DESIGNING A POLYCENTRIC KNEE IN RAT ROBOTIC HINDLIMB

EXPLORING SOCIO-CULTURAL IMPACTS ON PROSTHETICS

A Thesis Prospectus
In STS 4500
Presented to
The Faculty of the
School of Engineering and Applied Science
University of Virginia
In Partial Fulfillment of the Requirements for the Degree
Bachelor of Science in Biomedical Engineering

By
Jack Pessaud

December 13, 2024

Technical Team Members:
Hayden Penczak
Wolfang Reynolds
Grace Millick

On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

ADVISORS

Ben Laugelli, Department of Engineering and Society

Dr. Shawn Russell, Department of Mechanical Engineering

Introduction

Approximately 1.71 billion people have musculoskeletal conditions worldwide (World Health Organization, 2022). Many of these patients suffer from volumetric muscle loss (VML). This is a condition where a significant amount of muscle is gone to a point that it does not possess the capability to grow back. This affects the function and use of limbs and joints for the patient (Passipieri et al., 2017). This can be a significant financial and physical burden to those affected. This burden is why there is a need for precise and cost-effective modeling in research for musculoskeletal improvement, specifically, for devices that accurately mimic the physiological movement of human limbs. One of the primary areas of research is studying VML injuries in a patient's leg. To accomplish this goal, an accurate physical model is needed to study rat hindlimb movements. The chief threshold for this is creating a polycentric knee which would allow for the translational and rotational movements of the knee to be modeled. This will increase the ability of researchers to reliably repeat trials with different muscles activated and deactivated while simultaneously reducing cost. However, numerous factors besides pure accuracy impact the success of robotic replicas of limbs. Therefore, it is important to understand how various factors affect stakeholders and thus, the success of the design. I will draw on the STS framework of Social Construction and Technology to investigate how the impact of engineers' biases, public institutions and public media influenced the design and success of the DEKA arm. Because the challenge of creating a polycentric knee for a robotic rat hindlimb is sociotechnical in nature, it requires attending to both its technical and social aspects to accomplish successfully. In what follows, I set out two related research proposals: a technical project proposal for developing a polycentric knee rat robotic hindlimb and an STS project proposal for examining public media, public organizations, and engineers' bias in the development of the DEKA arm.

Technical Proposal

Rat modeling is essential for early stage research in numerous fields such as oncology, neurology, cardiovascular research, toxicology, and orthopedics. Rats provide a great insight for researchers because rats and humans have similar genomes at 2.75 million base pairs and 2.9 million base pairs respectively (*Rats - the Animal Model That Is Revitalizing Medical Research | Cyagen*, 2020). Furthermore, rats have well studied gait dynamics that allow for them to be comparatively analyzed to humans. This allows for injuries in rat hindlimb muscles that affect their gait to be researched and applied to humans with similar injuries in their comparative physiology (Dienes, 2024). However, the use of live rats in such studies can be tedious and expensive. Each test necessitates acquiring a rat model and spending time preparing the limb of the rat with its respective surgery so that it can mimic a given injury. Furthermore, after this surgery is completed, the rat cannot recover from it given the nature of volumetric muscle loss injuries (Passipieri et al., 2017). Additionally, the cost of acquiring and habitating each rat can be hundreds of dollars as well as the additional costs due to surgery on the rats (*Rat Resource & Research Center - Pricing*, n.d.). This cost can be significantly lessened by using an accurate robotic rat replica. This robotic model will allow for muscles to be turned off or lessened by the click of a button instead of a lengthy surgery while still allowing for physical impacts, which would not be in a computational model, like friction and uneven ground, to affect the gait. Furthermore, research trials can be accurately repeated for reliable and consistent results. However, in order for a robotic rat limb to be worth using it must accurately replicate the gait and movement of a live rat.

There are numerous models currently being used that replicate the gait of a rat. Most, however, use a simple ball and socket joint for the hip and a hinge joint for the knee (Aronhalt et al., 2023). This closely models a rat's hindlimb movement but cannot achieve the increased accuracy of a polycentric knee joint that captures both the translational and rotational movement. The simplicity of a hinge knee joint allows for easy manufacturing and development of a robotic model at the cost of accurate modeling of the gait. This is useful for generalized modeling of rat movement but is not acceptable for the study of specific muscle loss impact on gait where minute changes in movement are extremely important.

