Wearable Technology: Developing a Skin-Like Temperature Sensor; Exploring the Adversarial Relationship between Tourism and Marine Pollution as an Incentive for Improving Waste Management Practices

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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

In 1981, Luke Skywalker, the protagonist of *Star* Wars, lost his hand and was given a bionic replacement with full sensory capabilities (Hammock et al., 2013). This was one of the first notable appearances of robotic prosthetics in science fiction. Naturally, the technology was far ahead of its time. In the 1970s, Clippinger et al. (1974) succeeded in creating a prosthetic capable of limited discrete sensory feedback. It was a far cry from Luke's bionic hand, but it represented the early stages of research into replicating human sensory capabilities. Considering 21% of people with upper limb loss opt not to use prosthetics, the limitations of current technologies can outweigh the benefits (Biddiss et al., 2007). These limitations include a lack of sensory capabilities, notably the human skin's tactile sensing abilities. Thus, electronically replicating the human skin could hold great advancements in the fields of both medicine and robotics.

The term electronic skin, or e-skin, is used to refer to artificial skin designed to replicate the characteristics and sensing capabilities of human skin (Hammock et al., 2013). Human skin's complex neural network allows it to sense external stimuli and send the information to the brain, and e-skin seeks to replicate this function by producing electronic signals in response to stimuli. This requires creating a multifunctional array of sensors with the ability to detect changes in strain, temperature, vibrations, pressure, etc. (Zou et al., 2018). Thus, the building blocks of e-skin are skin-like sensors with these individual capabilities such as temperature sensors.

Temperature sensors are able to detect minute changes in the body. Beyond their use in developing e-skin, they have applications in developing robots, clinical diagnostics, and providing continuous health-care monitoring (Ray et al., 2019). In order to be a wearable device, skin sensors must reflect the primary mechanical properties of human skin. Other desired properties include durability, low-cost large-area manufacturing, lightweight and biocompatibility (Miyamoto et al., 2017). Thus, the material selection is a key consideration in the design of wearable sensors. Most skin sensors commonly detect motion through changes in either resistance or capacitance of electronically active material which allow a simple and straightforward design (Ray et al. 2019). The measured changes in the electrical property are a result of temperature changes altering the resistance of the electrically active material. As mechanical engineers, my team is primarily interested in the structural components of the sensor. We seek to design a skin-like sensor with an original geometric structure that measures temperature as a function of resistivity.

Technical Project

Wearable sensors are typically designed as thin films composed of a substrate with channels of electrically active material throughout. Recently, nanomesh conductors have been researched as an alternative, substrate-free approach which offers greater gas permeability and less skin inflammation than planar substrates (Miyamoto et al., 2017). Although this research holds promise, my team will design our sensor with a planar PDMS substrate since it functions as a mold for the active channels which is more compatible with the 3D printing process.

Changes in the temperature of a resistive sensor can be measured through its relationship with the change in resistance of the internal conductive channels. The relationship between temperature and resistance is defined as $\frac{R}{R_0} = \alpha T + 1$ where R is the resistance after a change in temperature, R_0 is the original resistance, α is the temperature coefficient of resistance, and T is the temperature at which *R* is measured (Xu, 2021). Thus, changes in the skin temperature of the sensor's user are reflected by a change in resistance.

Material selection is one of the most important design considerations. The substrate material ought to reflect the skin's material properties and the active material is chosen for its electrical performance. Two distinctive mechanical properties of human skin are its flexibility and stretchability. While flexibility can often be achieved by limiting the thickness of the substrate to a few micrometers, stretchability has proven more difficult to achieve. Thus, approaches to improving stretchability primarily depend on finding materials which are intrinsically stretchable and manipulating the geometric structure of the sensor (Hammock et al., 2013). The most common substrate material and the one my team will be using is polydimethylsiloxane (PDMS), an intrinsically stretchable and transparent silicon elastomer which is commercially available and has repeatedly been shown to perform well as a flexible substrate. Moreover, it is chemically favorable since it is a non-toxic, chemically inert and thermally stable material which bonds well with electronic material (Wang, 2018; Chen et al., 2019)

