Orthopaedic Implants

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SMART KNEE PROSTHESIS FOR ORTHOPEDIC SURGERY: THE IMPLANTABLE AND WEARABLE MEASUREMENT SYSTEM

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Introduction and Objectives: Recent advances in remote powering and telemetry permitted the use of sensors inside body. A few studies have been already done on smart knee prostheses, but all focused on monitoring the in-vivo contact forces and moments [1-4]. A smart design, compatible with mechanical structure of commercially-available knee prostheses, that provides force and accurate 3D kinematics feedback was suggested with all electronics housed in the polyethylene insert (PE) [6]. The current work addresses the designed kinematics and force measurement system of that smart implant and its validation in a robotic knee simulator.

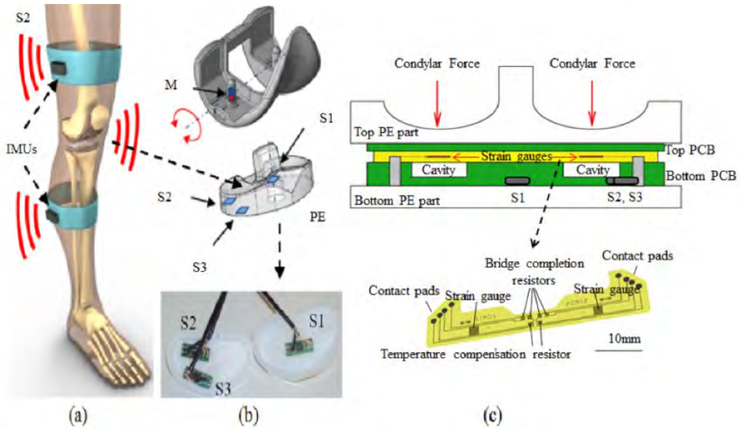
Methods: *Kinematics measurement*- Two inertial measurement units (IMUs), each consists of a 3D accelerometer and 3D gyroscope, were considered to be fixed on stretch belts and placed around the thigh and shank (Fig.a). Three anisotropic magnetoresistive (AMR) sensors (S1, S2, S3) were configured in PE, based on a sensitivity analysis. A magnet (M) was capsulated in the prosthesis femoral part to convert its movement to changes of magnetic field (Fig. b). Three angle estimators were deigned. First, a linear regression using only the implantable AMR sensors. Second estimator solely used IMUs' measurements using the strapdown integration of angular velocities [6] combined by a linear model for drift removal. Third estimator was based on a fusion of IMUs and low-frequency (10Hz) sampled AMRs in order to reduce power consumption of the implanted part. This estimator used strapdown integration of the angular velocities with a locally linear model, using the difference estimate (IMU-AMR) for drift removal.

Force measurement-Two biocompatible force sensing gauges fabricated and configured in the medial and lateral sides of PE, above two devised cavities in a sealed capsule (Fig.c). The sensors measure the forces applied on each condyle through the stretch of the layer on top of cavities. The sensors are placed into separate Wheatstone bridges where all elements were structured into the sensors for temperature compensation. The capsule was glued in between PE sections, and cured for 16 hours at 45ºC under the pressure. A linear model for each sensor was used for calibration.

Knee simulator- A robotic knee simulator was used to validate the force and kinematics measurements. It held the smart knee prosthesis with embedded sensors. The IMUs were attached to the simulator segments to provide wearable measurements. Data collected from subjects during treadmill walking using X-ray fluoroscopy, optical motion capture systems and an implanted instrumented prosthesis [7-8] were used to replicate 4 gait patterns in the simulator. A motion capture system (Vicon, UK) and reflective markers attached to the simulator segments, was used as the kinematic reference. A force sensor (ATI, USA) was integrated below the prosthesis tibial part in the robotic knee as the force reference.

Results: The obtained performances of AMR-based, IMU-based and IMU-AMR based flexion angle estimators over four gait patterns are shown in Table. IMU-based estimates were not very precise, but the use of AMR sensors either alone or in the fusion framework drastically improved the results, RMS error<1.2º. The raw measurements of the force sensors showed high corelation with the reference total forces, R^2>0.98. The obtained RMS errors for lateral and medial sensors on train data were 20.0N and 5.9N respectively

Figure:



Caption: (a) Wearable IMUs, (b) implanted AMR sensors (S1-3), (c) the capsule with designed strain gauges

Conclusion: Using implanted (AMR sensors and biocompatible embedded strain gauges) and wearable technology (IMU) a mixed measurement system was proposed able to estimate simultaneously the kinematics and force with a smart knee implant. Angle and force estimators were evaluated with realistic walking patterns replicated in a robotic knee simulator. The best kinematics estimation was obtained from fusion of IMUs and AMR sensors which is also optimum for reducing power consumption. The force sensors behaved linearly in fixed flexion angles, with no measurement drift. They can estimate the M-shape pattern of total force during gait, but showed different sensitivities to the applied forces in different angles. Fusion of estimated angles and force can enhance the force estimations.

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Table:

Estimators	E(error)	SD(error)	RMS(error)	R^2
AMR	0.46±0.09	1.09±0.30	1.19±0.28	0.99+0.00
IMU	1.65±1.45	1.70±1.11	2.43±1.70	0.97±0.03
IMU-AMR	0.47±0.10	1.08±0.25	1.18±0.25	0.99±0.00

Caption: Performance of different angle estimators

References: [1] Damm et al., *Clin. Biomech.*28(5), 2013.

[2] D'Lima et al., *J. Arthrop*. 21(2), 2006.

[3] Heinlein et al., *J. Biomech.* 40, 2007.

[4] Kirking et al., *J. Biomech.* 39(9), 2006.

[5] Arami et al, IEEE Trans Auto Scie Eng. 10(3), 2013.

[6] Favre et al., *J. Biomech.* 42(14), 2009.

[7] Barré et al., *IEEE Trans. Biomed. Eng.* 60(11), 2013.

[8] Fregly et al., *J. Orthop. Res.* 30(4), 2012.

Disclosure of Interest: None Declared