The polycentric knee joint allows for significant accuracy in the specifics of the gait cycle for the hindlimb movement in rats. By capturing both translational and rotational motion, there is a high confidence that the gait is accurate to what would be expected from a live rat. This allows researchers to target specific muscle activation and deactivation on the gait of a rat to visualize the small changes it may have on movement.

A polycentric joint can be achieved in a robotic rat model by using a four bar linkage which allows for a rotational and translational joint. The ability to determine the placement of the bars allows for the rotational and translational freedoms to be changed so that an optimal position can be achieved. This allows for reflection of a live rat's gait to a high degree of accuracy. Furthermore, analysis of four bar linkages has a strong history of use in human prosthetics (Greene, 1983). Additionally, there are various different actuators that can be utilized to mimic muscle activation such as the electro-hydraulic actuator (Bush, 2024). Motion capture data can be collected on the movement of the hindlimb with various different muscle activations. The motion capture data from the physical model will be compared to the computational model using the OpenSim software. This will be done by having at least three markers tracked through the motion of the knee joint moving through its gait. If the simulation shows that the ankle is within 5 mm of its position as compared to the computational model throughout the knee joint motion, it will be accepted that the design is viable.

STS Proposal

DEKA Integrated Solutions Corp. made the first prosthetic arm (the DEKA arm) capable of performing multiple simultaneous powered movements. DEKA partnered with the Defense Advanced Research Project Agency (DARPA) as well as the Department of Veterans Affairs (VA). The research concluded with 95% of Gen 2 users and 91 % of Gen 3 users reporting that they were able to perform new activities that they had not been able to previously perform with their old devices (*The LUKE/DEKA Advanced Prosthetic Arm*, 2018). This is due to the device's enhanced control and precision. It incorporates sensors and controls in a way that allows for multiple movements to be made at the same time as opposed to most single movement devices (*From Idea to Market in Eight Years, DARPA-Funded DEKA Arm System Earns FDA Approval*, 2014). Furthermore, the device allowed for user-centric feedback mechanisms. There were wireless sensors put in the users' shoe that allowed for them to control movements while minimizing the complexity of the hand or limb signals (*The LUKE/DEKA Advanced Prosthetic Arm*, 2018). Some might argue that it is the dominant design because it was the "best" in terms of an objective quality such as its users' reporting that they were able to perform more tasks than their previous prosthetics with less perceived disability (Resnik et al., 2018). Previous writers have argued that this increase in reported performance of tasks with less perceived disability is what led to the DEKA arm success, but they have not adequately addressed how outside perspectives have influenced the reception of the device.

Specifically, these perspectives do not adequately address the public confidence brought by DARPA's name, engineers' bias towards complexity in design without proven benefit, or outside public opinion based on cinema relation and not design qualifications. By analyzing other perspectives impact on the success of the DEKA arm, I will show how the DEKA arm became the most successful prosthetic. This will give important clarifying information into the successes of prosthetics that can illustrate better what needs are being met currently. This will allow for the needs of the users to be improved upon. I argue that the DEKA arm became the dominant prosthetic technology because engineers and the public thought it addressed their priorities and concerns better than alternate concepts because of its relation to popular media, "cool" design features, and ownership from impressive organizations.

To frame my analysis, I will draw on the framework of Social Construction and Technology (SCOT), which examines an understanding of technological development by how different factors, whether they be social, cultural, or political, shape technology as opposed to the "best" design always being chosen (Pinch et al., 1987). Important components of SCOT include interpretive flexibility. This is the idea that a piece of technology does not have a universal interpretation. Instead, it can be viewed differently by various stakeholders based on their backgrounds and priorities. Furthermore, these various views will cause stakeholders to see different aspects of a technology as the most important. This means that the success of a particular technology is due to relevant social groups and their interactions with the device (MacKenzie & Wajcman, 1999). For example, when looking at the DEKA arm the relevant social groups would not just be the users according to SCOT, but also include the family members of the user, the engineers, the public, DARPA, the industry at large, the VA, the finances, and many others.

