A Soft Wearable Robotic Exoskeleton for Elbow and Wrist Flexion and Extension

(Technical Paper)

The Hypersonic Missile: Revolutionary Weapon or Marketing Scheme?

(STS Paper)

A Thesis Prospectus Submitted to the

Faculty of the School of Engineering and Applied Science

University of Virginia • Charlottesville, Virginia

In Partial Fulfillment of the Requirements of the Degree

Bachelor of Science, School of Engineering

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Fall, 2023

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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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Technical Paper: A Soft Wearable Robotic Exoskeleton for Elbow and Wrist Flexion and Extension

Introduction

Neuromuscular disorders, strokes, and spinal cord injuries can lead to patients experiencing varying degrees of paresis/paralysis. Through extensive physical therapy, some patients are able to regain their lost motor skills by activating the muscle-brain connection. One technique used in physical therapy is passive movements, where the therapist manually moves the targeted limbs of the patient to induce neuroplastic changes [1]. Alternatively, robotic exoskeletons have been designed to help patients achieve these movements without direct assistance from a physical therapist. However, exoskeletons have not been widely adopted in clinical settings and they are typically rigid, heavy, and expensive. There has been an increase in the development of soft wearable exoskeletons in order to address the shortcomings of rigid exoskeletons that interfered with their ability to be useful outside of a clinical environment [2]. This project will focus on creating an affordable and portable exoskeleton to aid patients in regaining upper limb mobility, in particular, the flexion and extension of both the elbow and wrist joints. To achieve this, we will utilize two different types of actuators.

The current state of the art designs found in literature show that approximately 70% of exoskeletons for rehabilitation purposes are powered using an electric drive. Pneumatic exoskeletons make up a much smaller fraction despite offering a better force-to-weight ratio, largely due to the noise produced by air pumps [3]. Current designs also lack closed-loop feedback control and external programming, which would allow physical therapists or their

patients to adjust the rehabilitation regimen according to their progress. Stroke survivors typically experience reasonable recovery of the proximal upper limb muscles but limited recovery of the distal upper limb muscles, which play an important role in fine motor control. Wrist exoskeletons are a promising tool to aid in the rehabilitation of these skills [4]. The high cost of current rehabilitative robots prevents patients with financial constraints from benefiting from the device. To build off of designs found in literature and differentiate our device, the goal of our project is to combine the gross motor skills used in the elbow and fine motor skills used in the wrist in a financially affordable design.

Technical Design

The exoskeleton's design will feature two main modules: the elbow module and the wrist module. For the elbow module, a pneumatic artificial muscle (PAM) actuator will be used to create one degree of freedom, flexion and extension, at the elbow. PAMs are biomimetic actuators, designed to imitate the way muscles contract and extend [5]. The actuator will be inflated by an air pump located in a backpack worn by the patient. The PAM will have two connection points on the arm, one at the top of the arm brace and one on the forearm section of the arm brace (Figure 1). The inflation of the PAM will cause its contraction, and consequently, bending at the elbow. The contraction will be controlled by an Arduino connected to a three-way solenoid. There will need to be some control system for the solenoid to program when the valves are open to the pneumatic. To detect the change in the angle of the patient's elbow, an IMU sensor will be placed on the forearm to provide feedback control. Many stroke patients will have auditory overload issues [6]. Seeing as several upper limb rehabilitation are stroke patients, the

sound from the pumps will be mitigated to a maximum of 60 decibels using a soundproofing box. A couple of iterations of the box will be fabricated and tested with various materials, including dry-wall and sound-absorbing panels.