The electrically active material in our sensor will be multi-walled carbon nanotubes (MWCNTs). MWCNTs are also a common material choice for resistive sensors since they offer the advantages of stretchability, high conductivity and transparency as electrodes (Lipomi et al., 2011). Thus, the sensor's channels will be filled with a mixed MWCNT-PDMS composite. Giffney et al. (2017) demonstrated that printed MWCNTs/silicone polymer composite sensors could withstand stretching of up to 300% with a linear relationship between strain and resistance with low hysteresis. Embedding the channels into the PDMS substrate provides protection of the channels and increases the sensor's durability (Giffney et al., 2017). It is also important that the strain and resistance changes are reversible so the sensor can experience stress while remaining unbiased in its temperature measurements.

The first step is to design the mold and its channels on SolidWorks. Common channel shapes are either serpentine patterns or spirals. Our sensor will have a serpentine design since it is the simpler design and has proven to be an effective geometry for allowing large strains with minimal changes in conductivity (Jiachog Zhou et al., 2020). Once our team has settled on a design, the mold will be printed with a fused modeling deposition 3D printer. The PDMS substrate solution will be poured into the mold and allowed to cure until it is ready to be peeled off. Once the substrate has been peeled off, the channels will be exposed and available to fill with the MWCNT-PDMS filler. Prior to this, we will need to determine the desired ratio of MWCNTs to PDMS and check its electrical conductivity. The channels will be neatly filled with the mixture and a thin layer of PDMS will be coated on top to fully encapsulate the channels. Once the top layer finishes curing, our temperature sensor will be complete and ready to be tested. Our testing will primarily focus on the sensor’s ability to reflect a range of feasible human body temperatures through changes in resistance.

STS Framework

Although my technical project is related to temperature sensors, the balance of my paper will be research into marine pollution and tourism. It wasn’t until the late 1960s that marine pollution was first mentioned in scientific literature. The research came as a result of observations of the ingestion of plastic debris by marine life including seabirds and turtles (Bergmann et al., 2015). This led to questions of just how much litter was in the oceans and what are its potential impacts? While it is impossible to measure exactly how much debris is in the oceans, five major garbage patches have been identified and the largest has been titled the Great Pacific Garbage Patch. Garbage patches are aggregations of marine debris and are typically associated with ocean gyres which are circulating ocean currents (Sesini, 2011). The garbage patches form from accumulating debris caught in the currents. The patches keep building with very little biodegradation since the overwhelming majority of the debris is plastic. The properties of plastic which led to its mass production are the same ones which make it so detrimental to the environment: it is cheap, lightweight and corrosion-resistant which hinders biodegradation (W.C. et al., 2016). Furthermore, recent research into microplastics, small plastic fragments and particles, has raised new concerns since they are ubiquitous in the ocean and much more difficult to regulate (Bergmann et al., 2015).

There are four primary causes of marine pollution: sewage, tourism, fishing, and waste from ships. Sewage and tourism are considered land-based sources and account for approximately 80% of the debris in the ocean (Sesini, 2011). The pollution has well-documented and severe ramifications on marine ecosystems. Risks to marine life include potential entanglement in debris, ingestion of plastics, the smothering of marine habitats, chemical toxicity and opportunities to introduce invasive species into communities (Bergmann et al., 2015). These environmental impacts hurt more than just marine ecosystems; they lead to significant economic losses for people and countries as well.

Two industries can be identified as contributors and victims of marine pollution: fishing and tourism. In my research, I will focus specifically on tourism and its adversarial relationship with marine pollution. Tourism brings influxes of people to beaches which increases littering (Garcés-Ordóñez et al., 2020). This requires increased beach clean-ups or creates debris build-up and visually unappealing beaches. As a result, tourists are deterred from visiting and tourism revenue drops (Krelling et al, 2017). In 2011, severe flooding of South Korea's Nakdong River led to massive debris build-up off the coast of Geoje Island during the high tourist season. Between the costs of clean-up and the drop in visitors, an estimated $37 million US dollars were lost (Jang et al., 2014).

