the belt buckle.

The rubber band systematically measured the average jump height 6,3% higher and the squat position 31,4% lower for the single jumps. Systematic differences were expected.

For the continuous jumps the results were very consistent, average 0,1% too high. A comparison of 33 jumps is shown in figure 6.

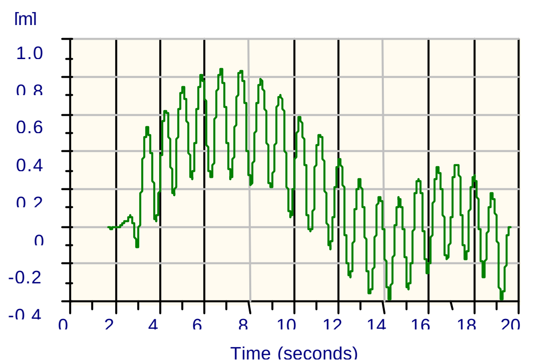

Figure 4 – Jump height s of 18 jumps using the "traditional" integration method. The calculated jump height fluctuates due to small errors in the measurement.

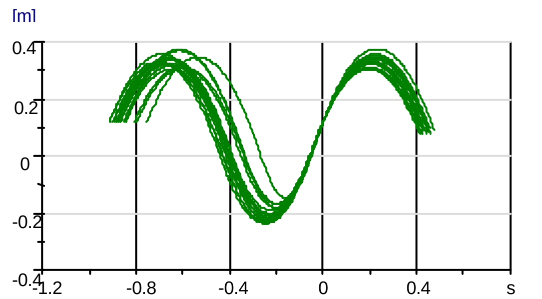

Figure 5 – Jump height s of 18 jumps using the described jump-to-jump method. At the instant of take-off (t=0) the jump height is always the same s(take-off) = ha

Discussion

The jump-to-jump method is a practical way to overcome the problems of "traditional" double integration over a series of continuous jumps. The method produces consistent velocity and jump height curves which connect smoothly from jump to jump (no discontinuities). It is based on easy to understand assumptions.

Nevertheless the jump-to-jump method is a compromise for the following reasons:

1. At mid flight time the velocity is not necessarily zero: A typical error occurs when the subject takes off with straight legs and lands with bent legs.
2. The jump height at takeoff (ha, ankle height) is not constant as assumed because:
   a) ha depends on the jump type
   b) ha has a jump-to-jump variability
   c) ha is has a inter- and intra-subject variability (jump type, fatigue, coordination, shoe size etc.)

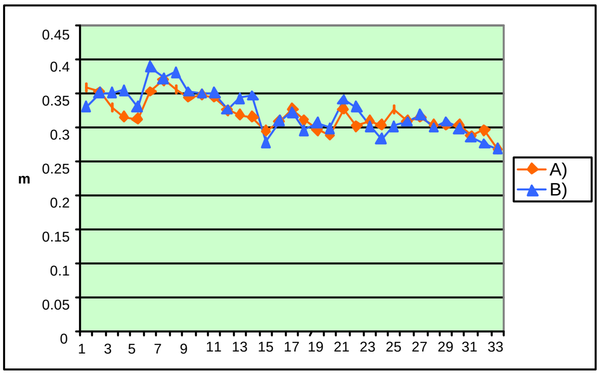

Figure 6 – Jump height s of 33 jumps A) measured with Quattro Jump using the proposed jump-to-jump integration and B) validated with a rubber band goniometer attached to the belt buckle.

To minimize the above described errors it is suggested that the method is used only for intra-subject comparison and only within the same jump type. The table for ha as a function of body height has to be verified and improved in an additional study.

With this limitation it still enables the analysis of fatigue parameters and gives a good insight into the concentric/eccentric phase.

References

1. Hatze H. Validity and Reliability of Methods for Testing Vertical Jump Performance. Journal of Applied Biomechanics 1998, 14, 127-140
2. Cheney, W. and Kincaid D. Numerical Mathematics and Computing (second edition). Brooks/Cole Publishing Co. Monterey California. ISBN 0-534-04356-9