A new method for internal-external rotation measurement in a prosthetic knee

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In this work, a magnetic measurement system was designed and tested to estimate the Internal-External rotation between the Tibial and Femural parts of a knee prosthesis. To obtain this, the sensors were inserted in polyethylene part while a permanent magnet was placed below the Tibial plate. The configuration was designed to keep the intrinsic unbiassness to the positive and negative internal-external angles. A linear regression model was used to map magnetic measurements of the sensors to the angles. For validation the prosthesis was placed in a mechanical simulator equipped with reflective markers tracked by optical motion capture system.

Keywords-knee prosthesis, knee internal external rotations

1. INTRODUCTION

There are a few studies on instrumented knee prostheses in the world, and most of these prostheses have been designed for measuring forces and moments applied on the prosthesis [1], [2], [3]. Those systems were implanted on a few subjects for measurements of joint loading in level walking and stair climbing [4], studying the components of joint contact forces during different activities and exercises [5], [6]. More recently, *in-vivo* force measurements in knee prosthesis was designed [7], in which the sensors and electronic components were positioned inside the polyethylene part of the implant offering this way no change in metallic components.

Although these works provided important outcomes for actual measurement of forces and moments, none of them were designed for *in-vivo* kinematic measurements. Indeed, implanted movement sensors can provide the actual kinematics of a prosthetic joint, and avoid the drawbacks of skin-mounted markers or sensors suffering from soft tissue artifact (STA) [8], [9], [10]. For example, the RMS error of the Stereophotogrammetry motion capture (MoCap) due to the STA, based on measurements on several subjects were reported in stance phase of walking between 2 to 5.3 degree for internal external (IE) rotations [10].

Recently we introduced a new concept of instrumented knee prosthesis to measure force and STA-free kinematics [11], however the kinematics was limited to abduction adduction (AA) and flexion extension (FE) rotations [11]. Considering the importance of the IE rotations in evaluation of the mobile-bearing prosthetic knee function, in the current work we focused on the design of a separate sensory system for measuring this rotation.

2. METHOD AND MATERIALS

Sensor Configuration and Angle Estimation Model

The F.I.R.S.T knee prosthesis (Symbios Orthopédie SA, Switzerland) was used, which has three main parts namely Femural part (FP), Tibial part (TP), and a Polyethylene insert (PE) [11]. Based on the conforming interface of FP and PE, we assumed that the IE rotation between FP and TP can be considered as the IE rotation between PE and TP. A magnet was placed below the TP (Fig. 1). This placement converts the IE rotations to the rotations of the magnet around a center of rotation. The magnet rotation causes the variation of magnetic flux, in two biaxial AMR sensors (HMC1512, Honeywell, USA) placed symmetrically to the axis of the magnet in PE and results in resistance change of the AMRs. Considering the signals of each biaxial AMR (i.e. sensor 1: A_1, B_1 and sensor 2: A_2, B_2), a linear regression model of measurements (1) was used to estimate IE rotations ($\hat{\theta}$).

$$\hat{\theta} = \alpha_0 + \alpha_1 A_1 + \alpha_2 B_1 + \alpha_3 A_2 + \alpha_4 B_2 \qquad (1)$$

Where α_i are the coefficients of the linear model were estimated by minimizing sum of squared differences between estimated angle and reference angle measured by a reference system.

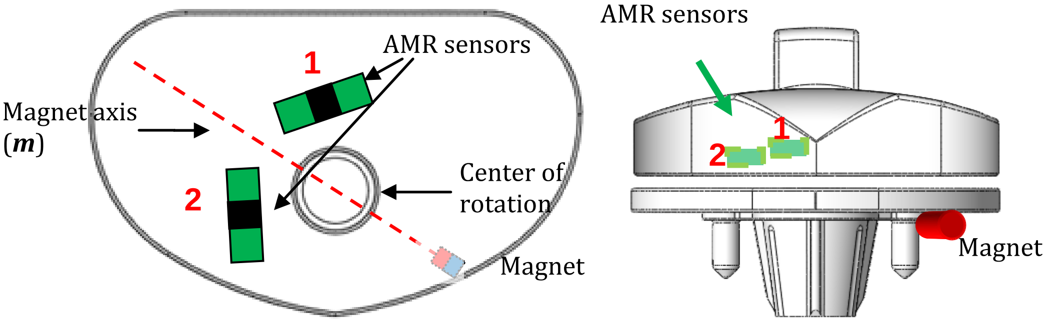

Figure 1. The configuration of sensors and magnet, left a PE cut, right a frontal-verical cut.

