Control of prosthetic arm rotation by sensing rotation of residual arm bone

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INTRODUCTION

Internal and external rotations of the arm are very useful for upper limb amputees [1, 2]. In this study, we have proposed a new approach for improving the rotational control of artificial limbs. This approach involves inserting a permanent magnet into the distal end of the residual bone of subjects with upper limb amputations (Figure 1). When the subjects rotate their residual bone relative to the surface of their arm, a corresponding change in the magnetic field distribution can be detected by magnetic sensors fixed within the prosthetic socket. Information on residual bone rotation is therefore derived and used as an input signal to control a powered rotator. **An advantage of this approach is the preservation of inherent proprioceptive awareness of arm rotation. Rotation of the residual bone can be sensed through the intact neural pathways and the angle of the prosthetic rotator will be matched to the angle of the bone.** This control approach should be easier and more intuitive than traditional electromyogram (EMG) [3] or EMG pattern recognition control methods [4], which rely heavily on visual feedback for the amputees to know how their arm is positioned.

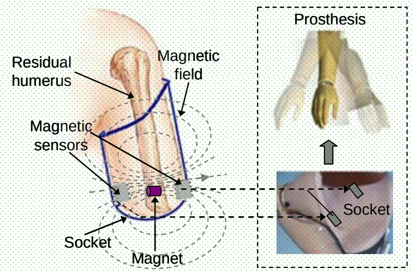

Figure 1: Proposed implementation of implanted magnet for control of prosthesis rotation by sensing rotation of the residual bone

METHODS

Both simulation and physical experimental studies have been conducted to evaluate the feasibility and performance of this new control method. The following parameters were used in modeling the system:

Simulation Model
- Model arm radius of 50 mm
- Magnet of 5 mm radius x 20 mm
- Br of 11 kG
- 25,000 elements
- 4,700 nodes

Physical Model
- Model arm radius of 50 mm
- Magnet of 6 mm dia. x 20 mm
- Br of 13.2 kG
- Model bone radius of 12.5 mm

The computer simulation (Figure 2) was conducted using finite element analysis (FEA) to model the upper arm and implanted magnet. Given the pre-magnetization of the permanent magnet, the magnetic flux density vector at each node was computed by FEMLAB.

In addition, the physical model (Figure 2) was constructed and the magnetic flux density at the surface of the arm was recorded using Hall Effect sensors. Two sensor configurations were implemented: (1) around the circumference of the model arm and (2) 20 mm ahead of the magnet along the axis of the model bone.

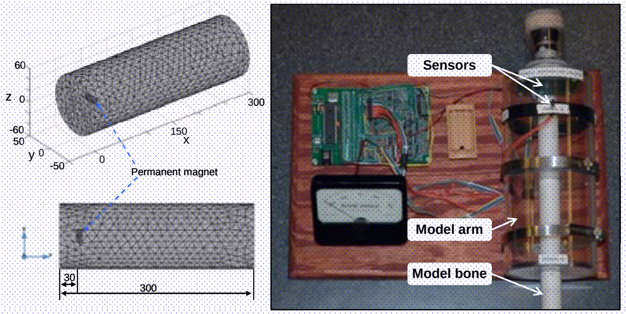

Figure 2: (Left) FEA model of upper arm with an inserted permanent magnet; (Right) Physical experimental model

RESULTS

FEA Model Results

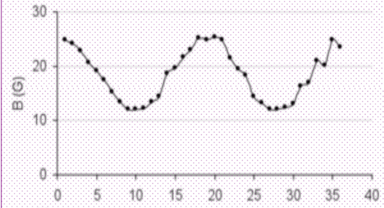

Figure 3a: Magnitude of simulated magnetic field density (B)

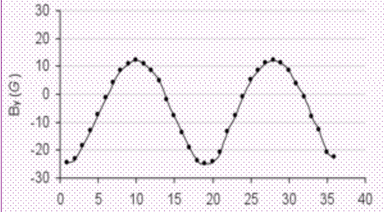

Figure 3b: Simulated magnetic field component in the y-direction (By)

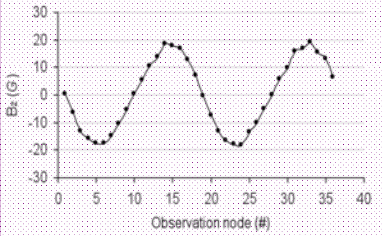

Figure 3c: Simulated magnetic field component in the z-direction (Bz)

Results from computer simulation model: Thirty-six equally-spaced surface nodes in the plane of the magnet and on the circumference of a transverse cross-section of the FEA arm model were chosen as the observation points of the magnetic field. The simulated field magnitude ($\vec{B}$) and its two components (B_y and B_z) at these nodes are shown in Figure 3a-c. The peak-to-peak magnetic field strength was about 35 *G* over 90 degrees for the two components. This provided a positioning resolution of about 0.39 *G* per degree rotation. Magnetic fields of this magnitude and resolution are detectable by suitably placed magnetic sensors in the prosthetic socket allowing the rotation angle of the residual bone to be measured and used to control a powered prosthetic rotator.

Results from physical experimental model: Two pairs of Hall Effect sensors, located along the axis of the bone, were used in the control mechanism for the prosthetic rotator. Each pair of sensors was subtracted differentially, with a gain of 10. The sensors gave a measure of the components of the magnetic field perpendicular to the axis of the bone. To determine the angle of bone rotation, the inverse tangent was taken of the components shown in Figure 4. The angle of the rotator was then successfully matched to the angle of the model bone.

Physical Model Results

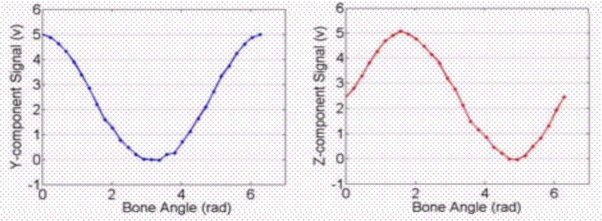

Figure 4: Sensor voltage readings from physical model, displaying magnetic field components

CONCLUSIONS

- New approach provides means to sense rotation of residual arm bone
  - Robust signals, seen in both the FEA analysis and physical experimental model
  - Angle determination possible from magnetic field sensors
  - Control scheme involves matching bone angle and powered rotator angle for intuitive control
- **Physiological proprioception remains intact**
- This study provides important guidelines for future development
- Similar methods may be applied for transradial prosthesis control

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