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

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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

According to the CDC, in 2022, 61 million adults in the United States live with a disability which accounts for 26% of the adult population (CDC, 2022). Rosemarie Garland-Thomson (2002) puts it another way when she says, “Disability is an identity category that anyone can enter at any time, and we will all join it if we live long enough” (p. 20). As can be seen, disability is a prominent aspect of life and the ways we handle it are hugely impactful on society. Additionally, from an individual perspective, disability can inhibit many activities and decrease quality of life. Yet, despite this, 1 in 5 adults with disabilities have an unmet healthcare need because of cost in the past year and many continue to suffer (CDC, 2022).

While not all disability can or should be treated, efforts to increase accessibility and quality of treatment continue to be needed. This paper investigates how one potential technology, inertial motion-sensing and measurement devices, can be used towards both of these ends. In brief, inertial measurement technology enables devices to read and interpret the inertial forces present on an object. This commonly refers to acceleration and angular velocity but can also include other measurements such as magnetic fields. Many of the current uses of inertial measurement technology involve estimating the position and orientation of an object using these inertial measurements and tracking all kinds of motion in 3D space. As such, an application of this technology shows much promise in the field of disability studies, especially for the 11.1% of disabled adults that have a mobility-related disability, by far the largest category (CDC, 2022).

However, the social implications of disability studies are important and disabled individuals are a historically marginalized group. The introduction of new treatment methods and technologies, in particular, has resulted in pervasive and severe negative consequences in the

past. Thus, as with any new technology, the potential use of inertial measurement technology in disability studies must be handled with care. This paper also considers the social implications of using inertial measurement technology and shows that it is not only beneficial from a medical perspective, but from a social one as well.

Throughout this paper, I present my argument for the introduction of inertial measurement technology to disability studies, particularly as a low-cost, easily-accessible alternative to current treatment methods. I first introduce my methods of research and analysis, detailing the frameworks through which I make my argument. I then synthesize research to argue the feasibility and usability of the technology in disability studies from a medical point of view. This is followed by a presentation of key STS literature surrounding disability studies as well as an analysis of the potential social implications of the technology and how they might be managed. Lastly, I conclude with a discussion of the advantages and disadvantages of inertial measurement technology and a look into the future of the technology.

Methods

Types of Sources

In my research, I accumulated a variety of different types of sources to address the questions posed in this paper. First, in an attempt to address the feasibility of using inertial measurement technology in disability studies as well as to inspire discussions on its potential uses, I compiled multiple research reports chronicling past research. This research detailed topics such as gait-analysis using inertial body sensors (Gong et al., 2015), continuous monitoring with wearable inertial sensors (Jalloul, 2018), and single inertial sensor systems for upper limb kinematics (Hughes et al., 2022). Other compiled sources dealt more with the social

ramifications of introducing a new technology including several foundational works on disability studies. This also included case studies and prior examples of introducing new technologies to disability studies and their ramifications. Lastly, I conducted an interview with Karen Millerson PT, DScPT, a pediatric physical therapist who works with disabled kids in the public school system. This interview was aimed at discussing a more personal viewpoint of technology in disability studies and how it affects real disabled individuals. In addition, the interview sought to gain Dr. Millerson's opinion of how inertial measurement technology in particular might be implemented and the dangers it could pose.

Frameworks

Next, to outline my method of analysis, I use two STS frameworks. The first is Disability Studies. Disability Studies, as summarized by Rachel Adams and coauthors (2015) in 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" (p. 2). In particular, this paper is interested in examining the assumptions that define disability and the experience of people with disabilities in the context of inertial measurement technology. The Disability Studies framework is ideal for this because it provides a lens and collection of prior studies through which to view and analyze disability. Furthermore, I also use the Social Construction of Technology, or SCOT, as a supplementary framework. SCOT describes and analyzes technological artifacts by focusing on the meanings assigned to them by relevant social groups (Bijker et al., 2012). 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. Since my problem deals with the application of inertial measurement 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 my goal.

