KINEMATIC MODELISATION OF JOINT DISPLACEMENT: VALIDATION IN HUMAN POINTING TASKS

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ABSTRACT

The aim of this study was to characterize a human pointing task and to validate a sigmoid model for the joint displacement in this movement. Nine subjects pointed three times ten targets located in their upper limb workspace. These targets were distributed in ipsilatéral, contralateral, proximal and distal spaces. Kinematic data showed that ipsilateral task is shorter. Finger peak velocity is higher and earlier than in contralateral task. Moreover, its trajectory curvature is greater in ipsilateral movements. Concerning joint displacement sigmoid model, predictive displacements are similar with experimental results. The model reliability is correlated with joint amplitude.

INTRODUCTION

Procedural animation in robotic and video games is actually an industrial challenge aimed to reduce the pre-production charges. For this purpose, heuristic models of joint displacements have to be performed aimed to deduce behavioral general laws while various movement generations, like pointing, grasping or dynamic tasks.

Joint displacement results from activation of synergistic actuators, i.e. agonist and antagonist muscles. Motor control of a mono-articular movement has to take into account two constraints (Van Ingen Schenau 1989), so-called anatomical and geometrical ones. During dynamic motion of an articulation, it is necessary to attain a zero velocity of the joint when its maximal amplitude is reached, in order to preserve its physical integrity (anatomical constraint). Moreover, in most cases, the purpose is to transfer the angular velocity of the joints into linear velocity of the distal extremity of the articular chain (geometrical constraint).

Therefore, joint displacement could be modeled under a sigmoid shape controlled by 7 adjusting variables, i.e. 3 temporal parameters (t_i, t_0, t_f), 3 spatial variables (θ_i, θ_0, θ_f) and the sigmoid slope corresponding to velocity peak (K) (Figure 1).

Thus, the main purpose of this study was to validate such a joint displacement model in human pointing tasks and to characterize these movements.

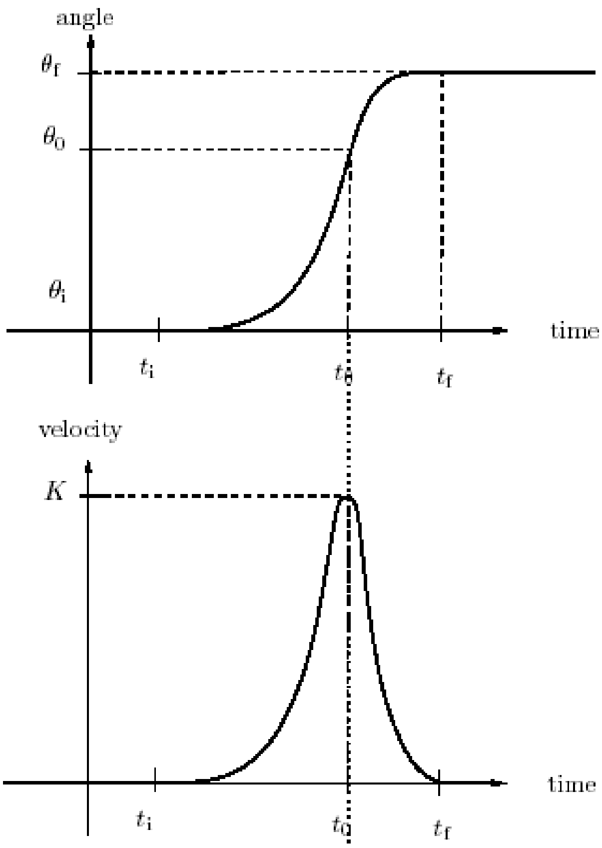


Figure 1: Joint kinematic's model and adjusting variables.

MATERIALS AND METHODS

Nine men right-handed pointed three times ten targets located in their upper limb workspace. Referring to the shoulder, targets were located along five axis (30°, 60°, 90°, 120°, 150°) and distributed between proximal and distal spaces (Figures 2). The position of the finger at the start of the movement was fixed at 40cm of the shoulder along the 90° axis.

The kinematic parameters of the movement were calculated in order to characterize the pointing task.

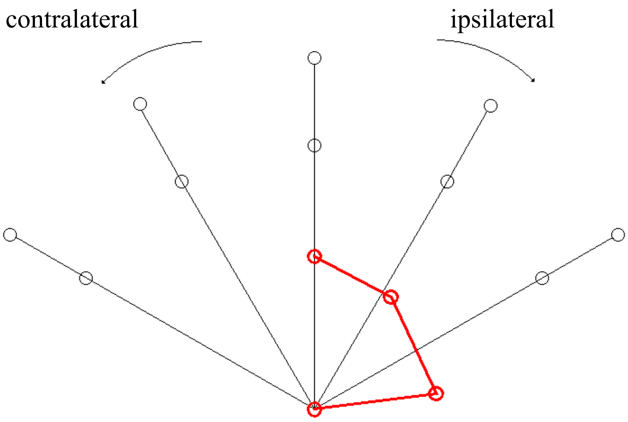


Figure 2: Schematic representation of targets' localizations and upper limb initial position.

