# Identifying knee prosthesis characteristics during swing phase through optimization

Charles Pontonnier, Coralie Villa, Joseph Bascou

# IDENTIFYING KNEE PROSTHESIS CHARACTERISTICS DURING SWING PHASE THROUGH OPTIMIZATION

**Charles Pontonnier (1,2,3), Coralie Villa (4), Joseph Bascou (4)**

*1. ENS Rennes, France; 2. Ecoles de Saint-Cyr Coëtquidan, France ; 3. IRISA/INRIA MimeTIC, France; 4. CERAH, France*

## Introduction

During gait, the swing phase is critical for above knee amputee people, as they cannot control their prosthetic shank and foot movement. The prosthetic knee kinematic and kinetic behavior are linked to its settings for swing phase such as stiffness and damping and its inertial characteristics [1], which can be optimized for a given gait velocity. This study presents a method to identify these settings and characteristics during swing phase using motion capture.

## Methods

**Model:** A passive knee prosthesis during swing phase was modeled as follows:

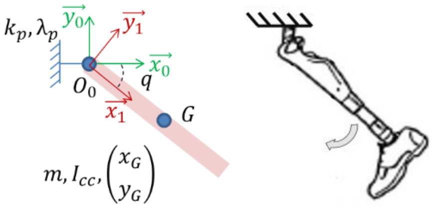

*Figure 1: Planar shank equipped with a passive knee prosthesis and its model.*

where $m$ was the shank and foot mass, $I_{cc}$ their moment of inertia and $(x_G, y_G)$ their center of mass position. The knee joint was modeled using two mechanical characteristics that can be tuned on the prosthesis: the stiffness $k_p$ and the damping $\lambda_p$.

The dynamics of such a system can be defined as:

$$\ddot{q} = f\left(q, \dot{q}, k_p, \lambda_p, m, I_{cc}, \begin{pmatrix} x_G \\ y_G \end{pmatrix}\right) \quad (1)$$

with $q, \dot{q}, \dot{q}$ the joint angle velocity and acceleration.

**Experimental data**: Two configurations of knee stiffness $k_p$ ($k_p$ for setting 1 < $k_p$ for setting 2) of the same knee / foot prosthesis were tested. The {shank+foot} inertia $I_{cc_{tr}}$ was estimated using a trifilar pendulum method [2]. Three motion trials were recorded for each configuration with an optoelectronic system (Vicon V8i, Oxford Metrics).

Each trial consisted in fixing the femoral part of the prosthesis, placing the shank part in a flexed position ($q \cong 90°$), and letting it freely extend ($q \cong 0°$) in a vertical plane, recording its movement($q_{exp}$) .

| Model | $m\ (kg)$ | $I_{cc_{tr}}(kg.m^2)$ | $(x_G\ y_G)(m)$ |
|---|---|---|---|
| {Shank+Foot} | 1.573 | 0.21 | [0.25 -0.02] |

*Table 1: {Shank+Foot} estimated characteristics.*

**Identification:** the knee $k_{p_{opt}}$ and $I_{cc_{opt}}$ characteristics were computed using the experimental data and the model, solving the following optimization problem using SQP algorithm [3]:

$$\min J = \sum_{i=1}^{n} (q_{exp}(t_i) - q(t_i))^2, k_p \text{ and } I_{cc} > 0 \quad (2)$$

where $k_{p_{opt}}$, $I_{cc_{opt}}$ are the stiffness and inertia values that make experimental and simulation data fit best, $n$ the number of frames of the capture, $q$ the angle obtained integrating equation (1) using a 4th order Runge-Kutta method and $q_{exp}$ the experimental angle.

### Results

Experimental and simulation results showed good agreement (Figure 2) and the knee characteristics could be obtained (Table 2).

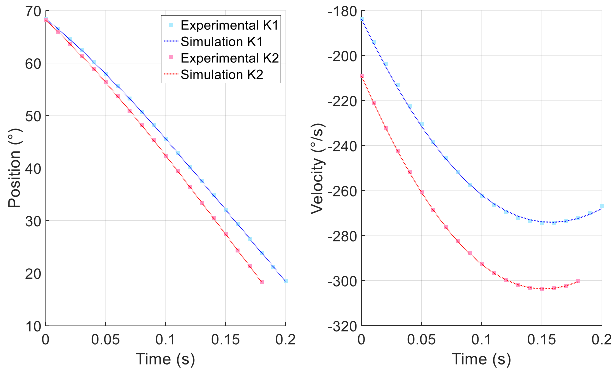


*Figure 2: Experimental and simulation knee kinematics (angular position and velocity) for both stiffness settings.*

| Characteristics | Setting 1 | Setting 2 |
|---|---|---|
| $k_{p_{opt}}$ (N.m/rad) | 5.84±0.51 | 7.47±0.82 |
| $I_{cc_{opt}}$ (kg.m²) | 0.20±0.01 | 0.23±0.02 |

*Table 2: Stiffness and inertia identification for both stiffness settings.*

## Discussion

The method properly estimated $I_{cc}$ for both conditions and logically estimated a higher $k_p$ for setting 2 than for setting 1. Future studies will aim at identifying more parameters through optimization, potentially allowing improvement in prosthetic fitting.

## References

1. Bonnet et al. CMBBE 12 S1:59-60, 2009
2. Harris and Crede, Shock And Vibration Handbook, BSG BOOKS, 1961
3. Boggs, et al, Acta numerica 4:1-51, 1995