Important Definitions

Lastly, disability is a term steeped in many stereotypes, perceptions, and conflicting definitions. As such, it is often not always clearly defined and what qualifies as a disability is ambiguous in nature. Similarly, many of the correlated terms I use throughout this paper are nebulous in definition. First, while I have already used it extensively in such a way, the term disability does not refer to a single coherent condition or category. Instead, as is claimed to be a central tenet of disability studies, "disability is produced as much by environmental and social factors as it is by bodily conditions" (Adams et al., 2015, p. 5). An individual's ability or inability to perform tasks, integrate into society, or navigate their environment is as much a function of their society and environment as it is a function of their body. Given this, I define the term disability as the combination of social, environmental, and bodily conditions that determine an individual's ability to perform a task. A disabled individual refers simply to someone who is restricted by their environment on account of their bodily condition.

To expand on the definition above, I can begin to think about the differences, or lack thereof, between physical and mental disabilities. It would seem at first glance that inertial measurement technology would apply almost exclusively to physical disabilities. However, in their discussion of cognition, Adams and coauthors (2015) recognize that, "embedded cognition reveals the extent to which we all depend on our physical and social environments to think" (p. 40). They find that this conceptualization of cognition, "blurs the line between 'physical' and 'mental' disabilities because no condition is strictly one or the other," (Adams et al., 2015, p. 40). An improvement in physical ability can lead to a subsequent improvement in mental

cognition and vice versa. Hence, the line between physical and mental disabilities remains blurred and is replaced by the concept of bodymind (Price, 2015). A term coined to represent the lack of separation between body and mind in disability studies.

One more term I define that is used extensively throughout this paper is treatment. Much discussion is afforded to the different types of treatment that inertial measurement technology could take the form of or participate in. Therefore, a simple and robust definition of treatment for the purposes of this paper refers to any action or practice that seeks to alleviate one of the barriers to a disabled person's ability, be it social, environmental, or bodily. Notably, this does not require the treatment to be directly administered to the disabled person themself.

Medical Usability

Before I begin to analyze how inertial measurement technology might impact the social dimensions of disability studies, I must first establish how usable the technology might be and what forms that use might take. Thankfully, numerous studies have been carried out that attempt to determine how similar sensors and technologies can be used to assist in treatment of disabilities. Additionally, I can gain valuable insight into the technology's potential use from Dr. Millerson in how she uses similar technologies and how she might envision inertial measurement technology in her work.

Relevant Studies

In 2015, Jiaqi Gong and coauthors ran a study investigating the potential of inertial body sensors to improve gait assessment, specifically for the diagnosis of multiple sclerosis. The study found that the inertial body sensors were able to identify differences in the gait of those with multiple sclerosis and healthy individuals by a statistically significant margin, (Gong et al.,

2015). Additionally, they implemented a new technique that demonstrated a much better separability than existing methods. The statistical measure associated with this better separability is a p-value of less than 0.0001, where a p-value of less than 0.05 is usually considered statistically significant (Gong et al., 2015). This study convincingly demonstrates the potential effectiveness of inertial measurement systems in disability diagnosis, specifically focused on movement-related disabilities.

However, diagnosis is not the only area of disability treatment to which inertial measurement technology has the potential to be applied. Multiple studies have studied the portability of the technology and the ability of patients to wear sensors. In 2018, Nahed Jalloul attempted to implement easily accessible wearable sensors utilizing recent advances in the miniaturization and sophistication of sensor technology. Jalloul (2018) reported on these wearable sensors by saying, "Monitoring a patient's health status remotely and continuously for a long duration without the need for hospitalization not only provides the opportunity for better management of the patient's condition, but also reduces the consequent healthcare costs" (para. 1). Wearable inertial measurement sensors, in particular, were shown to be effective for numerous different disabilities and movement disorders including gait-related disorders, tremors, motor response fluctuations, osteoarthritis, dyskinesia, and others. Furthermore, Jalloul (2018) says a major criticism of conventional methods is that they are, "…normally conducted through clinical visits that include subjective methods and are spread out over long periods of time: an issue which hinders physician's ability to properly evaluate the patient's progression" (para. 4). An issue which wearable inertial sensors largely fixes with their ability to provide objective and continuous measurements of patients' movements. Thus, an application of inertial measurement technology as a form of continuous care through wearable sensors shows much promise as well.