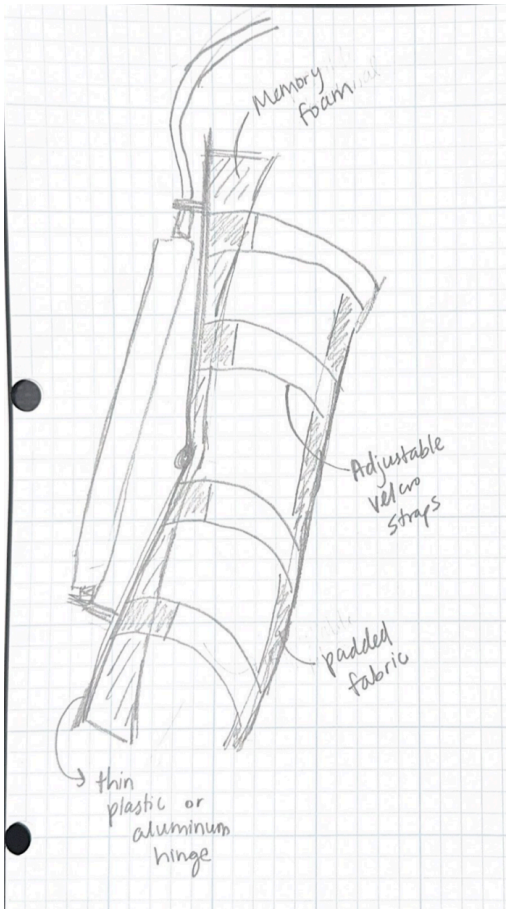

Figure 1: Initial Design for Elbow Exoskeleton

For the wrist module of the exoskeleton (Figure 2), flexion and extension will be created through the use of an RC servo motor based on the EMG and IMU collections. To house the motor, and provide structural support, a 3-D printed support structure will be used. A flexible polymer filament, such as TPU, will be preferred as it would be more compliant around the forearm/wrist than typical ABS or PLA plastics. The RC servo motor will be placed on the top of the forearm, and bevel gears will be used to reorient the axis of the output rotation. The

subsequent gear rotations will move the hinge which will apply the torque to the palm/hand to achieve the flexion/extension. The servo motor we chose has a maximum torque of 21.5 kg/cm at 6.8 V, which should be sufficient for wrist flexion/extension. The IMU will be placed on the back of the hand to sense the motion.

