KINEMATIC SIMULATION OF HANDBALL THROWING

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Abstract: Kinematic simulation of sport movements can be considered as an investigation tool for sport scientists. Nevertheless, kinematic simulation needs the specification of joint trajectories. Those trajectories can be modelled by control points and intermediate values can be computed with splines. So, a preliminary biomechanical analysis is required to model sport movements and especially to obtain the required control points. In addition to these control points, one has to define how the motion changes according to the situation, to consider these changes as inputs of the model. In handball throwing, one has to consider trajectories for all the joints and a set of operators that can adapt these control points to the situation: direction of the throw, ball speed, actions of opponents… The proposal of this study is to establish a model of handball throwing that could be adaptable to a maximum number of parameters, such as time of ball release, wrist position at ball release and throw type. The comparison of original joint trajectories obtained by motion capture with those obtained with such a model is encouraging. Moreover, the modification of an original movement produced trajectories that are closed to those obtained on real subjects placed in a similar situation. So, according to our results, this method looks promising to propose handball throwing simulations to sport scientists, even if only kinematics is considered.

Keywords: kinematic simulation, sport modelling, biomechanics, handball throwing

1. INTRODUCTION

Simulation is a good way to improve the technique of sport movements. Indeed computer simulation makes possible to validate (or not) investigations on human motion understanding. An hypothetical rule can be modelled in a computer module and tested in order to ensure that it produces coherent motions. Moreover, simulation gives the possibility to modify the movement in a larger way than real experiments do.

Several methods have been proposed in computer simulation in order to model human motion [Multon et al, 1999]. We can subdivide these methods in three main families. First, kinematic models consist in defining a mathematical expression to represent trajectories as a function of time [Zeltzer, 1982]. These models require to embed biomechanical knowledge on the studied motion, such as the phase duration [Bruderlin et al, 1996] or the trajectory of the ankle [Boulic et al, 1990] in human locomotion. Additional geometric constraints are added to ensure realistic adaptations to the skeleton of the subject and to the environment [Boulic et al, 1991].

Second, dynamics are used to ensure that the resulting motions verify the mechanical laws expressed in the Newton or Lagrangian formalism [Arnaldi et al, 1989]. The main problem of such a method is to design controllers to drive the motion equations. Several controllers are based on biomechanical knowledge on part of the motion. For example, maximum extensions and flexions angles of selected articulations (such as the knees and the hips) are used as objective functions to proportional derivative controllers [Hodgins, 1995]. Other controllers, such as constraint-based controllers [Multon et al, 1998] or those obtained through optimisation [van de Panne, 1994] are also tested. The main problems of these techniques still rely on the design of non-intuitive controller gains.

Third, motion capture and motion modification have been widely used by computing a new motion in the neighbourhood of the original one [Witkin and Popovic, 1995]. Additional constraints, such as spacetime constraints [Cohen ,1992; Gleicher and Litwinowicz, 1998] can also be added to make one part of the skeleton reach a target at a specific time. Another technique is to design coefficients with no

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dimension to abstract motion parameters and, then, to simulate new motions by scaling these coefficients [Li, 2002].

Our goal is to design a model that reacts as a real handball thrower does in a similar situation. Simulating a complete human skeleton with dynamics is quite impossible for such complex movements because of the controller gains design. Moreover, modifying a captured or an average motion generally produces realistic behaviours only in the closed neighbourhood of the original motion. As a large number of motion strategies can occur in handball throwing, this method seems difficult to apply.

Hence, we propose to carry-out a biomechanical experiment to identify control points that seem fundamentals for every captured throws. As a second step, a kinematic model is designed to enable computer simulation of handball throws while respecting the fundamentals identified in the biomechanical experiment.

2. DEFINITION OF THE MODEL

2.1. Representation of the model

We choose to model all the Cartesian trajectories of selected articulations involved in a human model composed of 30 degrees of freedom.

The human body is composed with rigid bodies connected with joints (either pivots or ball-and-socket joints).

We choose to model the Cartesian position of selected points: the root placed at the middle of the pelvis which trajectory is described according to a fixed Cartesian reference frame. The sternum and the two shoulders are designed relatively to the root, both two elbows and two wrists relatively to their respective shoulder, both two hips relatively to the root, both two knees and two ankles relatively to their respective hip and, finally, both two toes relatively to their respective ankle.

These trajectories expressed in the Cartesian reference frame instead of in the joint angular representation enable us to control parts of the skeleton. Indeed, motion parameters are generally specified in the Cartesian reference frame: position of the wrist at ball release, initial velocity vector of the ball, direction of the throw, height of the elbow… Modifying these trajectories is then more intuitive than tuning angles to release the ball at the required position and speed.

