The Squat Bot: A Lower-Limb Exoskeleton for Sitting and Standing Assistance

(Technical Paper)

Functional and Beautiful: Assistive Medical Devices for Patient Empowerment

(STS Paper)

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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.

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Introduction

My research, both technical and sociotechnical, intends to facilitate the creation of assistive medical devices that are readily embraced by users. This optimization will help patients feel comfortable, even empowered, when using a technology that addresses differences or deficiencies in their bodily function. One method for achieving this goal is the creation of devices that are both functional and beautiful. My work will mirror this, tackling both function and beauty. The function component is a Capstone project building a lower-limb orthotic exoskeleton for assistance standing up and sitting down. The beauty component is an STS thesis exploring the social factors contributing to the perception of aesthetics in assistive medical devices. Spanning multiple social groups beyond just patients, the ideal appearances of assistive devices continues to be flexible and up for debate. Technology meets stigmas, slim margins of error, and subjective ideals of beauty as form and function overlap.

Technical Topic

My technical project will be done under the guidance of Professor Sarah Sun in the MAE department. Professor Sun's research centers on wearable flexible or rigid robotic systems that enhance human movement and/or physical health. Specifically, I will be contributing to the design of a lower-limb exoskeleton for assistance standing and sitting. While multiple successful lower-limb exoskeletons exist for rehabilitation, the majority focus on gait assistance and adjustment (Kapsalyamov et al., 2019, *Soft Exosuits*, 2013). The niche of an assistive device for standing and sitting is not yet fully saturated, with limited designs including that by Chen et. al (2017) at the Chinese University of Hong Kong.

Over time, the human body inevitably deteriorates and the things we now take for granted become much more strenuous. According to Laporte et. al (1999), aging makes sitting and standing more difficult. Elderly people's muscular strength decreases, as does the range of motion in the hips and the knees. With an additional worsening in reaction time, these all combine for a much higher risk of falling. Surprisingly, elderly people generally retain their ankle mobility, which enables the creation of solutions limited to the hips and knees (Laporte et. al, 1999). Without help, elderly people are prone to adopting more sedentary lifestyles, which in turn tends to have detrimental health effects over time (Yen et. al, 2017). This technology could improve the quality of everyday life for a significant segment of the population.

We aim to develop a low cost device that will assist a patient with transitioning from a full standing position to an upright sitting position, and vice versa. This device focuses on increasing function of both the knee and hip joints, with the assumption that the patient's ankles function without assistance. In a fairly light device, the user will be able to sit and stand with ease as the lower limb exoskeleton will guide them through the necessary motions to stand and sit. The exoskeleton will be primarily rigid with high-torque stepper motors used as actuators.

Work on this project begins in the middle of the fall semester and continues through the spring semester. The final product is expected to be a functional prototype of the robotic device incorporating sensing, control, and actuation. With such a short timeline for design and prototyping, it is unlikely that we will be able to give significant consideration to the appearance of the device. This is already highlighting one of the main reasons that aesthetics may not be equally weighted in the design process: it takes up additional time in an already limited situation. Above all, a user's perception of the device's appearance is not a metric in the evaluation of capstone projects. This additional layer of context helps emphasize the importance of studying the STS topic.

STS Topic

Introduction

Highly-visible assistive medical devices can take the form of prosthetics (technology used to replace a part of the body), orthotics (technology used to support or enhance the body), or implants (e.g. machines to supplement a bodily function). When observing these devices, a false dichotomy can emerge between aesthetics and functionality in device design: a technology can either be state-of-the-art, highly-functional, and ugly; or it can be beautiful yet simplistic. Do these two things really conflict? I aim to explore current knowledge surrounding the visual design of assistive medical devices. Social factors surrounding these devices are augmented by the fact that they often become part of the user's body, affecting their own and others' perception of themselves. Since the users are already often vulnerable members of society, exposed to societal stigma on top of physical disadvantages, it is essential to understand this topic. Ultimately, this understanding will enable better design for patient empowerment.