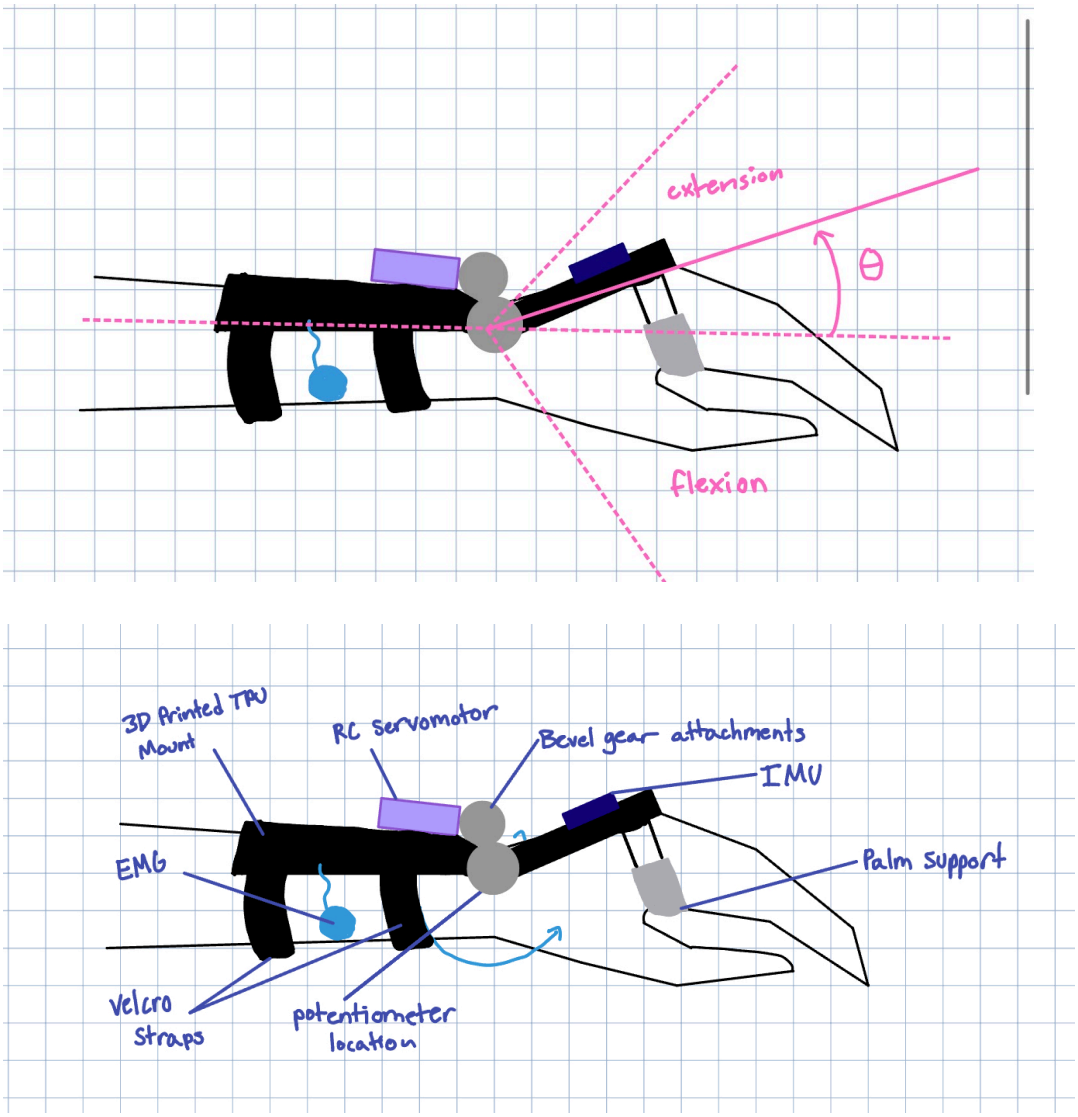

Figure 2: Wrist conceptual design components and range of motion

Methodology

To develop the research methodology, the study is structured based on identified gaps in literature of existing state-of-art designs. It was found that current rehabilitation exoskeletons prioritize gross motor skills. The focus of this project is on understanding the combination of fine and gross motor skill rehabilitation for individuals with elbow and wrist-related ailments. An ethnographic approach will be employed to seek out opinions from potential users and stakeholders. This includes physiotherapy patients and therapists. Surveys and interviews from people with disabilities will give a unique perspective on the exoskeleton.

Prototyping has been begun and will continue into Spring semester, allowing for iterative design. The team will experiment with various PAM configurations in order to determine a completely airtight and safe design, as well as derive the relationship between attached weight and maximum contraction. We will complete additional training and requirements to interview/ survey patients in the Spring Semester.

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STS Paper: The Hypersonic Missile: Revolutionary Weapon or Marketing Scheme?

Introduction

Hypersonic aerodynamics is widely applicable to space and defense technologies. One such defense technology is the hypersonic missile, which is designed to go hypersonic speeds within the Earth's atmosphere throughout its travel, as opposed to the ballistic missile, which leaves and then reenters Earth's atmosphere before landing on its target. My STS paper will investigate the US government's conviction that the hypersonic missile is the future of national defense. Defense contractors such as Lockheed Martin, Boeing, and RTX are all engaged in the formulation of hypersonic missile technology, calling it "a critical imperative" (RTX), "a key to battlefield supremacy" (Lockheed Martin), and even "the cutting edge of what's possible" (Boeing). One goal of my paper is to determine whether these are simply platitudes, or whether hypersonic missiles are truly an answer to US security needs. Another goal is to analyze the various factors playing a role in the US's interpretation of hypersonic weapons using the Sociology of Scientific Knowledge (SSK) framework.

Problem

Hypersonic missiles are described to be faster, more maneuverable, and less detectable than conventional missiles on both defense contractors' websites and in news media, yet The Union of Concerned Scientists (UCS) hosted a talk and published an article debunking these assertions using computational models of hypersonic and ballistic missiles. Further investigation is necessary to determine the soundness of UCS's argument and to find other resources for

technical comparison of the two technologies. But beyond the determination of the extent to which hypersonic missiles are necessary to our nation's defense, this case study contributes to a greater understanding of the internal workings of national defense spending and the economic, social, and political factors that come into play in the interpretation of emerging defense technologies. The US military has a large network of influence around the globe, providing aid to Ukraine and protection to NATO countries in an effort to maintain world order. Recognizing the central global importance of the US military, and considering that its funding comes from taxpayer dollars, it stands to reason that wasteful spending ought to be brought to the attention of the nation's citizens. (Haas, 2017) The US must maintain its technological leadership to stay ahead of its adversaries, and making poor investment decisions has global as well as domestic consequences.