To expand on these capabilities, as alluded to above, inertial measurement technology has the potential to provide low-cost and easily accessible treatment to medically underserved populations. In a recent 2022 study motivated to improve stroke outcomes in low-income countries and other traditionally medically underserved populations, Charmayne Mary Lee Hughes and coauthors assessed the accuracy and validity of using a single inertial measurement sensor to determine upper limb kinematics. In contrast to the more complicated arrangement of wearable sensors utilized in previous studies, Hughes and coauthors (2022) sought to demonstrate how even a single wearable sensor provides comparable results to standard reference systems and dramatically improves outcomes for the medically underserved. Since only one sensor is used, the system is easier and cheaper to distribute and requires less training to put on. Despite its simplicity, Hughes and coauthors (2022) concluded that the single sensor was statistically significantly correlated with the gold standard reference system for all tasks and measures. They claim that, "the T'ena single IMU sensor system is a valid and objective method by which to measure movement kinematics during functional tasks," (Hughes et al., 2022, p. 8). As a result, little to no compromise is made on efficacy in exchange for a cheaper and more readily accessible alternative to existing technologies allowing for better treatment of medically underserved populations.

Professional Opinions

When asked about how this technology might be useful in her work, Dr. Millerson emphatically agreed that it shows much potential. In fact, she admitted that she has used similar motion tracking technologies in the past such as Nintendo Wii controllers and Xbox motion tracking to help kids learn physical skills. Not only that, but a newer technology that her program has begun to use with kids in the past year is virtual reality (K. Millerson, personal

communication, November 18, 2022). Almost all current virtual reality technologies utilize inertial measurements to track movement between the real and virtual worlds, so in some way, she has already implemented aspects of inertial measurement technology to great effect. Dr. Millerson reported that one of the most beneficial uses of virtual reality so far has been its ability to work remotely, a feature that saw great use during the pandemic and continues to be used with disabled kids not able to come physically to school. When asked about how she envisions inertial measurement technology would enhance her work, she says, "So where I could see, is like, I teach it at school and then a student could access it on their own computers at home to get more practice" (K. Millerson, personal communication, November 18, 2022). Furthermore, repeatedly throughout the interview Dr. Millerson talks about how prohibitive cost often is in the school system, especially in specialized cases. She then mentions that the potential of inertial measurement technology as a low-cost option to many cases shows tremendous promise (K. Millerson, personal communication, November 18, 2022). In conclusion, Dr. Millerson makes clear that there are a multitude of different ways that inertial measurement technology has and could continue to see use in her work.

This collection of studies and professional opinions demonstrates both the variety and effectiveness of use cases that inertial measurement systems show potential for in the diagnosis and treatment of disabilities. In particular, the relatively low cost of inertial measurement sensors and the ability to wear them continuously and remotely has been shown to be greatly beneficial to the availability and quality of disability treatment. While other forms of usage have been demonstrated, such as in conjunction with virtual reality systems or helping to train physical skills, most current studies focused on the usage of this technology as wearable sensors that continuously gather data about body kinematics and movement. As such, the most likely form

treatment with inertial measurement technology would take were it used more widely is as wearable sensors.

Social Implications

While the above established the usability and benefits of inertial measurement technology in disability studies, I evaluated the technology almost exclusively from the medical model of disabilities. However, it is important to note that there is a difference between the perception of disability through the lens of a social problem and a medical problem. This does not invalidate the points made above, but simply argues that they are inadequate by themselves. In discussing an analogy between successive models of disability and traditional scientific enlightenment, Sharon Barnartt and Barbara Altman (2001) relay, "…the replacement of Newtonian mechanics by the Einsteinian theory of relativity did not invalidate the former approach, but merely showed its limitations" (p. 22). In the same way, a social model of disabilities does not invalidate former insights taken from the medical model but seeks to shed light on their shortcomings.

With this in mind, it is clear I must take care to analyze and prove the effectiveness of this new technology through the lens of a social science. In the case of this paper, the primary questions I seek to answer are if inertial measurement technology might have a negative social impact on those with disabilities and if such a solution might hide the true social issues at play. To answer these questions, I begin with a discussion of past disability technologies and their effects, followed by a consideration of the dangers of diagnostics and marginalization, and ending with a look into the concept of cure and disability dongles.