To support this argument, I will analyze evidence from various primary sources. For instance, DARPA's role in the designing of the system brings with it a public confidence due to DARPA's notoriety. This is not due to any achieved function of the design but because DARPA played a significant role in its creation (*From Idea to Market in Eight Years, DARPA-Funded DEKA Arm System Earns FDA Approval*, 2014). Additionally, engineers are fascinated by additional abilities of the device that may not actually make it superior. It was touted that the six user-selectable grips were a key design component of the device, but it was the number of design grips that was impressive to engineers and not the actual movements themselves which is what would be more applicable to the users (*From Idea to Market in Eight Years, DARPA-Funded DEKA Arm System Earns FDA Approval*, 2014). Finally, public fascination for the project due to its comparison to popular imagery of prosthetics like Luke Skywalker's hand in "Star Wars" drew public attention and support without necessarily showing that the design was superior. This can be seen foremost in the fact that it was referred to commonly as "the Luke arm" (Lewis, 2014). This attention because of the device's look improved its reception among the public without their knowledge of its uses or improvements over previous designs.

Conclusion

The design of a polycentric knee in a rat robotic hindlimb will allow for cheaper, more accurate, and more replicable research to be done on volumetric muscle loss impacts. This is an important beginning step that will allow for future strides to be made that will significantly improve the lives of many patients. The research into how engineers' bias, public organizations, and public media impact the development and success of the DEKA arm will allow for better understanding of how other stakeholders besides the users impact a design. The knowledge of these stakeholders' impacts will directly impact the research process as well as the final design.

This will allow for the development of the polycentric knee joint to be optimized with the knowledge of how various stakeholders, not typically considered, will impact the final design.

References

Aronhalt, E., Abramson, E., Goldsmith, C., Andrada, E., Nourse, W., Sutton, G., Szczecinski, N., & Quinn, R. (2023). Development of a Robotic Rat Hindlimb Model. *Lecture Notes in Computer Science*, 115–130. https://doi.org/10.1007/978-3-031-39504-8_8

Bush, S. (2024, September 9). *Electro-hydraulic actuators make a nimble leg*. Electronics Weekly. https://www.electronicsweekly.com/news/research-news/electro-hydraulic-actuators-make-a-nimble-leg-2024-09/

Dienes, J. (2024). *Rat Gait Biomechanics | University of Virginia School of Engineering and Applied Science*. Virginia.edu. https://engineering.virginia.edu/labs-groups/christ-lab/research-overview/rat-gait-biomechanics

From Idea to Market in Eight Years, DARPA-Funded DEKA Arm System Earns FDA Approval. (2014, May 9). Www.darpa.mil. https://www.darpa.mil/news-events/2014-05-09

Greene, M. P. (1983). *Four Bar Linkage Knee Analysis*.

Lewis, T. (2014, May 12). *DARPA's "Luke Skywalker" Arm Wins FDA Approval*. Livescience.com. https://www.livescience.com/45533-darpa-prosthetic-arm-approved-by-fda.html

MacKenzie, D. A., & Wajcman, J. (1999). *The Social Shaping of Technology*.

Passipieri, J. A., Baker, H. B., Siriwardane, M., Ellenburg, M. D., Vadhavkar, M., Saul, J. M., Tomblyn, S., Burnett, L., & Christ, G. J. (2017). Keratin Hydrogel Enhances In Vivo Skeletal Muscle Function in a Rat Model of Volumetric Muscle Loss. *Tissue Engineering Part A*, *23*(11-12), 556–571. https://doi.org/10.1089/ten.tea.2016.0458

Pinch, Trevor J. and Wiebe E. Bijker. (1987). “The Social Construction of Facts and Artifacts: Or How the Sociology of Science and the Sociology of Technology Might Benefit Each Other.” In *The Social Construction of Technology Systems*, ed. Wiebe E. Bijker, Thomas P. Hughes, and Trevor J. Pinch. Cambridge, MA: The MIT Press.

Rat Resource & Research Center - Pricing. (n.d.). Www.rrrc.us. https://www.rrrc.us/Pricing/

Rats - The Animal Model that is Revitalizing Medical Research | Cyagen. (2020, September 9). Www.cyagen.com. https://www.cyagen.com/us/en/community/technical-bulletin/rat-model.html

Resnik, L. J., Borgia, M. L., Acluche, F., Cancio, J. M., Latlief, G., & Sasson, N. (2018). How do the outcomes of the DEKA Arm compare to conventional prostheses? *PLOS ONE*, *13*(1), e0191326. https://doi.org/10.1371/journal.pone.0191326

The LUKE/DEKA advanced prosthetic arm. (2018, August 1). Www.research.va.gov. https://www.research.va.gov/research_in_action/The-LUKE-DEKA-advanced-prosthetic-arm.cfm

World Health Organization. (2022). *Musculoskeletal health*. Who.int; World Health Organization: WHO. https://www.who.int/news-room/fact-sheets/detail/musculoskeletal-conditions