DESIGN OF A WEARABLE SKIN-LIKE MECHANICAL STRAIN SENSOR

TECHNOLOGICAL POLITICS OF ARTIFICIAL INTELLIGENCE-BASED MEDICAL DIAGNOSTIC ALGORITHMS

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 Mechanical Engineering

By
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Fall 2021

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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

The COVID-19 pandemic fueled an explosion in the wearables market, driven primarily by heightened consumer interest in self-tracking COVID-19 symptoms and monitoring general personal health and wellness (Rimol, 2021). Consequently, global spending on wearable devices is projected to total $81.5 billion by the end of 2021, an 18.1% increase in just one year (Rimol, 2021). Interestingly, this widespread public adoption is occurring despite clear technological deficiencies: current wearable devices, like the Apple Watch, Oura Smart Ring, and Fitbit, can only evaluate—with questionable accuracy—a limited range of biophysical signals that have veritably minimal clinical relevance (Ray et al., 2019).

However, these devices have importantly served as a principal source of inspiration for necessary progress in the healthcare industry. State-of-the-art noninvasive physiological monitoring systems are capable of recording highly precise, clinically significant measurements, yet require operation by trained medical professionals in a laboratory environment, and are thus unfeasible for daily, continuous wellness monitoring (Ray et al., 2019). As such, the ideal sensor would combine the portability and accessibility of the former with the latter's precision and substantive medical pertinence. Extensive research with transparent, elastic conductors has brought this once elusive technology into existence, pioneering a new generation of noninvasive wearable electronic devices that can bend and stretch reversibly around the human skin to accurately gauge temperature, biopotential, pressure, strain, and motion (Ray et al., 2019).

Nonetheless, no technology exists in a vacuum; therefore, it is important to consider the economic, political, and social factors surrounding its deployment. In long-term applications, wearable electronics generate collections of data that would be cumbersome to examine manually. Accordingly, data scientists have forged artificial intelligence (AI)-based solutions that rely on neural networks, decision trees, and other modern statistical methods to perform the analysis required to find patterns and generate outcome predictions, in this case medical diagnoses. As a result of numerous interwoven socio-political and socio-economic circumstances, it is practically unattainable to build AI-based technologies with complete and utter fairness (Mehrabi et al., 2021). Moreover, the importance of acknowledging, understanding, and ultimately mitigating this implicit bias becomes all the more significant in the application at hand, where an AI system is serving as an adjudicator in delicate and potentially metamorphic decisions (Mehrabi et al., 2021).

To effectively support innovation in the healthcare industry, it is essential to analyze the surrounding technical and social implications. Regarding the technical, my team and I will design and fabricate a wearable skin-like mechanical strain sensor using proven system architectures and manufacturing methods to demonstrate the relative ease of developing and replicating these advanced devices. On the other hand, regarding the social, I will apply technological politics to assess how non-technical factors, including legislation, access to information, and user input, affect the implicit biases and overall performance of these AI-based diagnostic solutions. As such, combining these two independent analyses will enable the successful deployment of wearable devices that not only generate more accurate and applicable clinical measurements, but also appropriately integrate AI-based diagnostic capabilities without inadvertently disadvantaging specific user groups or violating privacy rights.

Technical Problem

Wearable devices on the market today are typically composed of a small, planar block of wireless sensors and electronics, loosely coupled to the wrist, shoulder, or finger (Ray et al., 2019). Accordingly, the rigid components are unable to form stable, intimate interfaces with the skin, presenting a severe limiting factor in attaining high-accuracy measurements (Ray et al., 2019). While this is acceptable for measuring basic parameters (e.g., heart rate, VO2 max) in recreational applications, motion-induced distortions cause even the most accurate wrist-mounted devices to fail when monitoring any activity beyond low-intensity exercise (Ray et al., 2019). That being said, transparent, elastic conductors are paving the way for a new category of wearable devices with the ability to conform to the curved, irregular surfaces of the human body (Ray et al., 2019). This next generation of electronics and optoelectronics could spur the development of interactive electronics, implantable medical devices, and robotic systems with human-like sensing capabilities that bend and stretch reversibly and wrap around organic surfaces without wrinkling (Lipomi et al., 2011). Effective design of such state-of-the-art skin-like wearable sensors requires the careful threefold analysis of physiological, material, and engineering factors.

First and foremost, it is imperative to consider the biocompatibility of the chosen materials, as negative psychological and physiological effects can originate from improper electronic skin (E-skin) administration (Miyamoto et al., 2017). Substances with a porous, flexible, and stretchable structure are the least invasive, as measured in terms of the three principal factors of gas permeability, weight, and softness (Miyamoto et al., 2017). Substrates in particular have been a subject of great interest owing to their desirable physical properties, extensive range of possible material compositions, and unique opportunity for highly efficient and economical manufacturing (Zardetto et al., 2011). Polydimethylsiloxane (PDMS) is currently the most widely applied thin-film substrate, with numerous advantages including chemical inertness, stability over a wide range of temperatures, transparency, and variable mechanical properties (Hammock et al., 2013).

According to Ray et al. (2019), the most popular fabrication approach involves the creation of a laminar composite that embeds thin films of carbon nanomaterials between layers of elastomeric substrates like PDMS. Typically, this is implemented by either the physical transfer or direct deposition of prefabricated films of single-walled carbon nanotubes (SWCNTs) onto the elastomeric membranes, where SWCNTs are specifically chosen as the stretchable filler material due to their superior electrical properties. Yet, implementing this design—such that it provides the intimate, conformal contact necessary for clinically-relevant diagnostic procedures—first requires a careful analysis of the trade-offs between sensitivity and stretchability (Ray et al., 2019).