Past Disability Technologies

A great source of insight into the problem of inertial measurement technology in disability treatment comes from examining past cases of new technology being introduced to disability studies and how they impacted disabled individuals through a social lens. By comparing and contrasting these cases, I can arrive at key takeaways that can apply to inertial measurement technology. One particularly contentious example of new disability treatments is applied behavior analysis (ABA) therapy. ABA therapy refers to a collection of techniques designed to help children with autism. However, ABA therapy has seen much criticism in recent years around the idea that it is abusive and forces neurotypical standards upon autistic children (The Controversy Around ABA, n.d.). The first of these criticisms derives from a history of repetitive and strict reinforcement that squashes kids' creativity and playful attitude. Additionally, while not considered acceptable today, early forms of the treatment included aversive reinforcement methods such as electric shocks (The Controversy Around ABA, n.d.). The second primary criticism stems from the tendency of ABA therapy to focus on eliminating behaviors and differences. It tries to get kids to fit a perfect mold of how they should behave, which is not only harmful to their individuality but establishes the precedent that neurodiversity is not accepted.

In contrast, the introduction of virtual reality into disability treatment has been a positive introduction that has resulted in an increased ability to effectively treat kids. As Dr. Millerson relays in her interview, virtual reality helps her kids train to navigate an environment and can be customized to specific environments or circumstances. It is especially useful in allowing remote treatment where kids can practice valuable skills from home when in-person therapy is not possible (K. Millerson, personal communication, November 18, 2022). The key differences between these two small case studies, and the drastic differences in their outcomes, come down

to their intention and implementation. In the case of ABA therapy, the primary focus was to eliminate undesirable behaviors. On the other hand, virtual reality is only intended to build skills. Additionally, ABA therapy was introduced as a revolutionary new technology and a complete solution to autism. Virtual reality, instead, is a supplementary technology used to assist and enhance existing treatments as well as reach new niches that were previously lacking. From this comparison, it is important to note that inertial measurement technology is unlikely to revolutionize disability treatment or present a complete solution on its own. Instead, inertial measurement technology should be approached with the potential to enhance existing treatment methods and breach new niches with the goal of adding more, not eliminating.

Diagnostics & Marginalization

This alone does not serve to combat all potential negative social impacts of introducing a new technology to disability studies. As Dorothy Nelkin and Laurence Tancredi (1994) make clear in the book *Dangerous Diagnostics,* seemingly objective cutting-edge technologies are often used to classify, marginalize, and control individuals. In summary, any system or technology that attempts to objectively classify or diagnose individuals is ripe for misuse and exploitation. *Dangerous Diagnostics* particularly cautions against, "the creation of an underclass deemed unemployable, untrainable, or uninsurable by such diagnostic tests," (Nelkin & Tancredi, 1994). This issue is particularly important for inertial measurement technology because, as is mentioned above, medical diagnosis is a potential and already explored use case of the technology. Furthermore, the study which used inertial measurements as a diagnostic tool used statistical techniques to make the determination. Statistics, as a practice, has seen much controversy over its perceived and purported objectivity yet often situational subjectivity and

rampant caveats. Thus, the technology is especially dangerous if greater weight is lent to its diagnoses on account of its incorrectly perceived objectivity

With such a danger presented, the question becomes how might we combat the misuse of inertial measurement technology in diagnostics? I would argue that the primary defense would be to prohibit the use of inertial measurement diagnosis as the sole arbiter of diagnosis. To echo what is stated above, the technology should not serve as an always reliable solution by itself, but as a tool with which to provide easier testing and be used in conjunction with other techniques tempered by a trained administer. This was reiterated in my discussion with Dr. Millerson. When I asked about the dangers of diagnostics with this technology, she said that she believes it would be, "mostly just a tool" (K. Millerson, personal communication, November 18, 2022). Considering this, the problem might not be the diagnostic tool itself but the social meanings embedded in the tool as a result of its application to disability studies. A point that is addressed further below in a discussion of the advantages and disadvantages of inertial measurement technology.