STS Framework

This paper will evaluate the US's decision to invest heavily in hypersonic missiles using the Science, Technology, and Society (STS) framework of the Sociology of Scientific Knowledge (SSK). The SSK framework intends to explain the interpretation of a technology within its historical, political, social, or economic context. The interconnection of international competition, national security, lucrative defense contracts, and human justice lends to complex ideas of the utility of hypersonic missiles. Ultimately, this discussion leads to the question of how much our national defense is guided by direct solutions to perceived security threats and how much is guided by misinformed notions of technological supremacy.

STS Topic: Methods and Sources

The discussion will be broken up into historical, political, and economic factors related to hypersonic missiles development, and will have separate sections for the current US hypersonic defense strategy and opposition to this strategy. This allows the direct use of the SSK framework to evaluate how these pressures affect the US's decision to invest in hypersonic missiles, and to determine whether this yields an optimized defense solution. The thesis will include 7 sections with sources for each section as detailed below:

1. Introduction
    - Introduce the competing claims about the utility of hypersonic missiles, what could be influencing these claims, and why it matters
    - Introduce SSK framework and its connection to the topic, as well as paper layout
2. Historical Context: The Hypersonic Revolution
    - Source #1: The Hypersonic Revolution: Case Studies in the History of Hypersonic Technology (1998 edition.)
        - Details the hypersonic projects leading up to 1998. One such example is the X-15 hypersonic research program, which desired to construct a piloted plane to fly hypersonic speeds.
3. Political Context: Tensions between the US, China, and Russia
    - Source #1: Vox news article — America's hypersonic arms race with China, explained
    - Source #2: Carnegie Endowment for International Peace
    - Source #3: Space Development Agency — U.S. touts progress in hypersonic arms race with China, Russia

- Source #4: A World in Disarray, Richard Haas
    - This book deals with the complexities of international relations and how world order is formed. More specifically, it details US-China relations with China's growing economic prosperity and intention to expand its sphere of influence into the South China Sea. It also discusses the Cold War arms race and how it issued relative peace.

4. Economic Context: The Defense Budget
    - Source #1: Department of Defense Spending Profile
        - Breaks down DoD spending into awards, contracts and grants. Includes budget and total commitments. Shows distribution of funds to defense-wide and military branches.
    - Source #2: Peter G. Peterson Foundation - Budget Basics: National Defense
5. Hypersonic Weapons Strategy
    - Source #1: Hypersonic Weapons: APPRAISING the "THIRD OFFSET"
    - Source #2: Hypersonic Weapons: A Challenge and Opportunity for Strategic Arms Control
    - Source #3: U.S. Hypersonic Weapons and Alternatives
6. Technical Assessment of Hypersonic Missiles
    - Source #1: Hypersonic Hype and the Ethics of Emerging Weapons Technology
        - Youtube video with two speakers, one from UCS and one from Stanton Nuclear Security. The UCS speaker, Dr. Cameron Tracy, explains why hypersonic missiles are not more effective than ballistic missiles, and paints the picture that defense contractors are deceiving the government for more funding.
    - Source #2: Slowing the Hypersonic Arms Race

    - Article by UCS that includes a background on hypersonic weapon development and defense spending with their own interpretation on why the US is investing in hypersonic programs. Has graphs supporting the inferiority of hypersonic missiles to ballistic missiles.
  - Source #3: Hypersonic Missiles Defense: Issues for Congress
7. Conclusions
  - Answer: Is the call for hypersonic missiles logical technologically?
  - Answer: Should the US continue engaging in the hypersonic arms race? To what extent?
  - In summary: How do various factors play a role in the interpretation of hypersonic weapons?

Conclusion

The issue of US defense spending decisions can be improved upon by my research, because my thesis will provide a comprehensive and unbiased look into the historical, political, economic, and technical factors influencing the decision to pursue hypersonic missiles. My research can potentially affirm or reject the prudence of participating in the hypersonics arms race. If I find that the UCS has ignored important factors related to the advantages of hypersonic missiles over ballistic missiles, this piece could turn into a discussion of why they might wish to influence the public against hypersonic missiles, and the conclusion may restore readers' faith in the US government and its ability to make logical decisions. However, if the UCS is correct in saying that hypersonic missiles are no better than ballistic missiles, and the US is investing because it has been deceived by defense contractors or because it is blindly jumping on the metaphorical

band wagon with Russia and China, then a reevaluation of the US government defense spending decision making process would be necessary. This would potentially cause the reader to lose trust in the government's ability to defend the nation and its interests.

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