Reference System and Validation

The actual IE angle was estimated by the reference motion capture system (MoCap) consisting of five cameras (Vicon, UK) and reflective markers fixed on a mechanical knee simulator which holds all parts of prosthesis, and is capable to rotate the prosthesis in 3D. To validate the system, we performed both static and dynamic measurements of IE rotations while the AMR sensors and the reference MoCap were synchronized. The static measurements included the measurements in 42 different angles, while in dynamic measurements, eight IE rotations were performed in range of [-11.3^0 9.7^0]. The *Mean* and *Standard Deviation (STD)* of the difference (error) between the actual angle (MoCap) and the estimated angle (AMR) were considered to estimate the accuracy and precision of the IE estimation.

3. RESULTS

An example of estimated angle in dynamic measurement versus the reference measured angle is depicted in Fig. 2. The IE angle estimations' errors for static and dynamic data are illustrated in table 1. An RMS error of less than 0.4^o was obtained in both static and dynamics conditions.

4. DISCUSSION AND CONCLUSION

This work showed how the low cost AMR sensors can be used to measure the Internal External rotation in prosthetic knee, while avoiding soft tissue artifact. The proposed configuration, consisting of two sensors and one permanent magnet, provided an unbiased highly accurate and precise estimation of IE angles. The results

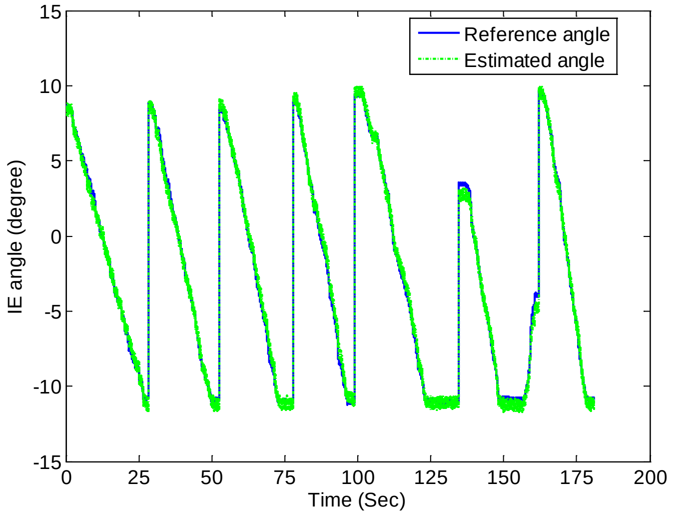

Figure 2. Estimated angle versus reference angle (dynamic measurements).

Table 1. Accuracy (Mean error) and precision (STD error) and RMS error of IE estimation

Movement Type	**Accuracy and Precision of estimation**		
	Mean error	***STD error***	***RMS error***
Static	0.00°	0.40°	0.40°
Dynamic	0.00°	0.37°	0.37°

depicted in the table 1 also postulate that the quality of estimation will not change because of the dynamicity of the movement. The linear regression model, which only used the crude measurements of channels of the sensors as its inputs, did not face any over-fitting thanks to its simple model.

In next step, the measurement systems for AA and FE rotations need to be combined with the proposed measurement system for IE rotations to provide 3D rotation measurement of the prosthetic knee.

5. ACKNOWLEDGMENT

The authors gratefully acknowledge the nano-Tera for funding the project (SNF20NAN1_123630). The authors also acknowledge P. Morel for his help on design of the mechanical simulator and Symbios Orthopdédie SA for providing the prosthesis.

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