Visualizing Position and Orientation in 3D Space Using Common External Controllers

(Technical Paper)

Inertial Motion-Sensing Technology to Aid Rehabilitation and Development of People with Disabilities

(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

Nicholas Miller

Fall, 2022

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

Signature _____ Date _____

Nicholas Miller

Approved _____ Date _____

Briana Morrison, Department of Computer Science

Approved _____ Date _____

Joshua Earle, Department of Engineering and Society

Introduction

Inertial sensing technology permeates much of our modern world, being used in a host of common devices for a variety of purposes. At its core, inertial motion sensing takes measurements of the inertial properties of a device and extrapolates information about the corresponding motion, position, or orientation of the device. In most inertial measurement units, abbreviated as IMUs, this takes the form of at least an accelerometer and gyroscope which measure the device's acceleration and angular velocity, respectively. This technology is used in devices ranging from GPS systems to mobile phones and videogame controllers to vehicles and aircraft, showing broad and extensive usage.

Despite the prevalence of inertial sensing technology in everyday devices, its use in small, independent projects is surprisingly restrictive. While obtaining an IMU is relatively simple, implementing the IMU in a useful manner from scratch requires a prohibitive amount of knowledge about hardware for the vast majority of people. Furthermore, there is little in the way of open access software to interpret raw inertial measurements in a useful manner. My technical project seeks to mitigate this problem by building an open access library to read and interpret inertial sensors on common devices that house them. In doing so, I hope that this inertial sensing technology becomes more accessible to the independent developers and smaller projects that often become the starting point for innovative ideas.

In connection with my technical project, there are many unexplored or incompletely explored potential uses of inertial sensing technology. My STS project investigates one of these, specifically its potential in aiding the rehabilitation and development of people with disabilities. The project involves analyzing the potential of the technology in this particular use case as well as the assumptions and reactions correlated with its use. I aim to not only answer the question of

whether increased usage of inertial sensing technology would be technically beneficial to the field, but also whether it would be welcome by those upon which it would be used.

This prospectus outlines both of these projects and describes their approaches in turn. It begins by taking a more in-depth look at the technical project, its results, and its continued path towards improvement. Then, the prospectus presents a greater discussion of the STS question by examining the importance of the question, defining relevant social groups, indicating the STS frameworks intended to be used, and developing a plan for research. Finally, the prospectus will present key sources that will be used in the STS project.

Technical Project

As mentioned above, there are currently few easily accessible ways to interface with common inertial sensing capable hardware, hampering the use of inertial sensing technology in small, independent projects. In hopes of making this technology available to more users, I built an openly-accessible library to interface with common inertial sensing capable devices. The focus of the project, among the many possible uses of inertial sensing technology, is on estimating the position and orientation of a device in 3D space. To this end, the project's functionality can be broken down into three distinct components: reading the device's inertial sensors, interpreting the read data into useful metrics, and visualizing those metrics as a position and orientation in 3D space. Each of these components are modular and work independently, thus allowing their use as both a complete pipeline and individual systems.

With this library, the user is able to receive and visualize accurate position and orientation data of a device for short periods of time without recalibration. As time progresses,

the system's state drifts from the state of the physical device due to noise and other factors, decreasing accuracy without a way to calibrate the sensors.

Currently, support only exists for the Nintendo JoyCon controller, as this was the device used throughout development. Additional work on this project would seek to expand the sensor reading component to work with other common devices, such as smartphones or other controllers, using the modular nature of the library. This would further the project's goal of increasing accessibility. The interpretation component could also be improved by exploring options to support recalibration and increase length of effective use-time. This improvement would include options such as using other sensors on a device to supplement calibration, better noise reduction algorithms, or manual recalibration.

