Inductive proximity sensing for an electromagnetically attached prosthetic limb

Shilpa Rao
Anatomics Lab
University of California, Los Angeles
raoshilpa@g.ucla.edu

Will Flanagan
Anatomics Lab
University of California, Los Angeles
wflan@ucla.edu

Tyler Clites
Anatomics Lab
University of California, Los Angeles
clites@ucla.edu

I. Introduction

Prosthetic limbs currently experience high rates of abandonment, largely due to the way these devices attach to the body. Current socket-based systems cause skin irritation, discomfort, and tissue damage. To address these issues, we have developed a novel prosthetic attachment method that uses magnetic attraction between a bone-anchored, ferromagnetic implant and an external electromagnet to hold the prosthesis onto the body (Figure 1). The implant is enclosed within the skin of the residual limb, resulting in a gap between the electromagnet and the implant. The size of this gap impacts the attractive force from the electromagnet; consequently, it is important to both measure and control the gap distance in real time.

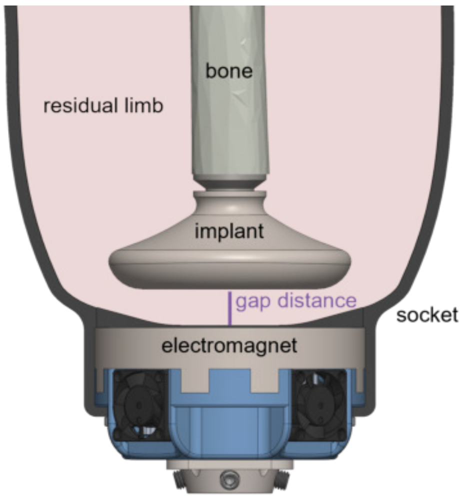

Figure 1: Implant and electromagnet for prosthetic attachment

Measuring gap distance directly is particularly difficult for this system. Any external sensor would have to measure distance through the skin into the residual limb, while operating in an extremely strong magnetic field. As such, we propose to measure the gap distance by probing the electrical inductance of the electromagnet coils. Coil inductance is impacted in a measurable way by magnetic field disturbance; when ferromagnetic material is separated from an electromagnet by a gap, previous studies have shown that inductance is a function of the gap distance [1]. Herein, we explore whether inductive sensing is a viable proximity-sensing method for an electromagnetic attachment system, how the inductance varies across the spectrum of voltage input frequencies, and whether we can characterize the noise of our signal.

II. Materials and Methods

To characterize inductance, we used an LCR meter (Stanford Research Systems SR720), capable of measuring inductance in real time. After calibrating the meter and connecting its terminals to the leads of the electromagnet, we varied the gap distance from 9.5 to 25.5 mm in 2 mm increments, based on the expected thickness of the skin and soft tissue between the implant and the electromagnet (Figure 2). The LCR meter powered the magnet with a sinusoidal voltage input (1 V amplitude). Impedance was characterized 5 times at each gap distance and frequency available on the meter: 100 hz, 1 kHz, 10 kHz, and 100 kHz. For each of these frequencies, we present the relationship between inductance and gap distance. The error bars were calculated to be one standard deviation above and below each mean. All analysis was conducted in Python.

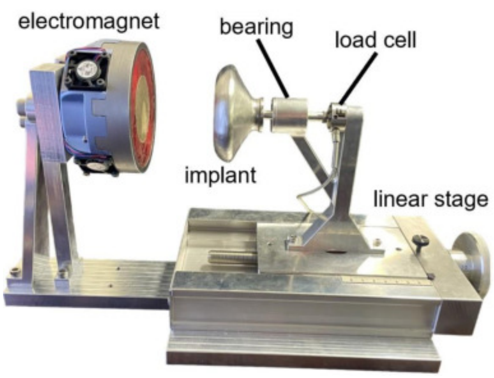

Figure 2: Electromagnet and implant test bench setup

III. Results, Discussion, Conclusion

Inductance changed in a measurable way as the gap distance between the magnet and implant increased, with a frequency dependence (Figure 3). At 100 hz, the trendline can best be described as an inverse exponential curve. At 1 kHz, the curve is still overall negative, but closer to a linear trend with a nearly negligible slope of 0.00364 mH/mm. At 10 kHz and 100 kHz, the trendlines are overall positive and reminiscent of a sigmoid, with negligible ranges. Our results are consistent with past studies [1], which found that at lower frequencies, the inflection in inductance spans a greater range (therefore introducing more potential to be used as a sensor) and has a negative trend. At the high end of the frequency spectrum, the data span a much smaller range, and the trend inverts (great gap distance corresponds to higher inductance) .

We observed relatively low variance across trials, at each of the different frequency inputs. This indicates that our inductance measurement is a repeatable indicator of gap distance. For the 100 hz input, which spanned the greatest range, the average standard deviation across all gap distances was 0.00861 mH, which was 1.437 % of the range of mean sensed inductances.

Our results show that inductive proximity sensing is a viable option for our electromagnetic prosthetic attachment system. The function between gap distance and impedance for a given excitation frequency was repeatable across trials, with little noise. Our experiment is limited by the fact that the gap distance was held static at each value during the experiment, rather than varying dynamically as it would in a real prosthetic application. It will be important to show that these results hold in dynamic conditions, where the sensing is applied in real time. Our next step will be to apply this sensing method to real time, closed-loop control of the electromagnet current.

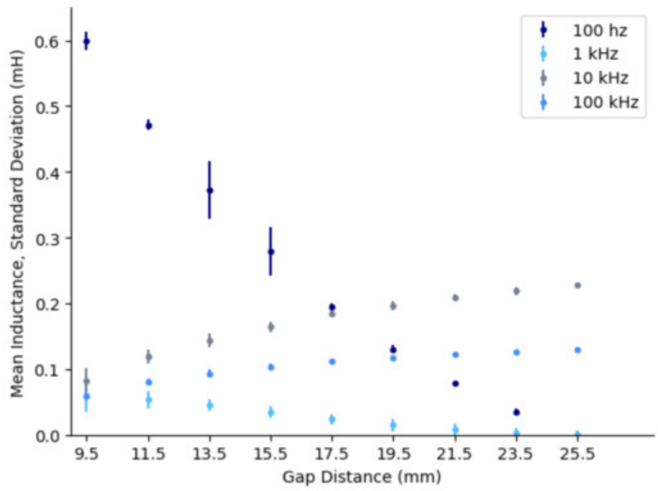

Figure 3: Gap Distance versus Inductance

IV. Visions

It is our expectation that inductive sensing will enable robust control of attractive force for electromagnetic attachment of prosthetic devices, which has the potential to alleviate pain and discomfort and improve socket attachment. Closed-loop control for electromagnetically attached prosthetics will increase the retention rate and decrease the upkeep of modern prosthetic devices, thereby democratizing access to lasting technologies with the potential to save lives.

References

[1] T. Kamf and J. Abrahamsson, "Self-Sensing Electromagnets for Robotic Tooling Systems: Combining Sensor and Actuator"