Mathematical expression of sigmoid

We try to determine a function $\theta \in$ from [0, T] to $\mathbb{R}$ of class C^2. Let t_i, t_0, t_f be 3 times such that

$$0 \leq t_i < t_0 < t_f \leq T.$$

We assume that function θ satisfies:

- $\theta = \theta_i$ on $[0, t_i]$,
- $\theta = \theta_f$ on $[t_f, T]$,
- It exists a number $\varepsilon \in \{-1,1\}$, such that $\varepsilon\theta$ is strictly increasing on $[t_i, t_f]$ with

$\varepsilon = Sign\ (\theta_f - \theta_i)$

- $\varepsilon\theta$ is strictly convex on $[t_i, t_0]$;
- $\varepsilon\theta$ is strictly concave on $[t_0, t_f]$.

Let K be a number defined by

$$K = \begin{cases} \max\limits_{t \in [t_i, t_f]} \theta'(t) & si\ \epsilon = 1, \\ \min\limits_{t \in [t_i, t_f]} \theta'(t) & si\ \epsilon = -1. \end{cases}$$

Some works are relative to expression of sigmoid (Drakopoulos 1995; Menon *et al*. 1996; Plamondon, 1995a 1995b 1998; Plamondon *et al*. 2003; Singh and Chandra 2003; Yun and Kim 2003) but these results can not used here.

We consider *α*, *β* et *k* defined by

$$\alpha = \frac{t_0 - t_i}{t_f - t_i},$$

$$\beta = \frac{\theta_0 - \theta_i}{\theta_f - \theta_i},$$

$$k = K\frac{t_f - t_i}{\theta_f - \theta_i}.$$

For all $a, b > 0$ et $\kappa > 2$, we define the function $H^{(a,b,\kappa)}$ over [0, *α*] by

$$H^{(a,b,\kappa)}(u) = a\left(1 - e^{-bu^{\kappa}}\right).$$

We set

$$r_0 = \frac{1}{e^{1/2} - 1} \approx 1{,}54.$$

The numbers a, b and κ are given by the following method: we set

$$\gamma = \frac{\beta}{k\alpha} \in \left]0, e^{\frac{1}{2}} - 1\right[.$$

There exists a unique $X \in \left]\frac{1}{2}, 1\right[$ such that

$$\left(e^X - 1\right)\frac{1 - X}{X} = \gamma,$$

and a, b and κ are given by

$$\kappa = \frac{1}{1 - X},$$

$$a = \frac{\beta}{1 - e^{-X}},$$

$$b = \frac{X}{\alpha^{\kappa}}.$$

For what follows, we set

$$(a, b, \kappa) = \mathcal{G}(\alpha, \beta, k).$$

We consider the vector A $= \left(t_i, t_0, t_f, \theta_i, \theta_0, \theta_f, K\right) \in \mathbb{R}^7$; we can define σ_A by the following method:

We assume

$$k \in \left]r_0\ max\left(\frac{\beta}{\alpha}, \frac{1-\beta}{1-\alpha}\right), +\infty\right[.$$

And we set for all $u \in [0, 1]$

$$g(u) = \begin{cases} H^{(\mathcal{G}(\alpha,\beta,k))}(u), & if\ u \leq \alpha, \\ 1 - H^{(\mathcal{G}(1-\alpha, 1-\beta, k))}(1-u), & if\ u > \alpha. \end{cases}$$

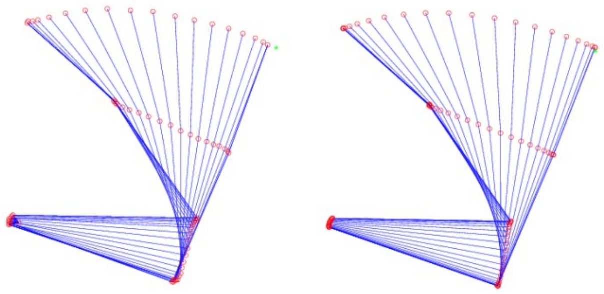
Finally, we consider the function σ_A defined by for all $t \in [0, T]$

$$\sigma_A(t) = \begin{cases} \theta_i, & if\ t \leq t_i, \\ (\theta_f - \theta_i)g\dfrac{t - t_i}{t_f - t_i} + \theta_i, & if\ t_i < t < t_f, \\ \theta_f, & if\ t \geq t_f. \end{cases}$$

RESULTS

Experimental results showed that coordinations in pointing tasks depended on target localization, i.*e*. contralateral *vs* ipsilateral spaces. So, elbow and wrist contributions were predominant for ipsilateral targets whereas shoulder's displacement was greater for contralateral ones. Angular joints' velocities presented higher mean and maximal values when targets were ipsilateral and distal. Concerning hand-path curvature, it depends on target distance and decreased with the distance between finger initial position and target localization.

When comparing the sigmoid model predictions and experimental upper limb joints' trajectories, the mean deviations along the 270 trials were 7.1 ± 4 mm, 9 ± 5 mm and 10.8 ± 7 mm for the shoulder, the elbow and the wrist respectively. These differences are slight in comparison with the upper limb length (80 ± 1,7cm). Moreover, as shown in figure 3, wired schematic representations of the pointing task for experimental and predicted movements are similar.



Figures 3: Wired schematic representation of upper limb displacement for experimental movement (on left) and model movement (on right).

CONCLUSION

Experimental data are in agreement with those of the literature (Tseng and Scholz 2003) and allowed to consider the general sigmoid model of joint displacement as valid for slow movements like pointing tasks. The interest of such a model is to formalize any articular movement and deducing, without degradation of the signal induced by its own noise, the joint velocity and acceleration curves.

Moreover, regarding to video games context, the sigmoid model seemed to be a valid tool in regard to procedural animation constraints.

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