STS Project

My STS project seeks to apply the technology examined in my technical project, inertial motion sensors, to the field of disability rehabilitation and development. To this end, I intend to answer two primary questions. First, is inertial motion sensing technology useful in the treatment and rehabilitation of disabilities? Second, are this new technology and the potential resulting forms of treatment acceptable and what kinds of assumptions are carried with them? The former is obviously necessary to establish whether implementing this technology in this field would even be beneficial, as well as examine what kinds of new treatments might be introduced or how existing treatments could be augmented. The latter question, however, is equally if not more important to ask, yet often forgotten. Before we attempt to implement any new technology, we must always consider the assumptions we are introducing with it. There are multiple cases of misguided treatments being introduced in the past that ultimately harm those affected and build

negative social constructions around perceived disability. For example, there is a great deal of controversy around ABA therapy to treat autism with some autistic advocates claiming that, "ABA tries to make kids with autism fit neurotypical standards," ("The Controversy Around ABA", n.d.). As such, it is important to closely examine how this technology will impact those being treated and what social constructions are we enforcing by using it.

In analyzing the problem of inertial motion sensors in the treatment and rehabilitation of disabilities from an STS perspective, I've defined four primary social groups that broadly define those relevant to the issue. These social groups are: those who receive treatment, those who administer treatment, those closely related to those who receive treatment, and the general public. To describe each of these more clearly, I will elaborate on my reasoning behind this classification.

Firstly, I chose the first social group as "those who receive treatment" to encompass all the people who would be directly impacted by the introduction of a new treatment using inertial sensors. Notably, this is not a social group of people with disabilities because such a classification would introduce the assumption that all those treated would have a disability. This would be ignorant of both the uncertain and ambiguous definition of disability as well as the potential for misdiagnosis or mistreatment. As a result, I chose a broad classification of all those who receive treatment. The second social group I defined simply refers to all the practitioners, care providers, and other personnel who directly administer the treatment. These people have a direct impact on how any potential treatment methods using inertial sensors are used, either appropriately or inappropriately. The third social group is those who are closely related to those who receive treatment. This broadly refers to any close relative or friend of someone who is a recipient of inertial sensor-based treatments, but is primarily intended to encompass any

guardians, parents, or decision-makers of the recipient. These characters have significant impact on the decision-making of the recipient, in some cases even full legal authority, and thus play an important role in their experience with any potential new treatments. Finally, the last social group of the general public refers to anyone not directly connected to any of the other groups. This category is not meant to be representative of any individuals, but rather society as a whole. The primary purpose for the introduction of this social group in the context of this problem is to consider and analyze how treatments might shape public perception of disability.

These definitions are meant to convey the broad nature of each category, however, for clarity and ease of use, these groups will be referred to as recipients, practitioners, relatives, and the public, respectively, in further discussion below.

Outside of the four social groups outlined above, some other groups that might be relevant but I have elected to exclude are officials and engineers. Officials includes any government, regulatory body, or other institutionalized officials that make decisions about the use of certain treatments. While this group would play an important role in deciding if and how inertial sensors would be used, they would not have a large impact on the actual experience of the recipients of said treatment. As such, I decided to exclude them from my consideration. Similarly, I chose to exclude the engineers and other developers who develop and create the technology because much of the technology already exists. We are only examining how existing technology could be applied to a different use case and so key decisions that might carry assumptions would be primarily present in those who use the technology, rather than those use built it.

To effectively analyze these social groups and the interaction between them in the context of this problem, I plan to use two STS frameworks. The first will be Disability Studies.

Disability Studies, as summarized by the book *Keywords for Disability Studies*, "…explores the social, cultural, and political dimensions of the concept of disability and what it means to be disabled," (Adams et al., 2015, p. 2). In particular, this research question is interested in examining the assumptions that define disability and the experience of people with disabilities in the context of inertial motion sensing technology. The Disability Studies framework is ideal for this because it provides a strong basis for the analysis of disability that will be foundational to our question. Furthermore, I also plan to use the Social Construction of Technology, or SCOT, as a supplementary framework in answering the research question. SCOT describes and analyzes technological artifacts by focusing on the meanings assigned to them by relevant social groups (Bijker et al., 2012, p. 40). A core concept of SCOT also deals with the variations of a technology that arise when used and changed by different social groups for different purposes that embed different meanings into them. Thus, since our problem deals with the application of inertial motion sensing technology to a new environment with different social groups, this approach of focusing on the social groups that are entwined with the technology aligns well with our question.