Moreover, we describe the motion of a member extremity (such as the wrist) relatively to its proximal origin (such as the shoulder) to make motion modification easier and more intuitive. For example, the modification of the wrist position at release is easier to modify relatively to its respective shoulder than relatively to the root, especially when intermediate articulations (such as the trunk flexion) also change. Each trajectory is also normalized according to the member or the kinematic sub-chain it belongs to. For example, the trajectory of the elbow in the shoulder reference frame is normalized according to the arm length. As a consequence, it enables to scale the motion to a new skeleton (with a different size).

2.2 Specificity of the elbows, knees and sternum

The aim of this model is to be adaptable to a large set of parameters. The modification of the wrist trajectory must induce a modification of the elbow trajectory (idem for the foot. For this reason, the elbows, the knees and the sternum trajectories are obtained by using analytical inverse kinematics with a constraint to be as closer as possible to the trajectory given by the model.

2.3. Mathematical modelling of the trajectories

We use cubic splines to approximate each trajectory [Watt and Watt, 1992]. The cubic splines are designed to fit the captured trajectories with an imposed maximum error. Hence, control points are added until the error between the resulting and the captured trajectory gone under this imposed threshold.

So to construct the splines, we need to specify the corresponding control points. In that case, the control points are represented by three parameters: the time, the joint coordinate on the concerned axe and finally, the derivative of this coordinate which gives the tangent of the curve at this specific time. To know these control points, we need to perform a dedicated biomechanical analysis of handball throwing that is done thanks to motion capture.

3. ANALYSIS OF HANDBALL THROWING

3.1. Experiment

Twelve male handball players took part of this study. These subjects play in the French Second League. The players completed informed consent, physical information and history on their handball practice.

Each subject, following warming up, threw at maximum velocity into a handball goal. They performed:

- 4 throws with the two feet on the ground with the last foot strike on the right foot,
- 4 throws with the two feet on the ground with the last foot strike on the left foot,

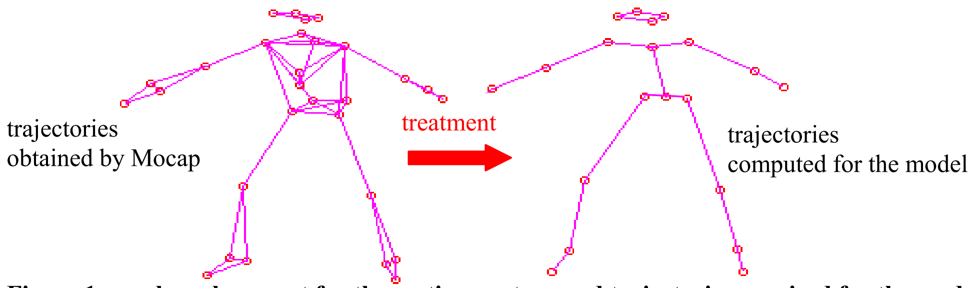

Figure 1: marker placement for the motion capture and trajectories required for the model.

- 4 jump in throws with the last foot strike on the right foot,
- 4 jump in throws with the last foot strike on the left foot.

For each throw, three-dimensional full body kinematic data are obtained at 60 Hz using an automatic opto-electronic motion capture system (Vicon, Oxford Metrics, England). Seven cameras are placed in a 9 m-radius circle with the centre being the throwing zone. Reflective, 20 mm diameter spherical markers are attached to each body segment as depicted in the left part of figure 1.

When occlusions occurred, the missing markers are calculated using the method developed by Ménardais et al [Ménardais et al, 2002]. The joint centres and the required trajectories are then computed using a method similar to that developed by Oxford Metrics in the Vicon software [Vicon, 2003].

The 60 Hz kinematic data are independently filtered using a Butterworth second order low-pass filter with a 10 Hz cut-off frequency.

3.2. Categories of movements for the two joint groups: "upper body" and "lower body"

The analysis described above allows us to specify the movement of each joint. We have detected that the joints can be subdivided into two groups: the "upper body" and the "lower body". The "upper body" is made up of the sternum, the elbow of the throwing arm, both shoulders and the wrist of the throwing arm. The "lower body" is composed of the remainder of the joints.

With the knowledge of handball game, for each joint group, it is also possible to distinguish different main categories of movements. For the "lower body", we consider if a jump occurs or not. For a jump, we also distinguish the motions for which the left or the right foot is used to jump. On the other hand, when the two feet are in contact with the ground, we distinguish if either the right or the left foot is in front of the body. Hence, four different main categories are identified.