STS Framework

The interaction of the technology and social factors will be examined through the Social Construction of Technology (SCOT) framework. SCOT presents a human lens through which to analyze technological development. It maintains that the interactions between social groups provide the impetus for design, rather than the "natural progress of innovations" posited by some scholars. Therefore, it can be seen as a counterpart to Technological Determinism, which claims that innovations beget themselves and that technology changes us more than we change it. As developed by Lee Humphreys (2005), SCOT also includes multiple ways to categorize social groups and their influence. These social groups, or "stakeholders," are Users, Producers, Bystanders, and Advocates, all of whom are defined below:

1. Users—People directly connected to the use of a technology. In this case, individuals in need of assistive medical devices, such as injured and disabled people. For assistive medical devices, the actions and opinions of users are crucial.
2. Producers—People and organizations creating the technology, and often the ones benefiting financially from its production. In this case, medical device manufacturers, research labs, engineers, designers, marketing teams, and investors. As a researcher building an exoskeleton, I am a producer myself.
3. Advocates—People and organizations who indirectly shape the best use of the technology and its public opinion. In this case, disability advocacy groups, political action groups, legislators, observational researchers, and media organizations.
4. Bystanders—People who do not fit into the above categories. In this case, friends and family members of the users, public observers, and individuals "posting" on mass media. This category, while nebulous, is highly important; bystanders contribute heavily to social stigma.

Finally, SCOT encompasses the idea of "stabilization," which notes that technological development takes time to be fully understood by a population. Emerging technologies will change in form and function as public perception of their usefulness changes. Assistive medical devices have yet to stabilize, since cultural ideas surrounding their ideal forms and stigmas are still fluid. For example, it is yet unclear what purpose a prosthetic limb takes in its appearance. Does it function as an accessory or as a tool? Does it enhance the body, or detract from it?

Methods and Key Concepts

Since prosthetics, orthotics, and implants all fall under my definition of “visible assistive devices,” the full thesis will utilize publications about each for three “case studies” of the intersection between social design factors and technical function factors. For one, a prosthetic leg can take many forms for many purposes, as explored by Sansoni et. al (2014; 2016). Orthotics, of course, is the focus of my technical project. I will incorporate the experiences of my own group, along with the precursors to our research (Chen et al., 2017). Lastly, multiple papers have explored the social dynamics of implants associated with diabetes management (Farrington, 2016; O’Kane et. al, 2015). Each case study will include opportunities to highlight unique stakeholders and social factors. They can also serve as supporting examples for the analysis of broader sociotechnical issues, some of which are described below.

To establish a scope for each individual analysis of assistive device form vs. function, the question must be asked: What is the goal for this device? One could say that it serves to restore function that has been lost. Does this mean that an ideal device cannot be distinguished from the rest of the body? The SCOT framework would indicate that prosthetics, orthotics, and implants are all at different levels of stabilization, with none complete. Prosthetics could be considered a “creative product” for self-expression rather than a “medical device” solely for regaining function (Sansoni et. al, 2016, p. 73). Orthotics can provide either rehabilitation or everyday assistance, with no standardization yet on the best appearance. Some users of insulin pump implants keep them hidden, while others decorate them with stickers (Farrington, 2016). For all three, one interesting development emerges in the literature: devices that are intentionally unnatural in appearance for visual appeal.

The disagreements regarding the ideal appearance of assistive devices stem from social, political, and economic factors. A discussion with graphical representations of all stakeholders in the process will aid in the elaboration of these factors. One economic example is Producers who want to cut costs in product development. Another particularly large sociopolitical factor attributed to Bystanders is public opinion of disability, which J. E. Harris describes in "The Aesthetics of Disability." The Users of the assistive devices may suffer from discrimination and judgment. Standing out can be harmful, as "collective tastes for normative representation of beauty, health, and effortlessness situate people with atypical sensory markers as risky" (Harris, 2019, p 960). Why, then, do some users of these devices seek to make them intentionally artificial-looking? The issue provides much room for discussion.