The timeline for researching and answering this question can be described in three steps. The first step will be to continue research about previous and potential applications of inertial sensing technology in disability treatment with the goal of answering my first STS question and informing the realities of any such treatments. Next, after defining the form that relevant treatments may take, further research will be done looking at disability studies and past examples of introducing new disability treatments. This will work towards answering my second STS question in the context of what has already been defined as potential forms of treatment. Lastly,

with my research concluded, I will analyze the problem through the frameworks and social groups mentioned above to come to a complete answer.

Key Texts

In beginning the research necessary to answer my STS research question, I have compiled four primary sources so far that will serve as a strong foundation for my project. These sources are described in turn below.

The first key source I have found is a study from 2015 called "Causal Analysis of Inertial Body Sensors for Enhancing Gait Assessment Separability towards Multiple Sclerosis Diagnosis" by Gong et al. (2015). This study discusses a technique for diagnosing various diseases, disorders, and injuries using inertial sensors for gait assessment. The paper also presents results from applying the technique in a pilot study that demonstrated using inertial sensors resulted in statistically significant better analysis and diagnosis than traditional methods (Gong et al., 2015). This study establishes older work on applying inertial sensing technology to disability studies and presents its advantages, a key part of answering the first question of my STS project.

The second key source I have included is, similarly, a study from 2022 called "Accuracy and Validity of a Single Inertial Measurement Unit-Based System to Determine Upper Limb Kinematics for Medically Underserved Populations" by Hughes et al. (2022). This is a newer study investigating the potential application of inertial sensors to rehabilitate stroke victims as a low-cost and portable alternative to more expensive options (Hughes et al., 2022). The study presents very recent findings on the applications of inertial sensing technology in the medical

field, particularly as a low-cost alternative, which is a strong piece of evidence for the first question of my STS project once again.

The third key source instead relates to the second question of my STS project and is *Keywords for Disability Studies* by Adams et al. (2015). This book serves as an introductory text to Disability Studies and a careful consideration of the language and assumptions that surround disabilities. The book is a strong foundation for my analysis of disabilities and will inform much of the discussion throughout my paper.

Lastly, the final key source is a book called *Dangerous Diagnostics: The Social Power of Biological Information* by Nelkin and Tancredi (1994). The book is a potent exploration of the negative impacts of diagnostic testing and the potential of its misuse to control individuals. Specifically, the book targets the ethical, social, and legal implications of new technologies that can lead to new forms of discrimination (Nelkin & Tancredi, 1994). This book will be a powerful source in contextualizing the discussion around the potential new techniques introduced by inertial sensing technology. It will be a key component of my project's examination of the negative implications of introducing new technologies and what we must avoid doing.

References

Adams, R., Reiss, B., & Serlin, D. (2015). *Keywords for Disability Studies*. New York University Press. http://ebookcentral.proquest.com/lib/uva/detail.action?docID=3564341

Bijker, W. E., Hughes, T. P., & Pinch, T. (Eds.). (2012). *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology* (Anniversary ed). MIT Press.

Gong, J., Lach, J., Qi, Y., & Goldman, M. D. (2015). Causal Analysis of Inertial Body Sensors for Enhancing Gait Assessment Separability towards Multiple Sclerosis Diagnosis. *2015 IEEE 12th International Conference on Wearable and Implantable Body Sensor Networks (Bsn)*. https://www.webofscience.com/wos/woscc/full-record/WOS:000380423600053

Hughes, C. M. L., Tran, B., Modan, A., & Zhang, X. (2022). Accuracy and Validity of a Single Inertial Measurement Unit-Based System to Determine Upper Limb Kinematics for Medically Underserved Populations. *Frontiers in Bioengineering and Biotechnology*, *10*, 918617. https://doi.org/10.3389/fbioe.2022.918617

Nelkin, D., & Tancredi, L. (1994). *Dangerous Diagnostics: The Social Power of Biological Information*. University of Chicago Press. https://press.uchicago.edu/ucp/books/book/chicago/D/bo3613694.html

The Controversy Around ABA. (n.d.). Child Mind Institute. Retrieved October 11, 2022, from https://childmind.org/article/controversy-around-applied-behavior-analysis/