For the "upper body", four different main throws are also identified. The criterion used to differentiate the categories is the position of the wrist relatively to the shoulder at ball release. These throws are the "external throw", the "internal throw", the "middle throw" and the "middle and high throw" as depicted in figure 2.

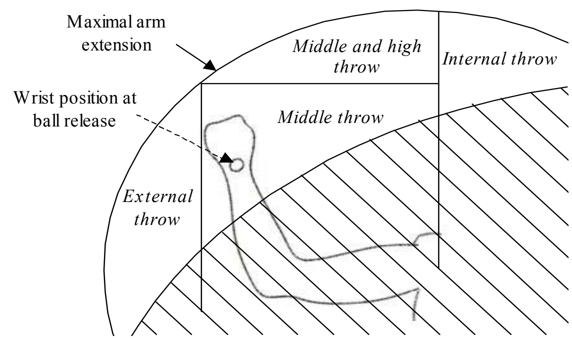

Figure 2: definition of the category of throws for the "upper body"

3.3. Time-decomposition of the throws

The whole throwing motion is subdivided into successive phases according to time events. For the "lower body", two phases are considered:

- the "previous phase" begins at the last foot strike but one and finishes at the beginning of the last step.
- the "last phase" represents the last step or the aerial phase in case of throw with jump. This phase finishes with the foot strike.

For the "upper body", three phases are considered:

- the "arm cocking phase" starts with the increasing of distance between each wrist and ends when the shoulder begins its forward movement.
- the "phase of the throw" ends at ball release.
- the "phase of deceleration" corresponds to the end of the motion.

Each phase is normalized by its duration in order to allow future adjustments imposed by a user, as an input of the simulation system. These phases are defined to have lots of possible movements. It is then possible to adjust a special movement only during one phase as the "arm cocking phase" without modify the other phases. In addition to the previous advantages, subdividing the movement into successive phases enables us to easily consider all the possible modifications locally to each phase.

4.MODELLING OF HANDBALL THROWING

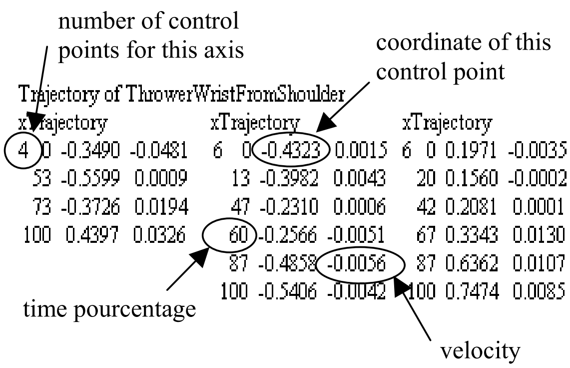

Figure 3 : Example of control points calculated for the wrist during the "throw phase" of the "middle and high" throw.

For each phase, each group of joint and each category of movements, we have made biomechanical analysis on the movements performed by our subjects. We have computed control points for these throws for all the trajectories considered for our model.

Wrist	Middle	Middle and high	External	Internal
X axis	4	4	4	4
Y axis	6	6	6	6
Z axis	6	6	6	6

Table 1: Number of control points for the wrist trajectory relatively to the shoulder during the "throw phase" for different categories of throws.

As in the biomechanical literature [Feltner and Dapena, 1986], each joint trajectory follows a similar shape, even if each thrower has a personified movement. So it is yet possible to define common control points between the throwers. Consequently, we define an average trajectory that is a compromise of all the players' styles. This average motion is also represented by the control points that are identified in all the measurements. Figure 3 gives the wrist control points for the throw phase of the "middle and high" throw. The number of control points required to specify the wrist trajectory during the "throw phase" are noted in table 1.

5. MOTION MODIFICATION

5.1. Trajectory modification

According to all the measurements, for each trajectory, a set of operators is identified. These operators are designed to enable the user to change high-level parameters, such as the position of the wrist at ball release and to calculate the corresponding modifications to apply to the control points.

Let us consider now the example of a change in the wrist position at ball release. For each category of throw, we have studied how the wrist trajectory varies according to the wrist position at ball release. Table 2 gives the changes of all the control points of the wrist trajectory depending on the final wrist position at ball release.

To this end, we modify the control points with the same method described for the wrist. So we analyse how the control points of this angular trajectory change according to the final orientation of the trunk.

As our model is based on the Cartesian trajectory of each point relatively to a father articulation, a two-steps process is proposed. First, all the Cartesian adaptations are performed to compute the new motion without taking the lateral flexion of the trunk into account. Next, the lateral flexion is applied to the trunk.

