FINDING A MINIMAL SET OF MARKERS FOR CENTER OF MASS ESTIMATION USING GRAVITATIONAL FALL

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INTRODUCTION

A recent article [1] demonstrates how the number of markers required to follow the trajectory of the center of mass (CoM) can be significantly reduced. The method is based on a model which requires training data in order to determine parameters of the model before its application. The training data consist of marker trajectories as well as (known) trajectory of the CoM. This paper presents an extension to the published method. The requirement of a known CoM trajectory in the training data is replaced by the requirement that the external forces acting on the body are known. One important such situation is gravitational (free) fall.

METHODS

The underlying model of the method is a system of point masses, with different masses and positions corresponding to markers attached to the moving body. The 3D trajectories of the markers are recorded with a motion capture system. The center of mass of the system of point masses is easily calculated as the weighted centroid of the different points

$$R = \frac{1}{M} \sum_{i=1}^{n} M_i r_i = \sum_i m_i r_i \qquad (1)$$

where we have introduced the normalized masses $m_i = M_i / M$. Applying the method is straight forward, once we have determined the normalized masses, and have measured the positions r_i of the points. The challenge lies in determining an appropriate distribution of mass, i.e. the m_i s. If the position of the CoM and those of the markers are known, we can use equation (1) to determine the mass distribution. The positions of the points and the CoM for a number of different frames of data gives a system of linear equations. Hence, we obtain the following quadratic optimization problem with the constraints that the solution is a distribution (of mass):

$$min \ \|Am - b\|^2$$
$$s.t \ m_i \geq 0, \ i = 1, \ldots, n \qquad (2)$$
$$\sum m_i = 1$$

where $m = (m_1, m_2, \ldots, m_n)$ is the vector of masses and A contains the positions of the n points at N distinct times. The vector b contains the corresponding position of the CoM. Further details can be found in [1].

To relax the requirement that the position of the CoM is known, consider gravitational fall with a known direction of the acceleration of gravity. From an unknown initial position and velocity of the CoM, we then know that the trajectory follows a parabolic curve. The idea of the proposed method extension is to include the unknown initial position and velocity into the optimization problem (2), and hence solve for these at the same time as solving for the mass distribution. Note that the trajectory of the CoM can be written $R(t) = R_0 + v_o t + 0.5 g t^2$, where the first two terms contains the unknowns. Hence, the criterion to minimize becomes

$$\|Am - R_o - v_o T_1 - 0.5 g T_2\|^2,$$

where the vector T_1 contains the time intervals from the initial time to that of each of the frames of data, and T_2 contains the same times, squared.

In a pilot study, a male gymnastics instructor performed jumps and somersaults on a trampoline. Motion capture data from 20 markers on the body were recorded at 150Hz using seven cameras (ProReflex, Qualisys AB, Gothenburg, Sweden). The duration of the flight phases were ca 1.2 s.

RESULTS AND DISCUSSION

Figure 1 shows good correspondence between the model output and the parabolic curve with estimated initial values.

Figure 1: Correspondence between model CoM and parabolic path of CoM in the sagittal plane for three jumps.
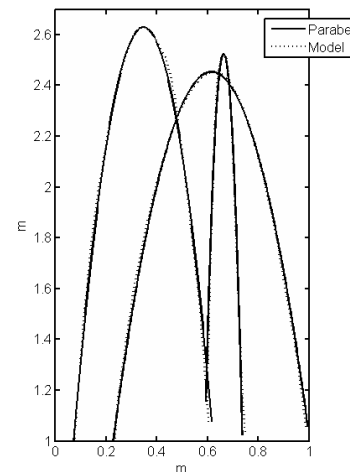
The method shows promising results in a pilot study. Further studies will include cross-validation, validation as in [2], and addressing the issues of how much movement of the body is necessary for model determination, and how well the model transfers to activities different from that of the training data.

REFERENCES

1. Forsell and Halvorsen. *J Biomech*. **42**(3): 361-5, 2009.
2. Rabuffetti and Baroni. *J Biomech*. **32**(3): 609-13, 1999.