The Cure & Disability Dongles

To continue my analysis on the potential negative social implications of introducing inertial measurement technology to disability treatment, I must still explore the concept of cure. Cure ideology refers to the belief that body-minds considered broken, or disabled, need to be fixed. As Eli Clare (2017) puts it in her book *Brilliant Imperfection*, "framing disability as a medical problem lodged in individual body-minds, which need to be treated or cured" (p. 8). Notably, this is in direct contrast with the definition of disability I provided above that describes it as a combination of social, environmental, and bodily conditions. Yet, this is a prominent viewpoint of supposed experts, doctors, and nondisabled people who choose to view disability as

a purely medical problem with purely medical solutions. Such a viewpoint ignores that disability is a social problem with many social dimensions.

Similarly, the disabled community has branded many new technologies as disability dongles in an effort to resist this one-sided belief that they need to be cured. These disability dongles are fancy, cutting-edge new technologies that claim to solve some great problem for disabled people and excite the populous about increased accessibility yet are useless in practice. They often attempt to solve a problem that never really existed in the first place (smith, 2019). Both cure ideology and disability dongles present the same issue. That disability is a personal problem that needs to be fixed for the individual disabled person. The onus is put on the disabled to adjust to and be fixed for an unwelcoming, unaccommodating environment. This is a fallacy that must be avoided with inertial measurement technology.

At first glance, inertial measurement technology appears as a textbook case of cure ideology and a disability dongle. It is an exciting new technology that promises great gains from the medical viewpoint of disability. The main difference is that inertial measurement technology, as it has been proposed and as has been repeatedly emphasized in this paper, is just a tool. It is not a disability dongle because it does not promise a solution to some new great problem but a boost to existing methods and treatments. This, admittedly, does not resolve it from the dangers of cure ideology. Since inertial measurement technology is most likely to be worn by disabled people, it could be viewed as an attempt to fix them rather than presenting a complete social solution. Similarly to diagnostics, this is a point that is discussed further below.

Discussion & Conclusion

Throughout this paper, I have discussed both advantages and disadvantages of the introduction of inertial measurement technology to disability studies and treatment. The advantages show the potential this technology has for increasing diagnostic accuracy and treatment effectiveness as well as for providing therapists and practitioners with new niche ways to interact with and serve their patients. The disadvantages address the potential social ramifications of the technology and how it might negatively impact the disabled population. Of these, there were two primary disadvantages discussed above that remain unresolved. Notably, the potential dangers of diagnostics and the dangers of the cure ideology that the technology might perpetuate. The cornerstone of both these issues thus far has been the nature of inertial measurement technology as a tool. It has the potential to be a tool used to aid and supplement treatment. In much the same way, the technology also has the potential to be a tool to exacerbate current social issues with disability depending heavily on how the technology is used and the meanings embedded in it by its use.

Given these concerns, great care must be taken that this technology is used appropriately. To claim that inertial measurement technology has amazing potential for good and no drawbacks in disability treatment would be entirely ignorant of the complex social dimensions at play. What I argue is not that this technology is an infallible solution that must be implemented with earnest. Such an argument is reminiscent of many of the misguided "solutions" of past disability technologies. Instead, I argue that inertial measurement technology's potential for good is greater than its potential for bad. I believe that the methods described throughout this paper, using inertial measurement technology as an alternative and enhancement to existing treatments, best mitigate the dangers and emphasize the strengths of the technology. While this is not a complete solution, any attempt to truly solve the concerns with this technology would require resolving the

deeply ingrained societal problems of disability at their core. Instead, future research on inertial measurement technology in disability treatment should be cognizant of the social model of disabilities and focused on how the technology can be consistently implemented to avoid and mitigate these unresolved social issues. Notably, while I was able to explore how a professional physical therapist feels about the technology through an interview, I was unable to get any interviews with disabled individuals who might use the technology. An exploration of this angle would be a fruitful avenue for more research. Despite its potential shortcomings, I believe inertial measurement technology should continue to be introduced to disability treatment, not with earnest, but with care.

Inertial measurement technology presents great opportunities for the enhancement of both efficacy and accessibility of disability treatment through low-cost, easy-access alternatives to existing treatments. With such a large population of disabled people, many of whom don't have access to needed treatment, this technology is a powerful tool that has the potential to improve lives and relationships in disability treatment for many. And so, the continued development of disability treatment using inertial measurement technology, from both a medical and social perspective, shows much promise for a better future.

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