5.2. Time modification

As specified above, each phase of the throw is considered separately with its own duration. This duration is normalised by the total duration of the whole motion. However, as the "upper body" and

X axis	Y axis	Z axis
$X_{1f} = X_{1i}$	$Y_{1f} = Y_{1i}$	$Z_{1f} = Z_{1i}$
$X_{2f} = X_{2i} + 1/3*\Delta X$	$Y_{2f} = Y_{2f} + ¼*\Delta Y$	$Z_{2f} = Z_{2i} + ¼*\Delta Z$
$X_{3f} = X_{3i} + 2/3*\Delta X$	$Y_{3f} = Y_{3f} + ½*\Delta Y$	$Z_{3f} = Z_{3i} + ½*\Delta Z$
$X_{4f} = X_{4i} + \Delta X$	$Y_{4f} = Y_{4f} + ¾*\Delta Y$	$Z_{4f} = Z_{4i} + ¾*\Delta Z$
	$Y_{5f} = Y_{5f} + \Delta Y$	$Z_{5f} = Z_{5i} + \Delta Z$
	$Y_{6f} = Y_{6f} + \Delta Y$	$Z_{6f} = Z_{6i} + \Delta Z$

Table 2: Modification of the control points linked to the wrist trajectory where (Xji, Yji, Zji) are the jth control point of the initial average trajectory, (Xjf, Yjf, Zjf) are the jth control point at ball release and (ΔX, ΔY, ΔZ) are the vector coordinates that linked the desired wrist position at ball release and the original one.

the “lower body” are dissociated, the specified duration for each throw is supposed to respect the synchronisation of the two parts. The analysis of the throw gives the mean duration of each phase and the synchronisation between them. Nevertheless, it is possible for the user to change these parameters.

The initial positions of a phase are set by the modified final positions. So, we are sure to have a continuous movement even if we modify a parameter during a phase.

6. RESULTS-DISCUSSION

6.1. Validity of the model

The model is embedded in a visualisation platform in which a user can specify high-level parameters through an interface dedicated to the handball application. This application enables us to visualise resulting motions given by the model.

This model needs to be validated in order to be used by sport scientists and coaches to test and improve knowledge on handball throwing. First, we compare the trajectories obtained by motion capture with the trajectories calculated by our model in similar situations. Figure 4 depicts that the modelled trajectories are very close to those obtained with motion capture.

The mathematical functions obtained by the movement analysis give positive results. The trajectories modified thanks to these mathematical functions on the control points are closed to theses measured by motion capture (see figure 4).

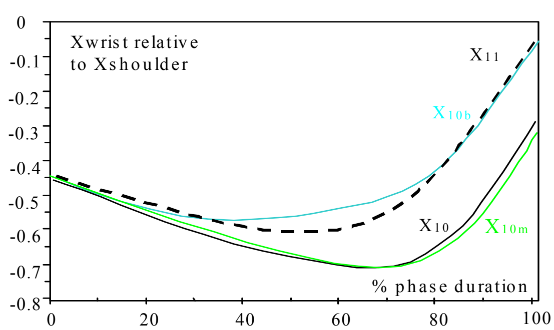

Figure 4 : Wrist X coordinate for trial 11 (X_{11}), trial 10 (X_{10}) obtained by motion capture, modelled trajectory of trial 10 (X_{10m}) and deformed trajectory of trial 10 (X_{10b}).

6.2. Perspectives

The modification of a trajectory with a kinematic method can give unrealistic results even if the use of inverse kinematics decreases this kind of possible errors. Indeed, the joint limits are not taken into account. The specification of forbidden areas for each joint can restrain these errors.

A limit of our model is due to the absence of the hand in our model. We know that the hand movement cannot be neglected but the understanding of the hand movements requires a specific study that has not been made yet. Taking the ball trajectory at release into account would be another interesting extent of our model.

To conclude, this model could be used in a lot of applications including computer animation and sport science. For instance, this model is used in a virtual reality application which aim is to identify the parameters considered by the goalkeeper to react. Thanks to this model we are able to modify one parameter and to evaluate its influence on the goalkeeper’s reaction [Bideau et al, 2003]. Moreover, it can validate our model if the simulated movements engender realistic goalkeeper’s reactions.

Our model is also used in the design of a new motion capture system. In this system, a model-based interpolation is used to retrieve missing or hidden markers.

This kind of association between simulation and analysis seems to be a promising tool to improve knowledge on human movement that is generally complex to analyse in real situations.

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