Defining Beauty

Finally, although I frequently reference the concept of beauty, there is debate over whether it is subjective or objective (Sartwell, 2022). Researchers have attempted to quantify beauty and design, with each creating a framework or model for its distillation (Hagendorn et. al, 2016; Gajendar, 2008). Without overcomplicating the thesis by introducing an aesthetic framework to compete with SCOT, it needs some definition of beauty. This definition will be mentioned again and again with "beautiful and functional" devices, as well as with "design" in the context of aesthetics. Gajendar's (2008) framework presents a reasonable starting point for this definition, as he mentions beauty as "a cumulative sense of how fundamental elements (style, performance, utility, and story) work in concert to achieve something memorable and desirable" (p. 8). Again, this comes dangerously close to overextending the scope of the thesis. I anticipate refining this definition of beauty to eliminate ambiguity with regards to its application to visible assistive devices.

Conclusion

Assistive medical devices lack perfection in multiple categories, not just function. Patients continue to suffer from stigmas surrounding disability and image (Harris, 2019). In the full thesis, I aim to investigate the false dichotomy present between function and form in the context of medical devices. The medical field is particularly susceptible to the promotion of this dichotomy because of the low margins for functional error. However, high standards for a product's function do not preclude high standards for its user appeal. By experiencing the process of device creation from both sides—as a device designer as well as a design researcher—I will be equipped to present a thorough assessment of best practices surrounding the user experience of highly-visible assistive medical devices. This will enable future designers and engineers to create devices that better empower patients.

Annotated Bibliography

Booher, A. K. (2010). Docile bodies, supercrips, and the plays of prosthetics. *International Journal of Feminist Approaches to Bioethics*, *3*(2), 63–89. https://doi.org/10.2979/fab.2010.3.2.63

Journal article looks at prosthetic users through the lens of "docile bodies" from Foucalt: people who can be used, changed, and improved. Also uses feminist lens. Talks about making prosthetics realistic vs. obviously technical at the bottom of p64. Very dense.

Chen, B., Zhong, C.-H., Zhao, X., Ma, H., Guan, X., Li, X., Liang, F.-Y., Jack, Qin, L., Sheung Wai Law, & Liao, W.-H. (2017). A wearable exoskeleton suit for motion assistance to paralysed patients. *Journal of Orthopaedic Translation*, *11*, 7–18. https://doi.org/10.1016/j.jot.2017.02.007

Relevant technical paper focused on standing and sitting assistance.

Farrington, C. (2016). Wearable technologies and stigma in diabetes: the role of medical aesthetics. *The Lancet Diabetes & Endocrinology*, *4*(7), 566–566. https://doi.org/10.1016/s2213-8587(16)00075-9

Journal paper commenting on the aesthetics of insulin pumps as well as interaction with social factors like diabetes stigma. Good reference for an interacting social factor.

Gajendar, U. (2008). Experiential aesthetics: a framework for beautiful experience. *Interactions: Vol 15, No 5*. https://dl.acm.org/doi/10.1145/1390085.1390087

Article that presents a framework for defining aesthetics in the context of object design, "identifying specific, tangible elements of a beautiful experience." May be used to speak more clearly and specifically about what it means to create assistive devices that are beautiful.

Hagedorn, T. J., Krishnamurty, S., & Grosse, I. R. (2016). An information model to support user-centered design of medical devices. *Journal of Biomedical Informatics*, *62*, 181–194. https://doi.org/10.1016/j.jbi.2016.07.010

Paper describing a model to quantitatively evaluate design, here interpreted as features of user interaction. May not be useful, but interesting as a note that there can be metrics to measure design.

Harris, J. E. (2019). The Aesthetics of Disability. *Columbia Law Review*, *119*(4), 895–972. https://www.jstor.org/stable/26632274

Journal paper that elaborates on the relationship between aesthetics and social interactions, especially with respect to discrimination against disabled people. Could help with more social factors and underscore the importance of aesthetics. Also good analysis of political factors. ~p958 has a good discussion of the effects of aesthetics on opinion.