Although relatively under-researched in comparison to other facets of marine pollution, much of the literature regarding tourism analyzes it as either solely a source of pollution or a source of economic loss. However, there is opportunity to jointly examine both sides of the relationship. Moreover, a comprehensive analysis of tourism's role provides a unique approach to addressing marine pollution due to the range of its scope. At the grassroots level, raising public awareness is an informal solution and can impact the behaviors of tourists whom are visiting beach destinations. However, formal policies and regulations should also be established to effectively manage and prevent further pollution. Considering many coastal cities and countries have tourism as their primary sources of economic revenue, understanding the economic impacts of marine pollution provides incentive to seek solutions on the governmental level.

Throughout my research, I will use Star's definition of infrastructure (1999) to establish and analyze the adverse relationship between marine pollution and tourism. Star defined infrastructure as having nine qualities, five of which are relevant to my investigation: embeddedness, reach/scope, embodiment of standards, invisible until broken and fixed in modular increments. Embeddedness refers to how infrastructure is so rooted in society and the environment that it can be difficult to differentiate singular aspects and relationships. Reach or scope is infrastructure's ability to have influence far beyond where it originated. Embodiment of standards refers to how it often becomes part of our regular practices and therefore it becomes easy to overlook the impact of our behaviors. Invisible until broken describes infrastructure's nature to be unnoticed and remain in the background until it breaks down in a way that demands attention. Lastly, infrastructure is fixed in modular increments due to its complexity and multiple relationships with various groups and other forms of infrastructure. Examining how marine pollution embodies each of these qualities and how tourism reinforces them will help me understand the adverse relationship between the two. Furthermore, recognizing this relationship as infrastructure makes it a more tangible problem to policymakers and the public which is important when seeking formal solutions.

Research Question and Methods

For my research, I am interested in the following question: how can the adversarial relationship between tourism and marine pollution incentivize countries into adopting more sustainable waste practices? To first establish the relationship, I will look at prior literature, specifically studies which demonstrate tourism is a cause of marine pollution and conversely, studies which demonstrate polluted beaches and waters are detrimental to the tourism industry. Furthermore, I will establish this relationship as a form of infrastructure by evaluating how it embodies the relevant qualities of infrastructure as outlined by Starr (1999). In particular, I will focus on the qualities of embeddedness, reach/scope, embodiment of standards, invisible until broken and fixed in modular increments. Establishing the relationship as infrastructure is important in seeking formal solutions since addressing infrastructure issues through policies and regulations is common practice.

The ultimate goal of my research is to use the adverse relationship as a mechanism for providing motive to adopting better solutions. My argument is centered around the economic incentive to address marine pollution through and for tourism. Thus, I will quantify the relationship by analyzing estimated economic losses as a result of pollution or lost tourism revenue to help build my argument. I will also evaluate think tank reports and current policies which address marine pollution. Specifically, I will see if any policies use tourism as a tool for combatting pollution and if they have been successful. This will assist me in proposing solutions to address the adverse relationship between marine pollution and tourism.

Conclusion

For my technical project, my team will design a skin-like temperature sensor which measures temperature as a function of resistivity. Skin sensors have potential applications in continuous health-care monitoring, clinical diagnostics, developing sensory prosthetics, the field of robotics, and athletic performance metrics. Perhaps one day our understanding will allow us to build electronic skin with full sensory capabilities akin to Luke Skywalker’s robotic hand. Simultaneously, I will be conducting research into the adverse relationship between marine pollution and tourism. By examining it through the lens of Star's definition of infrastructure, I will provide further incentives for adopting more sustainable waste management practices.

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