The goal of this technical project is to develop and manufacture a fully-functioning skin-like wearable mechanical strain sensor that will bridge the current divide in health and wellness monitoring, combining the portability and affordability of commercial devices with the relevancy and accuracy of medical-grade devices. It will be designed to capture the dynamic motions of the human body, with particular applications in clinical diagnostics (i.e., movement and neurological disorders) and athletic performance monitoring. In order to conform to size constraints and generate consistent clinically- and athletically-relevant measurements, the sensor will be intended for placement on the anterior deltoid (shoulder). Resistive strain sensors in a 4x2 array will be aligned to optimally measure uniaxial strain along the muscle fibers.

For relative ease of manufacturability, the sensor will employ an elastomeric substrate base with channels of conductors laminated to its surface. Taking into account relative commercial popularity and availability, PDMS will be used as the substrate material, and SWCNTs will be used as the conductive material. The actual fabrication process will be designed to utilize available resources, such as the Rapid Prototyping Lab, and all relevant work will be divided among the team of five students. Group meetings and check-ins with the capstone technical advisor will occur regularly to ensure that all project work is completed in a timely manner to established quality standards.

STS Problem

The growth of the Internet of Things (IoT) has propelled the world into an "information Big Bang" in which 2.5 quintillion bytes of data are generated daily (Marr, 2018). Per the three "Vs" of "volume, variety, and velocity", more data empowers more robust and concrete analysis (Kerry, 2020). As such, artificial intelligence (AI), a sweeping moniker for machine learning, algorithmic decision-making, and other modern statistical methods, is experiencing a boom in today's big data-driven world. AI-based technologies (e.g., speaker identification, image classification, and sentiment analysis) contain inhuman data-linking and pattern-matching capabilities, presenting a unique opportunity to achieve unparalleled levels of productivity and efficiency (Stahl, 2021). While the technology has been employed in everything from search engine optimization (SEO) to baseball analytics, one of the most promising applications to date lies in healthcare. Using large sets of clinical data, AI has found use in diagnosis, clinical decision-making, and personalized medicine, with impressive performance (Rigby, 2019).

However, this promising technology does not come without serious ethical, legal, and social implications rooted in issues of privacy and data protection, bias and transferability, and moral and professional responsibility (Carter et al., 2020). Currently, the privacy-related concern of patient confidentiality stands as the most frequently cited and hotly contested obstacle to the widespread implementation of AI-based diagnostic algorithms in the medical industry (Stahl, 2021). The artificial neural networks at the core of these algorithms rely on large training datasets, and accessing those datasets poses a clear cybersecurity risk from potential unwanted exposure to sensitive information (Stahl, 2021). Moreover, the algorithm may be able to formulate patterns and associated conclusions that violate patient confidence and consent, even in spite of rigorous data anonymization and randomization procedures (Stahl, 2021). In this way, the complex trade-off between user privacy and technological efficacy can be fully perceived: machine learning models with access to a greater range of data will be able to generate more accurate, refined, and consistent predictions, albeit at the possible violation of user privacy rights (Kerry, 2020).

If we continue to rush the deployment of AI-based diagnostic algorithms in the healthcare industry, then we will overlook critical effects of socio-political forces that threaten to not only compromise the effectiveness of this innovative technology but also severely infringe on the long-respected intrinsic right to patient confidentiality. Thus, I argue that the proper implementation of AI-based clinical diagnostic systems requires pre-existing legislation, precautionary oversight measures, and steady input and approval from all stakeholders—namely developers, deployers, and users—at each stage of the process (Kerry, 2020). To support this claim, I will apply the science, technology, and society (STS) framework of technological politics. At its interpretive crux, technological politics advances beyond the conventional view that technologies are inherently neutral objects that can be used for a political means, whether benevolent, malevolent, or even indifferent, conjecturing that they have built-in socio-political effects from their inception (Winner, 1980).

I propose that both technical and non-technical societal, legislative, and engineering factors must be carefully balanced during the development of AI-based diagnostic algorithms to avoid disadvantaging specific stakeholders. Ergo, technological politics provides an excellent investigative architecture to demonstrate how biases and tendencies can be unconsciously inscribed in AI-based medical technologies long before they are applied to any of their intended uses. This discussion will be augmented with evidence from reviews of targeted case studies and research, existing legislation and proposed remedies from institutional initiatives, and detailed examinations of genuine AI-based medical technologies.

Conclusion

This project will support the advancement of medical-based technologies by engaging a two-part analytical framework. This first necessitates the careful separation of the technical from the social in order to examine each in a "black box" devoid of potentially influential external factors. Only after this integral step is it possible to then draw thorough, absolute connections that resolve both the positive and negative feedback loops between the two. The purely technical component of the project will involve the complete lifecycle design of a mechanical skin-like strain sensor from conception to prototype to practical operation. One of the most important aspects of any new technology is replicability, and my team and I will strive to emulate the favorable results previously achieved from creating flexible electronics with elastomeric substrates and SWCNTs. Separately, the purely social component of the project will involve an intensive analysis of the technological politics of AI-based diagnostic algorithms in the healthcare industry. Ultimately, I aim to explore every aspect of wearable device deployment from a socio-technical lens, thereby arriving at the best means to incorporate the aforementioned technologies into the healthcare industry with minimal adverse effects on involved stakeholders at all levels.

Word Count: 1842

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