Humphreys, L. (2005). Reframing Social Groups, Closure, and Stabilization in the Social Construction of Technology. *Social Epistemology, 19*(2-3), 231–253. https://doi.org/10.1080//02691720500145449

SCOT overview and principal reference for application of the framework.

Kapsalyamov, A., Jamwal, P. K., Hussain, S., & Ghayesh, M. H. (2019). State of the Art Lower Limb Robotic Exoskeletons for Elderly Assistance. *IEEE Access*, *7*, 95075–95086. https://doi.org/10.1109/access.2019.2928010

Technical paper summarizing some of the lower-limb exoskeleton designs published.

Laporte, D., Chan, D., & Sveistrup, H. (1999). Rising from Sitting in Elderly People, Part 1: Implications of Biomechanics and Physiology. *British Journal of Occupational Therapy*, *62*(1), 36–42. https://doi.org/10.1177/030802269906200111. Analysis of sitting and standing difficulty for older people specifically. Notes ranges of motion in specific joints, as well as provides a helpful analysis with diagrams of the sitting and standing processes. The paper is old, but the material is unlikely to have changed significantly since then.

Laschowski, B., Razavian, R. S., & McPhee, J. (2021). Simulation of Stand-to-Sit Biomechanics for Robotic Exoskeletons and Prostheses With Energy Regeneration. *IEEE Transactions on Medical Robotics and Bionics*, *3*(2), 455–462. https://doi.org/10.1109/tmrb.2021.3058323

Technical paper with an example of necessary calculations for lower-limb exoskeletons.

O'Kane, A. A., Rogers, Y., & Blandford, A. E. (2015). Concealing or Revealing Mobile Medical Devices? *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*. https://doi.org/10.1145/2702123.2702453

Conference presentation and paper that identifies the social factors influencing use of diabetes-management devices. Specifically, whether or not users choose to use them within the view of others.

Sansoni, S., Speer, L., Wodehouse, A., & Buis, A. (2016). Aesthetic of prosthetic devices: From medical equipment to a work of design. In S. Fukuda (Ed.), *Emotional Engineering Volume 4* (pp. 73–92). Springer International Publishing. https://doi.org/10.1007/978-3-319-29433-9%E2%82%85

Book chapter that looks at prosthetics as a "'creative product' rather than 'medical device'". Specifically introduces the concept of intentionally robotic-looking prosthetics for visual appeal.

Sansoni, S., Wodehouse, A., & Buis, A. (2014). The Aesthetics of Prosthetic Design: From Theory to Practice. *DS 77: Proceedings of the DESIGN 2014 13th International Design*

Conference. 975-984.
https://www.designsociety.org/publication/35242/THE+AESTHETICS+OF+PROSTHETIC+DESIGN%3A+FROM+THEORY+TO+PRACTICE

Conference paper of case studies of below-knee prostheses. Maintains that aesthetically attractive prostheses improve the emotional well-being of the user. Notes the difference between prosthetics and orthotics (my technical project is an orthotic device).

Sartwell, C. (2022). *Beauty (Stanford Encyclopedia of Philosophy)*. Stanford.edu. https://plato.stanford.edu/entries/beauty/#:~:text=Though%20Plato%20and%20Aristotle%20disagree,the%20response%20of%20the%20beholder.

Soft Exosuits. (2013). Harvard.edu. https://biodesign.seas.harvard.edu/soft-exosuits

Relevant technical paper demonstrating a soft exoskeleton for aid walking.

Yen, C.-H., Ku, M.-H., & Wang, C. (2017). Self-reported Sitting Time is Associated With Decreased Mobility in Older Adults. *Journal of Geriatric Physical Therapy*, *40*(3), 167–173. https://doi.org/10.1519/jpt.0000000000000092. The detrimental effects of sedentary lifestyles for older adults, which is exacerbated by difficulty sitting and standing.